Tenth Edition (SNEC Exclusive)

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS

Exclusive Simplified Chinese insert enclosed

本特刊内附独家
中文插页

Q-Cells SE demonstrates the benefits of laser marking

Fraunhofer IST presents TCO deposition techniques

Neo Solar Power: single diffusion step selective-emitter cell fabrication

FZ Jülich: controlling the surface texture of sputtered ZnO:Al

Fraunhofer ISE: PV power plant quality assurance

本公司诚邀您莅临上海SNEC
E2馆 E2-112-113-115展台

Exclusive SNEC edition, February 2011 | SNEC国际太阳能光伏大会特刊，2011年2月 www.pv-tech.org

Photovoltaics International

Published by:
Semiconductor Media Ltd.,
Trans-World House, 100 City Road, London
EC1Y 2BP, UK
Tel: +44 (0) 207 871 0123
Fax: +44 (0) 207 871 0101
E-mail: info@pv-tech.org
Web: www.pv-tech.org

Publisher: David Owen
Managing Editor: Síle Mc Mahon
Chinese Editors: Xiaoyuan (Cathy) Li
Huangye Jiang
Senior Contributing Editor (U.S.): Tom Cheyney
Senior News Editor: Mark Osborne
Production Manager: Tina Davidian
News & Features Editor: Emma Hughes
Design: Daniel Brown
Junior Editor: Chris Whitmore
Commissioning Editor: Adam Morrison
Sales Director: Neill Wightman
Account Managers: Adam Morrison
Graham Davie
Daniel Ryder
Gary Kakoullis
David Evans
Ben Irving
Terpet Gill
Subscriptions Manager: Nick Richardson
Marketing Manager: Joy-Fleur Brettschneider

Cover image shows water droplets on a superhydrophobic coating as used for maintaining cleanliness and efficiency of solar cells. Image courtesy of Fraunhofer IST; Photographer: Rainer Meier.

Printed by C&C Joint Printing Co., Beijing Ltd.
Photovoltaics International
Tenth Edition
Fourth Quarter 2010
Photovoltaics International is a quarterly journal published in February, May, August and November.

ISSN: 1757-1197

卷首语

欢迎您阅读我们为SNEC专门筹划的Photovoltaics International特刊。本期杂志为SNEC(2011)国际太阳能光伏大会特别制作并独家发放给论坛的与会嘉宾。在此，我们要感谢上海新能源行业协会的常务副会长米月女士及其所领导的团队，他们的信任和大力支持使得我们此次能够作为SNEC金牌合作媒体的身份参与其中。

在过去的2010年，全球有75%的光伏组件产自中国，同时，德国市场在去年所安装的组件中近70%是由中国企业提供的。

本刊的长期读者可能会发现，此次特刊中的大部分内容来自2010年十一月出版的第十期季刊。但同时，我们PV-Tech团队也在本期特刊中增加了一些为SNEC读者量身打造的内容，包括双语封面文字、卷首语以及博客栏目的中文翻译等，此外，本特刊还包含了16页独家中文插页(详见第九页)。

随着SNEC国际太阳能光伏展在光伏业内的影响力日益扩大，Photovoltaics International已然成为此盛会的主要支持者。同时，我们还凭借旗下的中文产品一如既往地开发中国市场，并且，经过全新打造的cn.pv-tech.org中文官方网站也已在四个多月前顺利上线，快来订阅我们的免费电子周刊吧！

在您参观SNEC国际太阳能光伏展的时候，不妨屈尊至我们的展台(E2-112-113-115)。我们将即时报道全球最新产业动态，同时我们还将在此采访多位光伏产业决策层人士。

PV-Tech团队期待与您相约上海！

大卫·欧文
Photovoltaics International

Publisher's foreword

Welcome to our first special SNEC edition of the Photovoltaics International journal. This edition has been produced exclusively for the SNEC (2011) PV Power Conference and is only available to conference participants. Thank you to Mi Yue, Executive Vice Chairman of the Shanghai New Energy Industry Association, for inviting us to participate in the SNEC conference as a Gold Media Partner.

In 2010, 75% of global PV module manufacturing took place in China, while almost 70% of all modules installed in the German market for 2010 were supplied by Chinese companies.

Regular readers will recognise that the majority of this special volume is based around our November issue from 2010. We've added some features specially tailored for our SNEC audience, such as dual-language translations of our cover text, introduction, blog, and we have also added an exclusive 16-page section entirely in Simplified Chinese (p.9).

With the SNEC (2011) PV Power Exhibition becoming ever more influential in the PV world, Photovoltaics International has become a major supporter of the event. We have continued to expand our influence in the Chinese marketplace with our Chinese-language print editions and a newly-designed Chinese website, cn.pv-tech.org, which has been live for four months. Don't forget to sign up for our free weekly e-newsletter!

So while you are visiting the SNEC exhibition, don't forget to come and meet us at our booth (E2-112-113-115) where we will be writing live news as it happens around the globe, as well as conducting live video interviews with some of the major decision-makers in the PV industry.

See you in Shanghai!

David Owen
Photovoltaics International

Photovoltaics International

Photovoltaics International's primary focus is on assessing existing and new technologies for "real-world" supply chain solutions. The aim is to help engineers, managers and investors to understand the potential of equipment, materials, processes and services that can help the PV industry achieve grid parity. The Photovoltaics International advisory board has been selected to help guide the editorial direction of the technical journal so that it remains relevant to manufacturers and utility-grade installers of photovoltaic technology. The advisory board is made up of leading personnel currently working first-hand in the PV industry.

Editorial Advisory Board

Our editorial advisory board is made up of senior engineers from PV manufacturers worldwide. Meet some of our board members below:

Gerhard Rauter, Chief Operating Officer, Q-Cells SE

Since 1979, Gerhard Rauter – a native Austrian – had been working in managerial positions for Siemens AG at different facilities in Germany. In 2005 he became Vice President of Operations & Production with responsibility for the technology transfer between plants at home and abroad. As Vice President and Managing Director at Infineon Technologies Dresden GmbH & CO.OHG he was in charge of the Dresden facilities and their 2,350 employees since 2006. His main responsibilities at the Dresden facility had been in the fields of Development, Production and Quality. In October 2007 Gerhard Rauter was appointed as Chief Operating Officer at Q-Cells SE, being in charge of Production, InterServices, Quality, Safety and Process Technology.

Takashi Tomita, Senior Executive Fellow, Sharp Solar

Takashi Tomita has been working at Sharp for 34 years and is widely recognised as a fore-father of the solar industry in Japan. He was responsible for setting up Sharp's solar cell manufacturing facilities in Nara and silicon production in Toyama. Takashi's passion for solar power has led him to hold numerous posts outside of his roles at Sharp, including: Vice Representative at the Japan Photovoltaic Industry Association; Committee Member of Renewable Energy Portfolio Standard of METI; Adviser Board Member of Advanced Technology of Nara; Visiting Professor of Tohoku University; Adviser of ASUKA DBJ Partners (JAPAN) and Adviser of Global Catalyst Partners (US).

Dr. Kuo En Chang, President of Solar Division, Motech Industries, Inc.

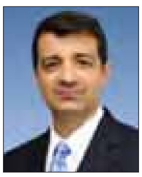
Dr. Kuo En Chang joined Motech in 1999 as Chief Technology Officer and became President of the Solar Division in 2008, with responsibility for all technology and manufacturing. Motech is the sixth largest solar cell producer in the world. Before Dr. Chang joined Motech Solar, he worked on secondary battery research at the Industrial Technology Research Institute (ITRI) for more than three years. Dr. Chang holds a Ph.D. degree in Metallurgical & Materials Engineering from the University of Alabama.

Professor Eicke R. Weber, Director of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg

Professor Eicke R. Weber is the Director of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg. Weber has earned an international reputation as a materials researcher for defects in silicon and III-V semiconductors such as gallium arsenide and gallium nitride. He spent 23 years in the U.S. in research roles, most recently as Professor at the University of California in Berkeley. Weber is also the Chair of Applied Physics, Solar Energy, at the University of Freiburg, and during his career has been the recipient of several prestigious awards including the Alexander von Humboldt Prize in 1994, and the German Cross of Merit on ribbon in June 2006.

Dr. Zhengrong Shi, Chief Executive Officer, Suntech

Dr. Zhengrong Shi is founder, CEO and Chairman of the board of directors of Suntech. Prior to founding Suntech in 2001, he was a Research Director and Executive Director of Pacific Solar Pty., Ltd., the next-generation thin-film technology company, before which he was a Senior Research Scientist and leader of the Thin Film Solar Cells Research Group in the Centre of Excellence for Photovoltaic Engineering at the University of New South Wales in Australia. Dr. Shi holds 11 patents in PV technologies and is a much-published author in the industry. His work has earned him such accolades as "Hero of the Environment" (TIME magazine 2007) and "Corporate Citizen of the Year" at the China Business Leaders Awards 2007. A member of the NYSE advisory board, Dr. Shi has a Bachelor's degree in optical science, a Master's degree in laser physics and a Ph.D. in electrical engineering.



Dr. John Iannelli, Chief Technology Officer, Emcore Corp

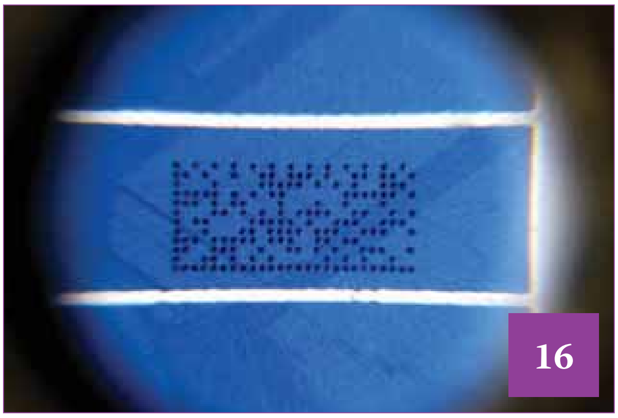
Dr. John Iannelli joined Emcore in January 2003 through the acquisition of Ortel. Prior to his current role as Chief Technology Officer, Dr. Iannelli was Senior Director of Engineering of Emcore's Broadband division. Currently, Dr. Iannelli oversees scientific and technical issues, as well as the ongoing research to further Emcore's technology. He has made seminal inventions, has numerous publications and has been issued several U.S. patents. Dr. Iannelli holds a Ph.D. and M.S. degree in applied physics from the California Institute of Technology, a B.S. degree in physics from Rensselaer Polytechnic Institute, and a Master's degree in Business Administration from the University of Southern California.

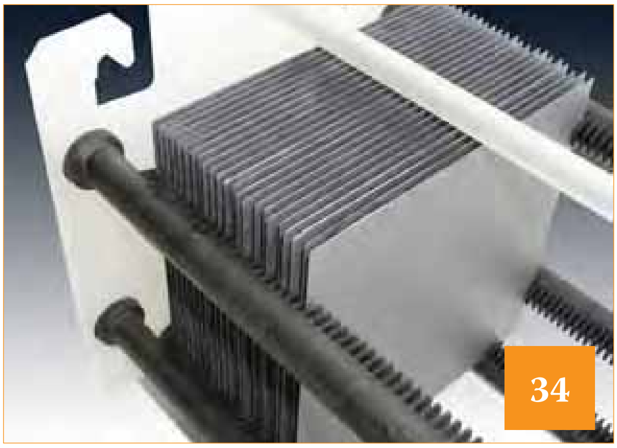
Dr. G. Rajeswaran, President and CTO of Moser Baer Photovoltaic Ltd

Raj served as President and CTO of Moser Baer Photovoltaic Ltd. from July 2007 until October 2008, since which time he has been Group CTO for all the Moser Baer business units and holder of the CEO function for launching new businesses. He spent 22 years with Eastman Kodak Company as the Vice President of Advanced Development & Strategic Initiatives, where he managed Kodak's Japan display operations including technology & business development in Japan, Taiwan, Korea and China. He has also served as Vice President and on the board of SK Display Corporation, and worked in technology development with Brookhaven National Laboratory. Raj has a Ph.D., an M.Tech. and a B.E. in electrical engineering. A much-published author, speaker and patent holder, Raj is a member of the Society for Information Display (SID) and has chaired several international conferences in the field of OLEDs.

Contents

Photovoltaics International

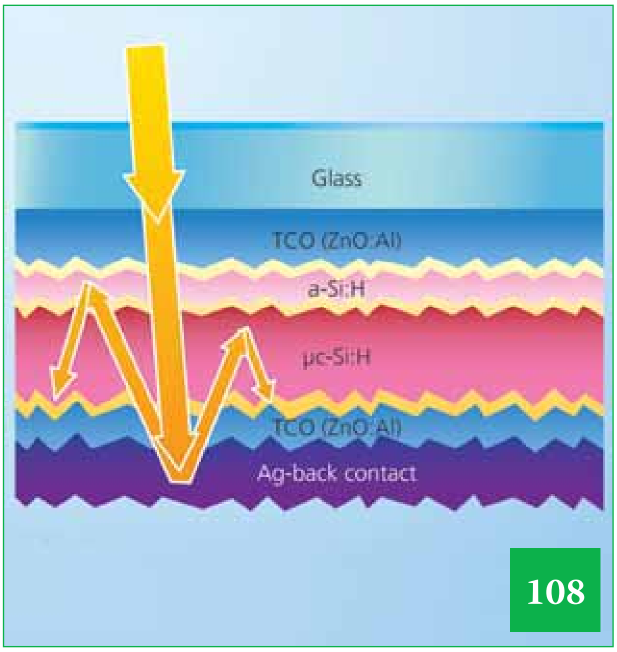

16

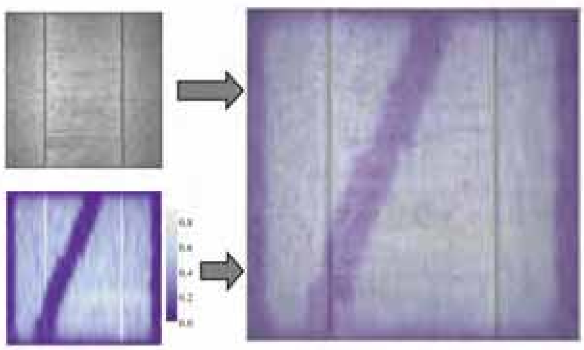

34


87

Contents

Photovoltaics International





S:7.6378"

S:11.063"
T:11.6929"
B:11.9291"

Ad Number: **MET_GON_P02190G017-09PE4**
Publication(s): Photovoltaics International
This ad prepared by: SGL Communications for BBDO Toronto • 2 Bloor St. West, Toronto, Ontario • phone **416.413.7495** • fax **416.944.7883**
File Location: SGL_A-M:Volumes:SGL_A-M:MEDT-SED:,Ä¢Magazine:Germany versions_Mag:Germany_Northern Sign_Mag:MET_GON_P02190G017-09PE4.indd

This proof was produced by the following department:
PREPRESS

BBDO TORONTO

JOB SPECIFICS

Client: MEDT
Creative Name: Northern Sign English
Agency Docket #: MET GON P02448
Main Docket #: SED COR P02448
Art Director: None
Copy Writer: None
Print Production: Milan Stojanovic
Retoucher: None
Live: 7.6378" x 11.063"
Trim: 8.2677" x 11.6929"
Bleed: 8.5039" x 11.9291"
Artwork Scale: 1:1
Print Scale: 100%

FILE SPECIFICATIONS:

File Name:
MET_GON_P02190G017-09PE4.indd
Creation Date: 8-23-2010 2:17 PM
Last Modified: 8-23-2010 4:23 PM
Workstation: T06-0204
InDesign Version: CS3
App. Version: 5.0.2
Round #: 1 Page Count: 1

GRAPHIC PRODUCTION:

Operator: Jason Rooney
Correction: None

PREMEDIA OPERATOR:

Operator: Gordon Clarke

INKS:

Cyan
MAGENTA
YELLOW
BLACK

FONTS & PLACED IMAGES

Family	Style	
Helvetica Neue Bold, 65 Medium	77 Bold Condensed, 55 Roman, 75	
File Name	**Colour Space**	**Eff. Res (PPI)**
ONPopulationSign_440.eps	CMYK	544 ppi
2007_Trillium Ontario.eps		
2007_Ontario Canada		
OntMap_REVISED_July09.eps		

SIGNOFFS:

Creative:
Production:
Premedia:
Proofreading:
Account:
Client:

R6

Contents

171

174

SNEC国际太阳能光伏大会
特供中文插页

Photovoltaics International团队为此次SNEC国际太阳能光伏大会与会嘉宾独家制作了此份中文插页。在此，我们向新老读者介绍并展示了业内多家知名公司及其光伏制造领域的前沿产品。本英文版季刊向读者提供了光伏产业内最优秀的独家技术文章。

欲了解我们正不断完善的中文技术文献详情，敬请登陆我们的中文官方网站：cn.pv-tech.org。期待在不久的将来与您相约在我们的光伏世界。

.ORG PVTECH

关注每日光伏新闻，请在线注册并接收我们每周出版的电子期刊。

现在就来免费注册吧: http://cn.pv-tech.org/

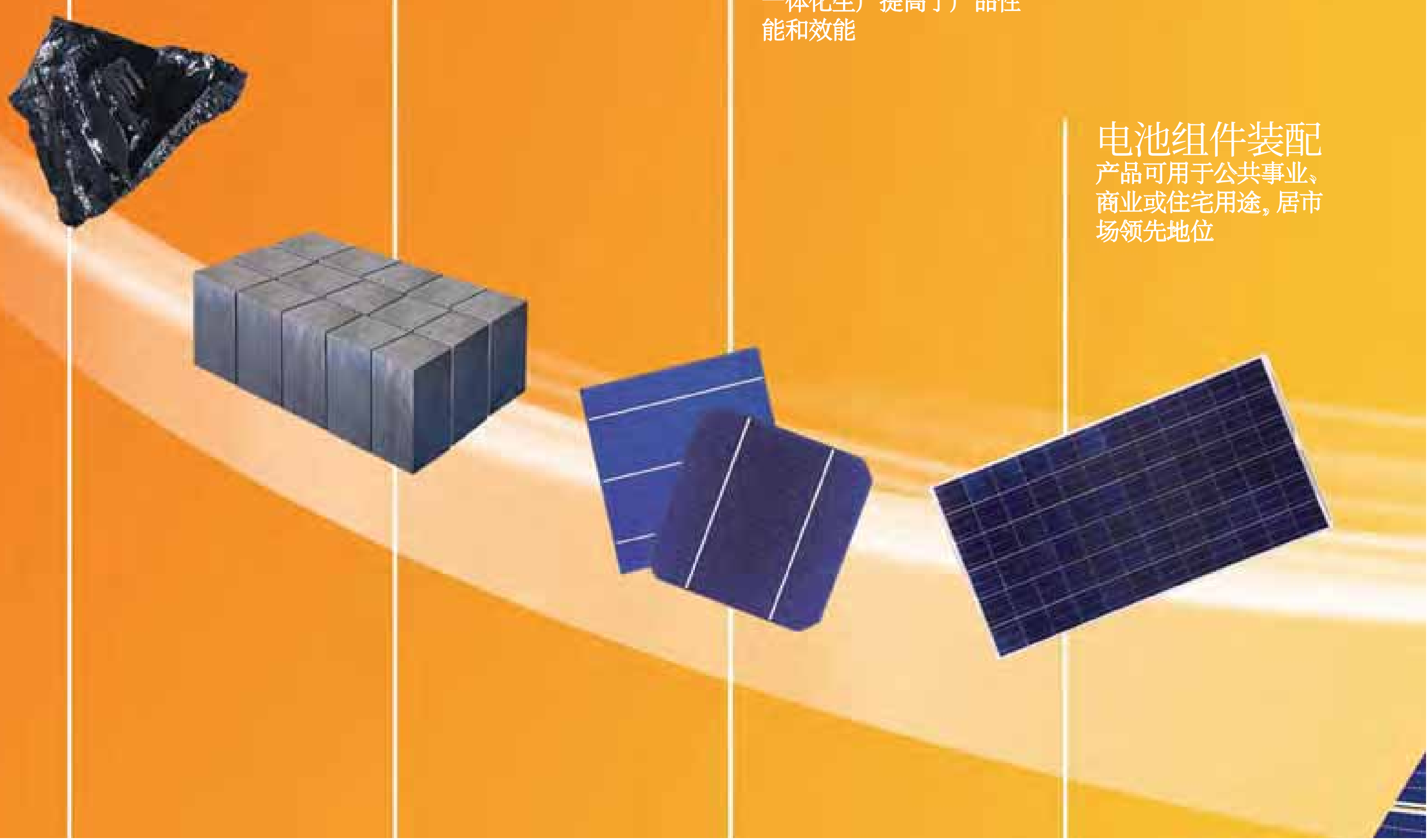
利用太阳能

晶体硅
高级硅确保质量上乘

硅锭和硅片加工
控制环境条件，确保产品的一致性和可靠性

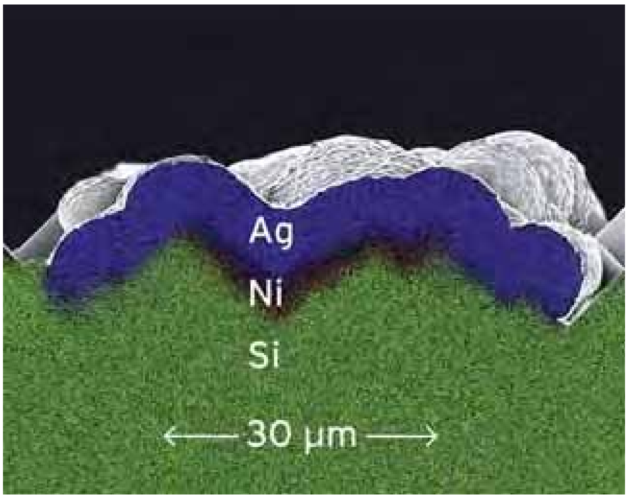
电池生产
一体化生产提高了产品性能和效能

电池组件装配
产品可用于公共事业、商业或住宅用途，居市场领先地位



产品目录

RENA Selective Emitter解决方案可保障1%的效率提升



联系方式：
RENA GmbH
Ob der Eck 5, 78148 Guetenbach
Germany
电话：+49 7723 9313-0
传真：+49 7723 9313-50
电子邮件：info@rena.com
官方网站：www.rena.com

为解决当前使用印刷接触极技术所制造的标准太阳能电池所存在的转换率不足的问题，RENA公司近日推出了一款背式选择性发射极解决方案。该方案的制作流程包含两个步骤：第一步是在SelectDop液晶聚合物(LCP)上同时进行SiN烧蚀和磷掺杂两项工艺；第二步是在RENA InCellPlate操作平台中进行可自我调节的电镀工艺。

RENA选择性发射极解决方案在两方面提高了电池的转换率。其中之一是在产品的几何结构设计方面进行改善，即使用50µm宽的电极接触替代传统印刷技术中120µm的电极接触，这样，额外的活跃区域即可为电池带来约0.5%的转换率。而另外所增加出来的0.5%的转换率是通过改善产品的蓝光响应来实现的，即在活跃区域降低掺杂程度。

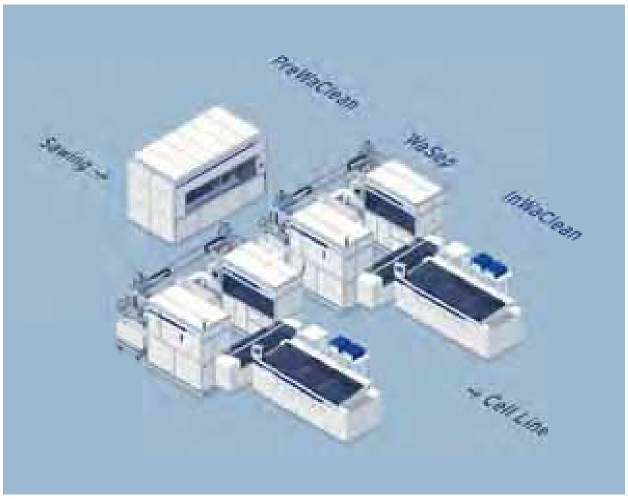
在SelectDop LCP中，液体引导激光束可在SiN上刻出一条35µm宽的激光线。并且，通过使用亚磷酸稀释剂作为引导液体，该工艺可同时在这些激光线上进行可自我调节的n++型掺杂。此外，随后在这些激光刻蚀线上进行的NiAg电镀也同样是一个可自我调节的工艺流程，从而避免了在制作流程中出现错位情况。

该解决方案可应用于n型发射极和前接触晶硅太阳能电池的制作，吞吐量在每小时1200至1400片硅片之间。与传统印刷技术相比，此技术可确保将转换率提高一个百分点。

此选择性发射极解决方案现已面市。

RENA

RENA旗下Wafer Cluster硅片集成处理设备可实现每小时高达8000块硅片的吞吐量



联系方式：
RENA GmbH
Ob der Eck 5, 78148 Guetenbach
Germany
电话：+49 7723 9313-0
传真：+49 7723 9313-50
电子邮件：info@rena.com
官方网站：www.rena.com

目前，业内现有技术在对切割后的硅片进行清洗和分离时，无法满足现有市场对吞吐量和对破损率的标准。有鉴于此，RENA公司研发出一款具备高吞吐量的硅片清洁分离解决方案——RENA Wafer Cluster。这款设备独特的喷头设计可带来显著的预清洁效果，并且它还具有胶体剥离、新式水下分离和链式清洁系统等特性。

RENA公司将已得到市场认可的预清洗设备PreWaClean、两套硅片分离设备WaSep和两套内嵌式硅片清洗干燥系统InWaClean相结合，组装成了具有高达每小时8000片硅片吞吐量的新一代RENA Wafer Cluster硅片晶圆处理系统。

除了通过加装新式水下分离系统WaSep和新转辊系统InWaClean等方式来改善系统的吞吐量，该系统还集成了其他各种不同工艺优化设备。其中之一就是在WaSep中加装无接触流体硅片传输系统，即可实现硅片的自动对齐。另一个重要新功能是加装在InWaClean中的清理模块优化配置，凭借持续不断的硅片传送，该功能可在高吞吐量条件下对清洁干燥流程进行优化。

目前，Wafer Cluster组合设备的硅片吞吐量已达到了每小时8000块。

RENA

产品目录

SOMONT 新型串焊机——帮助客户更成功

A member of Meyer Burger Group

联系方式：
Somont GmbH
电话：+86 (0)21-6360 2455
传真：+86 (0)21-6350 4715
电子邮件：info@somont.com
官方网站：www.somont.com

生产高品质光伏组件的经济型电池焊接设备

高性能、高品质——光伏组件生产的关键

- 速度：> 120片 / 小时 实际产能（非额定值）
- 极低的破损率 < 0.2 %*
- 每年产量高达30 MW
- 串焊机运行时间比高达95%
- 多种配置，确保您随需所用：如电池串分选，电池串铺设等

操作简单，维护方便

- 调整快捷：从2至3汇流条相互调整时间<45分钟
- 可方便对设备各个区域进行操作和控制。
- 快速安装和小批量试产可在一周内完成

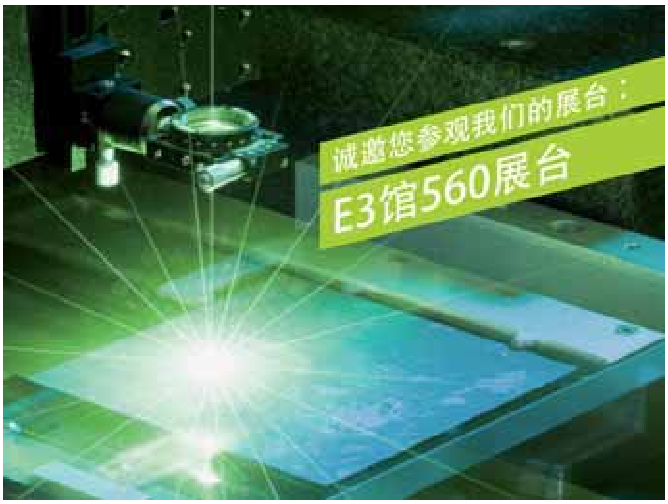
最可靠的焊接工艺

- 高度灵活性，可适用多种材料
  - 根据电池厚度变化自动进行调整
  - 能够根据2条或3条汇流条方便快捷地进行调整
- 焊带与电池片间撕剥力稳定
- 随您所愿，满足您不同的需求。
  - 电池片上热应力水平降低，减少隐裂
  - 温度平稳升降——适当处理电池片和焊条热膨胀系数
  - 精确、稳定的焊接结果

* 180μ 6”电池，预分选，10片电池/串

SOMONT
CELL CONNECTING

Manz一步完成选择性发射极设备



Manz一步完成选择性发射极设备不仅占地面积小，还拥有无懈可击的竞争优势：无需任何耗材，可增加最高0.5%的转换效率，且不超过一年即可获得投资回报。晶体硅太阳能电池片生产最重要的目标之一，就是具体降低每瓦的生产成本，途径之一是将选择性发射极结合在量产的太阳能电池片生产中，借由增加蓝光反应来提高太阳能电池片的转换效率。

与一般晶体硅太阳能电池片生产相比，Manz研发的一步完成选择性发射极技术，是在扩散和磷玻璃蚀刻之间增加一道工序，利用激光局部的扫描晶体硅片表面，将磷由磷玻璃层局部液状扩散以形成高浓度的磷参杂分布区域。在镀抗反射层之后，将金属电极印刷在这个区域上，局部植入可降低硅体和金属之间的接触电阻，从而使低参杂发射极拥有更高的阻值。

联系方式：
公司：曼兹自动化技术服务（上海）有限公司
地址：201203 上海市浦东新区张江高科技园区科苑路88号上海德意志工商中心222室
电话：+86 (0)21-2898 6072
传真：+86 (0)21-2989 6073
电子邮箱：info@manz-automation.com
官方网站：www.manz-automation.com

manz
passion for efficiency

产品目录

Madico旗下Protekt背板性能卓越

联系方式：
Madico Inc.
Steve Goldman
Asia Sales Manager
Cebu, Philippines
US/Worldwide mobile：1-781-640-9229
Phillippine office：+63-32-340-8190
Phillippine mobile：+63-927-482-6890

Madico公司跻身成为全球光伏背板内的领军企业之一，所生产的背板系列产品可有效防止面板发生降解作用并为太阳能组件提供长期稳定性。旗下高效Protekt 系列产品具有功率最大化、粘结度强、电气绝缘性卓越、耐水解、阻燃、热稳定性优良等特性。

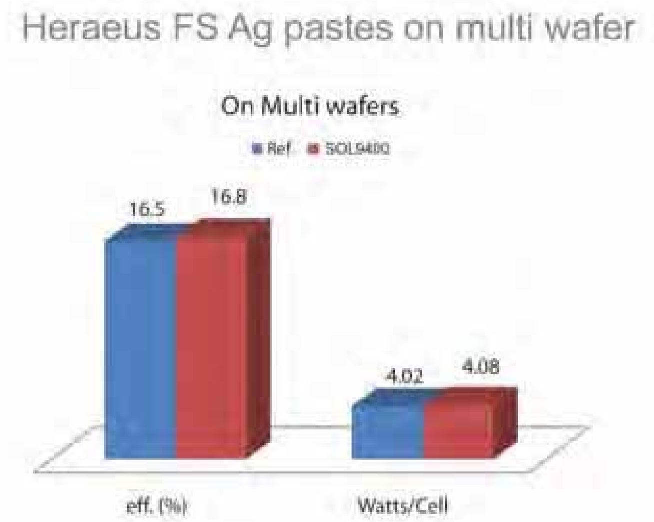
该系列背板专为光伏产业的发展而研制，并为行业性能标准的制定提供了相关标准。Protekt技术使用了含有添加剂的氟聚合物基，可实现在各种气候条件下产品的长期稳定性。同时，公司的背板产品还公司旗下的所有产品均接受了大规模的内部及第三方测试，以验证其性能已超过了行业所要求的标准，并可为面板在其使用寿命内提供了安全保障。

Protekt产品是一款超薄型背板，可承载极大的电介质强度。该系列产品及接受了一系列测试以在阻燃性及电气绝缘性方面达到UL认证标准。此外，Protekt系列产品还已通过了大规模的湿热测试，其结果已超过了UL及TUV所制定的1000小时行业标准。自2007年作为首款非复合背模板面市以来，Protekt系列产品现已遍及全球。凭借所拥有的位于全球各地的四座生产基地，Madico的产能将于2011年超过12GW，以确保其产品供应可满足市场需求。

欲了解更多详情，敬请登陆www.madicopv.com(英文)

MADICO PV BACKSHEETS

贺利氏HeraSOL9400系列产品



联系方式：
Heraeus Materials Technology Shanghai Ltd.
No.1 Guang Zhong Road, Zhuanqiao Town, Minhang District
201108 Shanghai, P. R. China
电话：+86 (0)21-3357 5688
传真：+86 (0)21-3357 5699
电子邮件：th.hmts@heraeus.com
官方网站：www.pvsilverpaste.com

在高品质和高效率的激烈市场竞争中，太阳能电池制造商把期望转向贺利氏，以帮助他们在众多的竞争对手中脱颖而出。贺利氏确立了在研发太阳能电池银浆领域主导地位的同时，凭借其最佳性价比的优势而荣获最高品质供应商的声誉。我们最新推出的晶体硅太阳能电池正面银浆HeraSOL9400系列产品也必将这一优势继续发扬光大。HeraSOL9400系列产品是专门为高转换效率和高产出电池线工艺所配制，从各个方面都优越于我们现有市场领先的浆料SOL9235H。

HeraSOL9400系列产品以其独特的化学配方大大的增强了对SiNx:H减反射膜的穿透，因此，显著改善了银电极反射结的接触性能。若想进一步了解我们的HeraSOL9400系列和其他更多的产品，请尽快与我们联系，以早日体验贺利氏为您提供的优质产品和服务.

- 业界领先品质
- 出色的高宽比
- 优异的接触性能
- 无镉
- 更少的每瓦耗银量
- 更高的电池性价比

Heraeus

产品目录

Tritan™ Metallization Firing System - BTU金属化烧结设备(Tritan™)

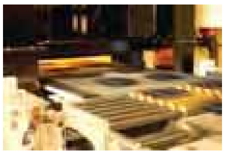
Tritan™金属化烧结设备具备BTU公司独有的三带速技术，可让用户获得一秒200摄氏度的快速升温能力，同时不会影响到干燥和冷却区的温度曲线。三网带设计为优化温度曲线带来了突破性的提高。目前客户演示测试证明了Tritan能提高填充因子，从而提高电池转换效率。再加上Tritan使用成本低，顾客可生产出每瓦成本最低的太阳能电池。

Tritan的炉腔可上下开合，便于维护和更新升级。Tritan是至这类开关式炉问世的第一台。炉腔可完全开合，加上长寿命加热灯管，这些都最大程度减少了停机时间。干燥部分还衬有不锈钢炉面，清洗方便。

Tritan™可与所有主流印刷和测试设备整合使用。和其他BTU产品一样，Tritan™烧结炉是通过带有触摸屏功能的WINCON™控制。WINCON™是BTU基于Windows操作系统的多语种人机界面软件。

Tritan在2009年首次在全球市场推出。在美国和中国上海的BTU太阳能实验室，客户都可做机台演示和工艺试验.

联系方式：
BTU国际公司
地址：上海浦东外高桥保税区加太路25号 邮编 200131
电话：+86 (0)21-5866 9098
传真：+86 (0)21-5866 9231
电子邮件：sales@btu.com
官方网站：www.btu.com



空气产品公司：可靠的全球硅烷供应商

如果您想购买硅烷，空气产品公司是您明智的选择！20多年来，我们一直在全球范围内向客户提供安全、可靠并具有极高性价比的硅烷。在为集成电路、平板显示器和光伏电池（硅薄膜和晶体硅光伏电池）等新一代产品制造厂供应大流量硅烷方面，空气产品公司是公认的行业领军企业。

空气产品公司为客户提供的硅烷来自于道康宁和REC两家公司，确保了供货的可靠性。由于增加了硅烷制造，道康宁通过其在Hemlock Semiconductor Group的主导地位，积极扩大其三甲基硅烷(3MS)和四甲基硅烷(4MS)两种电子特气的产能，并增强了其在多晶硅生产方面的行业领先地位。空气产品公司在致力于帮助您降低硅烷成本实现长期目标的同时，为您提供高质量的产品。

无论客户的工厂建造在何处，空气产品公司现有的供应链以及遍布全球的基础设施都能够为您提供硅烷。我们拥有高流量气体输送系统的专利产品和充足的硅烷槽罐车，能够满足各种行业的安全规定和标准。

空气产品公司——您的首选硅烷供应商。

联系方式：
空气产品公司
联系人：Henry Gu
电话：+86 (0)21-3896 4405
电子邮件：guhy@airproducts.com
官方网站：www.airproducts.com/sunsource

产品目录

3S Modultec——JT层压生产线 实现太阳能组件封装最高产能

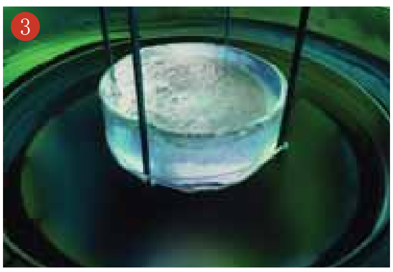
JT层压生产线是专门用于封装晶片电池组件和太阳能光伏建筑一体化（BIPV）组件的层压机。此生产线能够在一个层压循环内同时层压四个60片电池片组件或者三个72片电池片组件，循环时间为7.5分钟/批。该生产技术确保了最高的产能和无与伦比的工艺重复性：XL工艺（三腔体层压工艺，TÜV认证）具有每个组件112秒的最短循环时间，同时免维护专利混合加热板可实现卓越的温度均匀性（±1°C）。标准化配件和全天候认证服务实现了98%的正常运行时间比与99.8%的良率。XL层压生产线的产能高达60~80MWp/年，超过市售标准层压机200%以上，单位MW的占地面积减少了约50%。模块化设计理念不仅便于将来产能扩建，并且确保仅在一周内即可完成安装及小批量试产。

- 最低运行成本和最高良率
- TÜV认证且市场认可的三腔体层压工艺（已装机规模1.5GW）
- 专利混合加热板（温度均匀性±1°C）确保组件质量最高且层压循环时间最短

联系方式：
3S
电话：+ 41 (0)32 391 1111
传真：+ 41 (0)32 391 1112
电子邮件：info@3-s.ch
官方网站：www.3-s.ch

3S MODULTEC
MODULE SOLUTIONS

GT Solar 洞悉晶体生长工艺知识和设备，向全球客户提供高价值服务。



1-多晶硅料生产
- 高产能CVD西门子还原炉
- 每千克硅料产品的生产能耗最低
- 三氯硅烷（TCS）和硅烷生产成套方案
- 工程项目支持

2-多晶硅铸锭
- 光伏（PV）生产定向凝固系统---DSS多晶铸锭炉
- 高产能
- 高质量硅锭
- 高硅锭成品率

3-蓝宝石晶体生长
- 先进的蓝宝石晶体生长炉
- 2、4、6 和 8 英寸晶芯
- 提供高亮度 HB LED 应用的最高质量的原料
- 高产能，低运营成本

晶体生长专家
从多晶硅原料，到多晶硅铸锭，再到高质量人造蓝宝石，GT Solar 通过其无与伦比的工艺知识和经实际生产验证的制造设备，向太阳能光伏和 LED 行业的领先生产者传递价值。

GT Solar — 转变创新愿景，传递可持续价值，满足客户最严格的生产要求。

联系方式：GT Solar Hong Kong, Limited
Units 3210 - 3212, Tower 6
The Gateway, Harbour City
Tsimshatsui, Kowloon, Hong Kong
电话：+852 2153 0858
传真：+852 2153 0859
电子邮件：asiainfo@gtsolar.com
官方网站：www.gtsolar.com

GTSOLAR

产品目录

欧瑞康新式生产线ThinFab

欧瑞康太阳能全新的用以生产薄膜硅组件的“ThinFab”生产线，将打破生产成本每峰瓦0.50欧元的纪录。ThinFab方案将薄膜硅组件的能源回收期降至一年以内，实现该产业里光伏生产工厂的最低耗能。

欧瑞康太阳能的薄膜硅组件均采用无毒材料，是半透明玻璃和其他建筑一体化(BIPV)应用的理想组件。薄膜硅组件在漫射光和低光下表现良好，最适用于高温天气。它的生产线是完整的系统，但也是模块化和可升级的，因此能够让客户通过采用最新技术实现快速扩展，从而满足快速增长的太阳能光伏需求，这些需求能加速光伏能源的成本日趋接近平价上网。

欧瑞康太阳能拥有的Micromorph® （非微晶叠层）专利可以追溯到1993年，第一个集成了高效率的沉积透明导电氧化物（TCO）层，第一个把高效率的Micromorph®工艺商业化，并支持客户整合。它是目前市场上唯一可用的端对端的Micromorph®解决方案，提供最低的发电成本，提供最高的未来降低成本的可能性。

dyMat PYE® - 世界第一的光伏组件背板

保护光伏组件的背板的性能决定了光伏组件的使用时间。COVEME dyMat PYE®系列背板代表着背板的最高品质，我们的生产过程和检验测试都是按照光伏行业的通用标准和规定执行的。dyMat PYE®的原料是强化型PET，用这种材料制造的组件在极端的环境条件下能保持高绝缘性和超强的耐候性。因此，dyMat PYE®系列背板可以保证25年以上的使用寿命（超过3,000小时的湿热测试）。

COVEME是生产和研发聚酯薄膜的全球领导者，特别是在光伏领域，COVEME已经是全球产量最大的背板公司。因为COVEME在欧洲和亚洲都有自己的生产工厂，所以可以及时有效的向客户提供客户所需数量的背板。

dyMat PYE®背板既有最好的品质，又不受供应量的限制，是光伏组件制造工厂所需背板的首选品牌。

产品目录

阳光模拟器SunSim 3c和SunSim 3b

Pasan阳光模拟器是可用于光伏组件生产线和实验室的组件测量设备，以高测量精密度闻名于世。

高测量精度意味着带给客户更高的利润。

IEC国际标准采用3个物理参数将阳光模拟器的性能划分为A级（最佳）至C级：

- 与自然光的光谱匹配度（AM 1.5）
- 整个辐照表面上的光分布均匀性
- 光强稳定性

Pasan阳光模拟器的性能优于国际IEC A级标准的两倍，为A+级。Pasan设备的测量精度在目前市场上最高，并且得到权威机构TÜV Rheinland的认证。

Pasan阳光模拟器提供多种工业接口（硬件、软件），可以集成在规模化生产线中。由于校准程序进行了优化，并且维护要求低，因此正常运行时间比非常高。梅耶博格全球服务网络确保提供专业的本地化技术支持。

行业内领先的制造商和认证机构都非常信赖Pasan检测设备。

联系方式：
Pasan SA
电话：+41 32 391 16 00（瑞士）
传真：+41 32 391 16 99（瑞士）
电话：+86 (0)21-6360 2455，梅耶博格机械设备（上海）有限公司
电子邮件：info@pasan.ch
官方网站：www.pasan.ch

PASAN MEASUREMENT SYSTEMS

在线装片机 - InlineLoader

在线装片机是先进的太阳能电池板处理系统。它能将扩散炉流程整合到一个全自动在线的环境中。

在线装片机连接在线植绒槽的传送设备上。在线装片机取出整排的电池板进行逐一检查， 然后将电池板装入扩散舟。装载完成后，这些扩散舟会被送到扩散炉内进行处理。内置的扩散舟缓冲区可以在扩散流程前后存放扩散舟，这使产能改变可在线或成批完成。处理完成后可对电池板电阻进行测试。扩散舟然后转入卸载站将电池板从扩散舟上卸载并再次对所有电池板进行目测。之后，在线装片机将电池片放到传送设备上，该传送设备再将电池片移到与下道工序即玻璃蚀刻清洗植绒槽相连接的中间缓冲区。在线装片机的产出率是每小时3000片。

电池板生产的效率对光电产业正变得越来越重要，因此需要创新的生产解决方案。在线装片机正好满足了在线环境下对高效装载系统的需求。在线装片机可以让生产商将以下二者完美结合：即高效且100%在线质量检测和批量扩散工序的优越处理。

联系方式：
develop Mechanics NV
Heiveldekens 5
2550 Kontich
Belgium
电话：+ 32 (0)3 650 1400
传真：+ 32 (0)3 650 1401
电子邮件：info@develop.be
官方网站：www.develop.be

develop
we develop for you

产品目录

Semilab PV-2000 测试系统，提供领先的无接触、无损伤、扫描测试

PV-2000是Semilab公司最新推出的多功能测试平台，可以针对太阳能级硅片、工艺片以及成品电池片，可选择的功能包括：

- 表面光电压法（SPV法）测试少子体扩散长度（体寿命）
- 准稳态微波光电导衰减法（QSS-μPCD）测试不同注入水平的少子寿命、表面复合速率、结饱和电流Jo 、掺杂补偿度等
- 无接触CV，表征钝化层质量，包括：界面态缺陷电荷密度（Dit）、表面势垒（Vsb）、电学厚度（EOT）等
- 结寿命、快速光致衰减（ALID）
- 方块电阻(R_s)、并联电阻（R_{sh}）、短路电流(I_{sc})、开路电压(V_{oc})等参数的无接触扫描

应用：晶体硅太阳能电池材料检测和和生产工艺监控。

Semilab公司是业界领先的测试技术提供商，可为用户提供全面的测试方案，如：椭偏仪、光致发光（PL）、厚度、电阻率、诱导电流、反射率、光学检测等，均可实现离线或在线测试

联系我们：
Semilab Trade (Shanghai) Co., Ltd.
瑟米莱伯贸易（上海）有限公司
3rd Floor, B2 Building, BETWIN, No. 889, Shangcheng Road,
Pudong, Shanghai (200120), P.R.China
上海浦东新区商城路889号波特营B2幢3层（邮编：200120）
电话： +86 (0)21-5836 2889
传真： +86 (0)21-5836 2887
电子邮件：info.china@semilab.com
官方网站：www.semilab.com | www.semilab.com.cn

GlueMaster

GlueMaster涂胶机用于将单晶或多晶硅锭、玻璃垫板和工件夹粘合在一起。梅耶博格公司提供各种型号的GlueMaster自动化设备。

由于采用自动涂胶工艺，GlueMaster避免了人工操作错误，并大大减少了底部崩边。这种100%可重复的切割工艺可使切片良率提高3%，粘胶剂节约50%，从而极大了缩短了投资回收周期。

自动化涂胶设备包括GlueMaster 1（仅用于涂胶）到GlueMaster 5，晶锭、玻璃垫板和工件夹（包括所需缓存器）均采用自动化操作。

产能：

GlueMaster 1：20块/小时（装载5次，每次装载4x255mm多晶硅锭）= 480MW/年（或665MW单晶硅锭）

GlueMaster 5：30块/小时=720MW/年（或1GB单晶硅锭/年）

实例：

以产能为100MW的晶片厂为例，GlueMaster 1可将良率提高1%，并节约30%的粘胶剂（相当于每年节约900,000美元）。

产能利用率越高以及自动化程度越高，良率的提高幅度就越大。如果采用满负荷（即20块/小时）生产，GlueMaster 1可将良率提高3%。

联系方式：
Meyer Burger Ltd
Allmendstrasse 86
CH-3600 Thun
Switzerland
电话：+41 33 439 05 05
传真：+41 33 439 05 10
电子邮件：mbinfo@meyerburger.ch
官方网站：www.meyerburger.ch

MB WAFERTEC
SWISS SLICING SYSTEMS

多晶硅硅片制造流程上的降本增产策略

此技术文章节选自印刷版《Photovoltaics International》季刊

马克 · 奥斯本(Mark Osborne),
Photovoltaics International
高级新闻编辑

摘要

目前光伏市场中有约60%的多晶硅太阳能电池是以多晶硅硅片作为基底的，因此，多晶硅硅片可谓是光伏产业的核心主力。多晶硅硅片由于有较高的转换效率，在价格上占足了优势，并且这一优势还将随着电池技术的发展而继续持续下去。但事实上，从2008年下半年开始并持续了2009年大半年的光伏市场需求的下降，确实对硅片价格造成了冲击。面对资本成本相对较高、价格压力不断增加以及对质量和控制的要求提高，硅片制造商正努力实行严格且可持续的生产成本削减战略，以满足客户的各种需求。本文将着重探讨可用于实现更严格的质量标准的策略，以及如何降低下游厂商的生产成本、提高电池转换率等问题。

前言

在过去的2009年里，多晶硅、硅片，以及组件的价格急遽下跌。据iSuppi公司最近的一项调查显示，晶硅组件的价格下跌了37.8%，同时，太阳能硅片的价格下降了50%，而多晶硅价格的降幅则达到了80%。

这家市场调研公司预测，2010年相关产品的价格仍将进一步下跌，但降幅将远小于09年。在谈及2010年的价格走势时，iSuppli公司认为晶硅组件的价格将下降20%，太阳能硅片和多晶硅将分别下降18.2%和56.3%。（见图1）许多业内观察家都认为，随着业内主要制造商及各新兴制造商对各自多晶硅产品的进一步扩产，涉及业内整个供应链的降价情况已成定局。

当然，对于一个追求难以实现的电网平价，甚至更低价格的产业来说，原材料降价是实现目标的重要前提条件。而且只有实现了电网平价，才能赋予太阳能比其他形式的可再生能源更大的优势，从而使从业者从中获益。

“价格的下跌必将改变太阳能产业的现状，”iSuppli公司光伏系统高级总监兼首席分析师亨宁·维希特(Henning Wicht)表示，“光伏产品价格的大幅下降意味着价格结构正经历着一场不可逆转的调整，而这种情况必然会促使整个产业向更具竞争性的市场形态转型。”

iSuppli公司认为，为了应对产品的大幅降价，各光伏产品制造商应继续将精力放在节省成本方面，以弥补其2009年所遭受的利润损失。维希特先生还指出，当成本下调的幅度最终与价格下降的程度相一致时，整个产业的总体利润水平将可得到改善。

这对于多晶硅和硅片制造商来说是十分重要的。尽管他们曾经历价格的剧烈下跌，但是比起那些纯粹组件制造商这样的下游企业来说，也具有相当高的资本成本。

当然，硅片制造商也同样要面对各种挑战。随着市场对硅片的强劲需求创造出一个相对严峻的供应形势，若想应对客户的需求，进一步的资本扩张势在必行。通常情况下，在市场需求强劲时期，设备的交货期将延至九个月以上，因为像铸锭炉和线锯等关键设备的生产周期都相对漫长。大多数这些设备规模庞大、工艺复杂，因此很难在较短的交货时间内保证制造质量。

多晶硅的重要性

日前，多晶硅的短缺造成了供应链上的断流，而这种危机很有可能向硅片产业转移。这就使得整个产业在计划增产并采取实际行动的同时，需大力发展各自的生产力。

正如图2所示，iSuppli公司对硅片制造商的增产计划做了调查，实际结果表明，硅片的产量只有小幅上涨(左柱)。中柱表示那些本应实现却未付诸实践的增产计划。只有在2012年及之后的年份里，那些增产计划才有可能大规模实现。

可以说，这样一份报告仅仅是再次为硅片制造商们带来压力、促使其优化现有的产品吞吐量、出货量和总体产量而已。新技术的引进同样可以提高产量，同时还可降低生产成本。

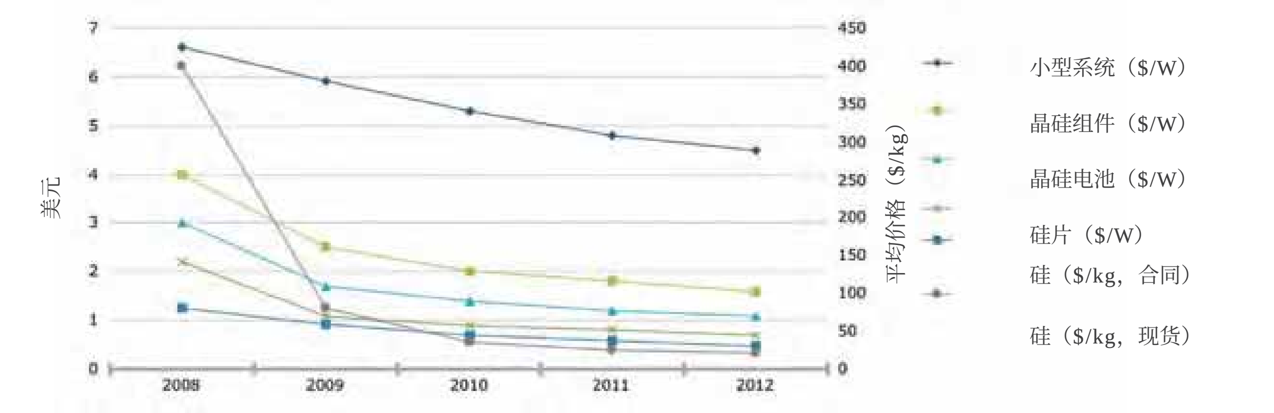


图1：2008-2012年销售均价预测（US$/MW）

图片来源：iSuppli公司

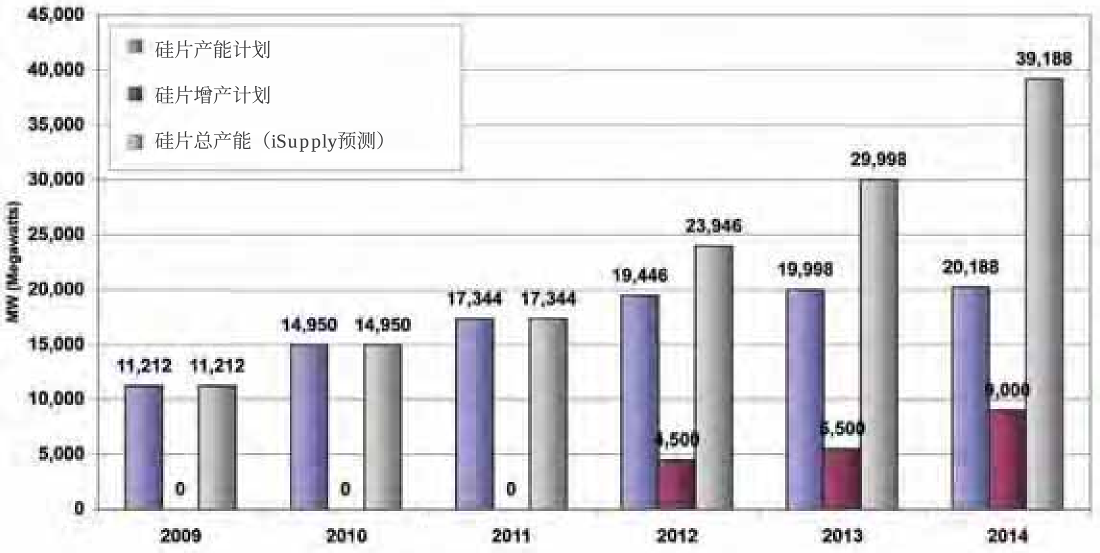


图2：全球太阳能硅片产量计划（MW）

图片来源：iSuppli公司

那些有能力成功应对这些挑战的企业不仅能凭此降低成本，从中获利，还能争取到那些需要以低成本来维持竞争力的下游客户。而那些下游企业也能从总体价格不断下降的大环境中获益匪浅。

毫无疑问，多晶硅和太阳能硅片的关系密不可分。硅片价格之所以下跌，在很大程度上是由自08年中期起出现的原生多晶硅价格下跌所导致的。许多市场调研报告均指出，持续的产能扩张将导致价格的进一步下跌。Bernreuter信息研究公司近日所公布的一份报告指出，至2012年止，全球多晶硅产量将达25万吨，其中仅中国就可生产8万吨，占到全球总产量的近三分之一。

Bernreuter信息研究公司创始人约翰内斯·本罗伊特(Johannes Bernreuter)在接受本刊采访时表示，今年多晶硅的供需动态平衡将使得产品的现货价格浮动在每千克45至50美元之间。

本罗伊特先生还表示：“就我个人认为，在2011年里，中国制造商的大规模产量将很可能将生产成本降至每千克35美元以下。同时也会使现货价格降至相应水平。这种情况最快将会在年底，甚至更早出现。”因此，硅片价格将会进一步下跌，但正如我们在2009年里所经历的那样，产品降价的负担将远大于生产成本，从而导致了边际利润额的大幅缩水。但从另一个角度来看，那些硅片制造商实际上能够从多晶硅的多渠道供应中获益。曾任赛维太阳能公司(LDK Solar)生产副总监的产业顾问尼克·萨诺(Nick Sarno)认为，目前市场上可获得的原生多晶硅的质量已越来越好，并且硅锭的制造过程对硅废料的依赖性也越来越低，因此，业内材料质量在总体上得到了提高，从而使硅片制造商从中获利。

“这就可以在硅片制造流程的各个阶段进行成本下调。”萨诺先生还表示，“缩短在硅废料采购、分类及储存阶段的工时并不会对整个生产流程造成很大影响，但优质原生材料的供应可改善硅锭、硅片及硅块的质量，减少废料的产生，降低消耗品的使用量，从而全面提高产品质量。”

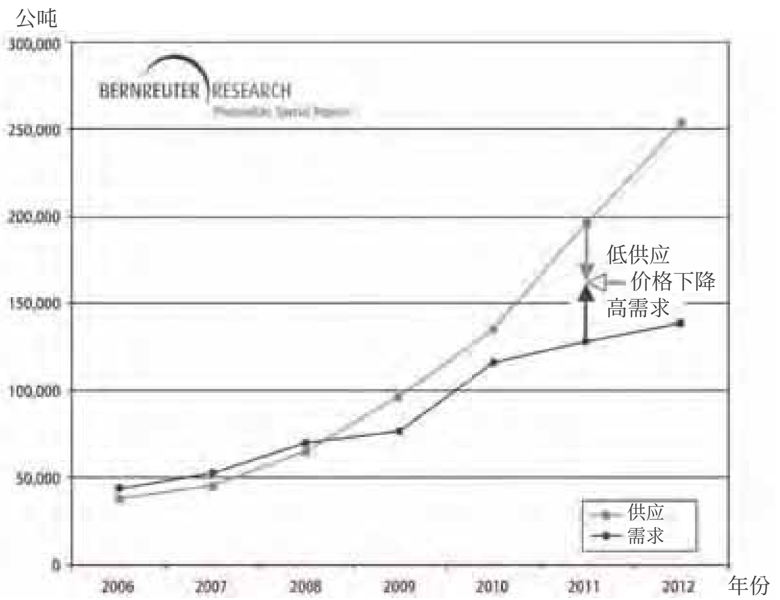


图3：Bernreuter Research：多晶硅供需价格分布

关于铸锭炉
——尺寸是有效之道吗？

为了降低硅锭成本，增加硅锭尺寸逐渐成为一种主流趋势。硅锭尺寸越大，其所制成的硅块就越多，从中就能够制造出更多的硅片，进而可提高总体产量(见表一)。这就需要大尺寸的硅锭生长熔炉。目前，大多数硅锭的生产使用的都是定向凝固系统(Directional Solidification System，简称DSS)铸锭炉，该系统可使用450kg的铸锭炉对多晶硅硅锭的铸造进行量产。500kg和800kg以上规模的铸锭炉制造技术也已得到了长足的发展，并且，在不远的将来，1000kg以上的铸锭炉定将会在整个产业不屑的努力下成为现实的。

目前市场中，铸锭炉尺寸发展的最大制约是无法在技术上实现大尺寸坩埚的制造。通常情况下，业内企业应对此问题的方式是在大型铸锭炉内

产品型号		JZ-270	JZ-450	JZ-520	JZ-800
多晶硅初始消耗（kg）		270	450	520	800
凝固锭预计尺寸（毫米）	长、宽	680	840	840	996
	厚度	250	270	315	345
裁剪块预计尺寸（毫米）	长、宽	156	156	156	156
	厚度	200	220	265	295
锭的预计切割重量（kg）		181.4	311.8	375.7	602.2
锭的预计产量		67.2	69.3	72.3	75.3

表一：JYT大型熔炉效益分析

同时使用多个坩埚，以实现设备的最优使用和产量的增加。

“从资本扩张的角度来看，这一策略的好处很多。”萨尔诺先生表示，“这一策略不仅可以适应大型多坩埚制造实现后的投资形式发展，同时由于坩埚尺寸的限制而无法扩大铸锭炉可有效防止过度投资。”

坩埚制造商正试图同时解决多个问题。除了要满足对大尺寸坩埚不断上涨的需求，其中以450kg的坩埚最受欢迎，还同时为未来制造更大尺寸的坩埚进行设备更新。

石英坩埚制造业龙头赛瑞丹公司(Ceradyne)已于2010年上半年对其赛瑞丹(天津)工业陶瓷的工厂进行增产计划，同时，旗下的赛瑞丹(天津)先进材料公司的新厂区也已破土动工，预计将于2011年初期实现运营，以满足不断上涨的市场需求。

GT Solar公司是DSS铸锭炉领域内的主要供应商，该公司在过去的几年里对市场面对大型设备不断上涨的需求有着充分的了解。在2009及2010两个财政年度里，GT Solar公司共向市场售出近10亿美元的资本设备，用于为已有终端用户增建设备约8GW至10GW。

有趣的是，GT Solar公司光伏设备部门产品营销总监周先生(Henry Chou)在交谈中所提及的首要问题却并不是扩大铸锭炉尺寸的问题。周总监所谈及的第一件事是，随着产业市场的日趋成熟，GT Solar公司所关注的是其称为“价值尺度”的问题。通过使用简化的变量来强调生产成本，公司期望凭借提高制造工具的吞吐量来降低成本，以获得较高的产量以及较好的硅锭总体质量。这种方法可以在从硅锭至硅片切割的整个流程中减少浪费情况，同时降低成本。

“事实上，获得较高质量的硅片并不意味着电池制造商能够获得较高的电池转换率。”周总监还指出，“我们所寻求的是每小时所生产的千克数。”

周总监还表示，衡量铸锭炉成本下调的两大关键指标是铸锭炉的吞吐量及产量。其中，吞吐量与铸锭炉在单位处理时间里的熔料量有关。

“有趣的是，如果炉料的分量开始大幅增加的话，所花费的处理时间也将随之增加。根据处理时间长短的不同，分离杂质的质量以及晶体的生长可改变整体的最优平衡。因此，由于晶体生长周期也相应延长，即使铸造出大型的硅锭，也并不意味着能获得更高的吞吐量。”

图4：赛瑞丹（天津）工业陶瓷有限公司的钳锅

周总监还认为，如果硅锭尺寸超出了600kg，就很可能会导致对其他设备进行调整，从而在事实上增加了生产成本。使用超过450kg的熔料量将成为不可避免的趋势这一结论看起来并不成熟。该公司近日凭借旗下的DSS450铸锭炉及其辅助设备和相关服务，获高达2亿美元的资产估算额。众多硅片制造商与其签署了订单，其中包括天威新能源、Phoenix光伏科技公司、英利绿色能源公司、晶澳太阳能(JA Solar)和中美晶硅产品公司(Sino-American Silicon Products，简称SAS)。

在2010年5月初的时候，GT Solar推出了一款新产品DSS450HP高性能硅锭生长炉，该铸锭炉拥有经过热优化的第二代热区技术。据称该技术可保证在提供业内领先晶硅质量的同时提高设备吞吐量。DSS450和DSS240两个机型的用户可通过加装现场升级组件将设备改装成新型DSS450HP设备。这就意味着，硅片制造商将更倾向于在短期内选用已成熟的技术来扩大其硅锭/铸锭炉的尺寸。

浆料解决方案

浆料是硅片制造的核心。浆料常被与线锯配合使用，用来将硅锭切割成硅片。通常情况下浆料是一种由碳化硅和乙二醇混合而成的磨料。与其说使用浆料来切割硅锭，不如说是腐蚀硅锭来得准确。在大多数情况下，当谈及整个硅片制造流程中哪一步骤是节约成本最关键的环节时，浆料从来都是当之无愧的第一名。

当浆料沿着线锯的准绳流至硅锭上时，其中的腐蚀性碳化硅(即沙砾即可将硅锭切割成硅片)。浆料应该经常更换并进行处理，以保证所产硅片的数量和质量，并同时将单位成本维持在可接受的范围内。

尽管浆料对于硅片生产流程来说十分重要，其在生产成品中所占的比例也不容忽视。浆料的成本通常仅次于对晶硅本身的成本花销。尽管新型浆料的价格相对较低，仅为每千克3.5美元，但总体成本升高得却很快。假设一条生产线上使用了10台线锯，其运营成本可高达每年1600万美元，而这其中还不包括废料排污费和工人劳务费。

对于大多数制造商来说，浆料的再处理高居各运营成本中的前五位。对此项业务进行优化可在硅片生产成本和总体质量等方面获得显著且长久的成就。

据业内领先的浆料回收公司CRS Reprocessing Services 表示，正准备开展浆料再处理的项目或已开始使

图5：GT Solar 生产的DSS450HP型锭生长炉

用新工艺的硅片制造商能够借由边际效益的大幅改善而获益匪浅。以10台线锯同时运行、硅片月产量385吨为例，若开展浆料再处理业务，每年可在净回收成本、公用事业和基础设施投资上节省800至1000万美元。

“在CRS公司，我们能够回收80%至90%的沙砾及硅片承载器。”CRS公司创始人兼总裁比尔•劳伦斯(Bill Lawrence)表示，“浆料的实际回收利用量是一个取决于硅片尺寸、硅片厚度、线锯设置以及浆料中硅含量的一个变量。对于含油浆料来说，用来清洗硅片及设备的清洗剂的回收率一般都在90%以上。因此，浆料的回收率越高，可重复使用材料的回收量就越大，从而使得花费在新材料上的资金就越少。”

尼克•萨诺(Nick Sarno)对于浆料回收利用的益处见解颇丰，其在赛维LDK太阳能任职期间曾针对回收再利用作出许多战略举动。萨诺先生表示，赛维LDK太阳能拥有一套3万吨级的回收系统(见图7)，同时，公司还将在硅片年产能增至2GW以上的同时加装一套相似的设备。萨诺先生反复强调，成本规避是公司发展中的重点因素，而材料的回收利用可有效降低新材料的使用量。

图6：CRS Reprocessing Services经典泥浆回收系统。

而意料之中的是，CRS公司的劳伦斯先生仍旧反对硅片制造商试图设计修建厂内回收系统的趋势，坚持认为将这一业务交由拥有全套供应设备及管理系统的第三方专家是最好的选择。

“在厂内自行进行浆料回收利用的缺点就是其沙砾和硅片承载器的回收率均十分低。通常，此种操作仅能回收极小的一部分硅片承载器，仅为20-30%左右。此外，自行进行回收利用将很有可能影响到产品质量的监控以及公司的产能，并进而导致产品规格下降、实验室验证工具受限和停产时间延长等问题。”

“就长远来看，可提高沙砾和硅片承载器的最佳再处理解决方案，能够将一套10线锯设备的月均总体运营成本降低27.5至37.5万美元。上述这些因素，再加上那些对于业务发展不是十分总要的资金来源，可大幅减少公司期望借由厂内回收再利用系统而获得的潜在业绩。”

总体来看，当谈及浆料再处理时，企业通常会面临四个选择：自行处理、在第三方场地进行处理、在生产现场进行处理以及不进行浆料再处理。

劳伦斯先生指出了目前在欧洲盛行的在第三方场地进行再处理工艺的一些相关费用问题。他认为，使用在第三方场地进行再处理所产生的服务费用其实是十分具有相对竞争力的，甚至可能低于常见的现场再处理工艺的花销。但是，在第三方场地进行再处理工艺也却确实会产生一项其他方面的不可忽视的费用。

其中最主要的一块就是运费，而这其中分为货运和航运两部分。运费的高低在很大程度上取决于浆料的多少以及运输距离的远近。在某些情况下，这笔费用是十分庞大的。通常情况下运费的费率为在境内每千克3美分，而跨境运输为每千克40美分。如果一名客户每月要进行800吨的浆料再处理，那么其每月在此项目上的花费就高达20万美元以上。同时，在第三方场地进行浆料再处理也要求制造商拥有大量的替代浆料以保证自身的生产业务。

上述所提及的许多问题已在如半导体制造业这种平行产业内引起极大的关注，在半导体制造业内，大多企业都采用现场回收再利用的方式，并受惠于其所带来的其他益处。

就产品质量监控来说，现场浆料再处理对于制造商来说具有完全的操作透明性，并可即时获得质量过关的浆料。同时由于浆料从未离开过生产区域，整个过程均在封闭的作业流程中进行，因此可以避免外界污染进入生产流程的风险。此外，专业人士在进行的现场测试时也能够轻松便捷地进行各种调节，以获取质量稳定优良的浆料，进而有助于在保证低废料率的同时获得硅片的高产量。

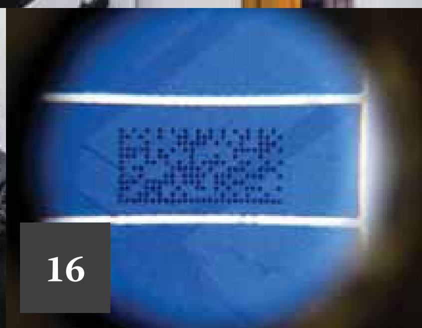
在此，笔者再次强调，产品质量是整个产业的发展核心，即使在祈求简单的成本分析的过程中也不应忽视。优化产量和提高质量可更有效地节约成本。

- 三万吨级浆料回收系统已于2009年9月投产使用
- 公司将于2010年中期新增一套三万吨级设备

图7：赛维LDK太阳能的厂内泥浆回收系统。

想了解更多吗？
请登录PV-Tech.org在线杂志库:
www.pv-tech.org/journal_archive

Fab & Facilities



News

Q-Cells to build 150MW module plant in Germany

Although Q-Cells has partnered with a range of PV module manufacturers to fabricate its modules using its own solar cells, CEO Nedim Cen said in a third-quarter conference call with financial analysts that the company is building a 150MW module plant in Thalheim, Germany, which will be dedicated to its Q.Peak-branded modules. According to Q-Cells, the Q-Peak modules employ monocrystalline cells and will be its premium solar module offering. The ramp-up of the module line has already started, Q-Cells confirmed to *PV-Tech*.

Q-Cells does not have any internal module manufacturing capability as it is still transitioning to becoming an integrated PV systems provider and away from just being a solar cell supplier. Targeting the residential and commercial rooftop markets with its 'Q.Peak' products within Europe, Cen noted that only the highest efficiency cells will be used in the module plant, which is designed to meet demand for such products.

Bringing a certain amount of module production in-house could be seen as a way to meet the tightest of quality standards as the company transitions to wanting to become a premier supplier, according to Cen. Q-Cells' CEO also noted the need to have module production close to its cell R&D centre in Thalheim to speed product development. Q-Cells declined to reveal the capital expenditure planned for the module facility.

Source: Q-Cells

Q-Cells module inspection.

Capacity News Focus

Suntech opens U.S. module plant and makes plans for joint venture in Canada

Suntech, the world's biggest crystalline module manufacturer, has officially opened its first module assembly plant in the U.S. The 30MW plant, located in Goodyear, Arizona, is assembling Suntech's 280W Vd-series modules, which will be used primarily for commercial- and utility-scale applications rather than residential as they are compliant for procurement in American Recovery and Reinvestment Act (ARRA) projects. Arizona Governor Jan Brewer presided over the grand opening ceremony.

Suntech said that, due to strong demand and targets to reach up to 120MW of annual production capacity, it is preparing to expand the facility to 50MW early next year. Suntech also reiterated its plans for research collaboration with Arizona State University. The 117,000 square-foot facility currently employs 75 people but with the planned expansion to 50MW, total workforce is expected to reach about 150 by the end of 2011.

In other news, Suntech has signed a letter of intent with Calisolar to construct a solar silicon manufacturing facility in Ontario, Canada, in order to significantly expand the existing manufacturing operations in Vaughan. The plant will add new operators and engineers, doubling total employment at Calisolar's wholly owned subsidiary, 6N Silicon, to more than 350. As set forth in the LOI, Suntech will assist with financing the expansion and enter a multiyear agreement to purchase solar silicon produced by Calisolar at the new manufacturing facility

First Solar to build thin-film plant in Vietnam; plans to double capacity by 2012

CdTe thin-film leader First Solar will build new facilities in Vietnam and the U.S. as it attempts to double its manufacturing capacity to over 2.7GW by 2012. Two four-line manufacturing plants are expected to add 500MW of capacity and will be completed in 2012. Currently, First Solar is capacity constrained but is building further new lines in Malaysia and France. The Vietnam plant is the company's first in that country and follows semiconductor leader Intel in locating production in the country.

First Solar said that each plant would create approximately 600 jobs and noted that, thanks to its utility-scale project pipeline in the U.S., a further 1,000 construction jobs would be created during

Source: First Solar

First Solar manufacturing plant, Perrysburg, Ohio.

the completion of these projects. As with previous new factory announcements, First Solar said that negotiations and site assessments are ongoing in both countries. The company will announce site locations at a later date.

Saint-Gobain and Hyundai Heavy Industries to build 100MW CIGS thin-film plant

A new joint venture (JV) has been formed between Saint-Gobain and Hyundai Heavy Industries (HHI) to build and operate a 100MW CIGS (copper, indium, gallium, selenide) thin-film module plant in Korea. The JV will be called Hyundai Avancis and the new partners said the plant will be operational in the second quarter of 2012, with an initial investment of US$196.9 million.

Having acquired the outstanding 50% stake in Avancis from Shell in August 2009, Saint-Gobain has already announced a new 100MW CIGS plant to be built in Torgau, Germany. This plant will become operational a quarter before Hyundai Avancis and will provide the design plueprint for the Korean plant.

Innotech Solar lays first stone at German production site

Innotech Solar began constructing its new solar cell production site located in the

Source: Innotech Solar

The Innotech team cements the first stone at the new facility.

Eastern German city of Halle on October 27th. The facility is expected to initially create 80 new jobs in the region, with plans to increase the number of employees as the site progresses.

Innotech Solar was assisted in the investment process by Germany Trade & Invest and the Investment and Marketing Corporation Saxony-Anhalt.

Umicore invests €30 million to expand thin-film materials production

Newly-developed rotary target bonding technology will be employed as part of a €30-million investment by Umicore to expand production of rotary sputtering targets needed for thin-film PV deposition processes. The capacity expansions are to take place at all three of Umicore's existing target manufacturing facilities based in Providence, Rhode Island, Balzers, Liechtenstein and Hsinchu, Taiwan.

Umicore also highlighted that new test and development facilities would be established at its Balzers and Providence plants, which are intended to facilitate technological and strategic partnerships with selected equipment makers and producers, as well as support its customers in production line optimization and product development and testing.

Solarfun to spend US$130 million to increase capacity in 2011

In an effort to further reduce its manufacturing cost structures, Solarfun is planning to spend approximately US$130 million to boost capacity of its wafering and cell production to become more integrated. The company expects to construct additional buildings, facilities and infrastructure, especially for its ingot and wire saw operations in 2011. The capital expenditure is being financed by the recent equity injection from the Hanwha Group, as well as net cash flow from operations and cash in hand.

Solarfun noted that it had already succeeded in reaching its current capacity expansion plans for 2010, which included 360MW in ingot manufacturing capacity,

Fab & Facilities Order Focus

Silfab Ontario contracts SCC Solar for engineering and additional services on new Canadian plant

SCC Solar has agreed to provide program and engineering construction management for Silfab Ontario's soon-to-be-constructed solar module manufacturing plant. Silfab's plant in Mississauga, Ontario, Canada, will start its first production phase at the beginning of 2011. Working with Green to Green Engineering, who will take care of the module production line design and process, SCC will provide the program control and engineering for the construction, utilities and other services the project necessitates. The Mississauga plant's focal point will be Silfab's silicon modules, but the company also has plans to produce for original equipment manufacturer companies.

Chiyoda lands EPC contract with Tokuyama Corporation

The Chiyoda Corporation has secured an engineering, procurement and construction contract with the Tokuyama Corporation for the development of a polycrystalline silicon plant in Samalaju Industrial Park, northeast of Bintulu, Sarawak, Malaysia. The companies did not disclose the contract amount, but did advise that the plant is expected to produce 6,000 tonnes per year.

Chiyoda has been involved with the project since 2008, when it started the front-end engineering design and basic planning work. Construction of the new plant is expected to begin early next year with operations set to start in 2013.

Voltaix executes agreement with Wonik Materials for expansion of germane production in South Korea

Voltaix entered into an agreement with Wonik Materials for the construction of a 25MT germane production facility at Voltaix's South Korea site. Voltaix considers the expansion a move in the right direction to meet customers' needs for germane supplies as their demand increases throughout Korea and East Asia. Wonike and Voltaix acknowledged that their distribution agreement in Korea will continue.

Prediktor supplies Photovoltech with the APIS Click & Trace MES

Prediktor is to supply Photovoltech with the APIS Click & Trace manufacturing execution system (MES) solution for its new in-line photovoltaic cell production plant based in Tienen, Belgium.

Shinsung Holdings adopts Applied Materials' 'SmartFactory' MES

Korean-based solar cell manufacturer, Shinsung Holdings, has adopted Applied Materials' SmartFactory manufacturing execution system (MES) software, the first publicly announced deal since Applied launched the system.

Applied Materials claimed that Shinsung had selected its MES because of the ability of the SmartFactory system to combine multiple production lines into a single virtual factory. Process flow modifications could also be implemented in real time to deliver higher and more consistent factory output, according to the company.

ABB Automation supplies Elkem Solar with electrical and automation systems

The process line at Elkem Solar's Kristiansand, Norway-based facility is to be outfitted with an ABB Automation electrical and automation system on the System 800xA platform. Elkem recently invested US$700 million in the new facility, which holds the capacity to produce 6,000 metric tonnes of high-purity silicon per year.

The production line has five independent process steps for which ABB Norway has supplied all electrical high-/low-voltage infrastructures to the plant. ABB also furnished a process automation based on the System 800xA for two of the process steps. The process line was brought into operation in July 2009.

ib vogt commissioned for solar manufacturing plant in India

ib vogt has won its first major order from India for the building of a solar manufacturing plant for an unidentified Indian Multinational. ib vogt has been commissioned to undertake the factory design, planning and construction management, which began in April 2010, and is expected to reach completion by the end of June 2011.

400MW in wire saw capacity, 500MW of cell capacity and 900MW in module capacity. This represents increases of 100MW in cell capacity and 200MW in module capacity compared to the end of the second quarter of 2010.

However, with higher capital cost and longer equipment lead times, Solarfun does not currently have a balanced integrated manufacturing infrastructure, being top heavy with higher module capacity than wafering and cell production. The plans for 2011 include boosting ingot capacity from 360MW to 510MW and wire saw capacity from 400MW to 572MW. Solar capacity will also be increased from 550MW to 820MW, better matching its module capacity.

Solarfun also noted that it plans to continue to reduce processing costs through enhanced manufacturing efficiencies and other R&D breakthroughs. The decision to further ramp its manufacturing capacity is to meet expected customer demand in 2011.

Source: Solarfun

Solarfun cell sorting.

Mecasolar adds new facility in Ontario

Mecasolar has opened its newest manufacturing facility in Wallaceburg, Ontario, Canada, which boasts 20,000 square feet and enough space to potentially add two acres of outside storage. Mecasolar's new centre can produce 8,000 solar trackers per year and will manufacture both two-axis solar trackers and 15kW one-axis trackers. Mecasolar is looking to this new manufacturing facility to better supply its customers in Ontario and the northeast U.S. with easier delivery. Orders are already in place with delivery expected by next November.

Solargiga and Liaoning enter JV for 500MW multicrystalline silicon solar wafers and ingots project

Solargiga Energy Holdings and Liaoning Oxiranchem have agreed on entering a joint venture for the production of 500MW capacity multicrystalline silicon solar ingots and wafers. Construction on the project, located in Longqiwan New Zone, Jinzhou, Liaoning Province, China, will be divided into two separate phases over a five-year period. The first phase will hold a capacity of 200MW with an expected two-year completion. The second phase will take three years to construct and will account for 300MW. Solargiga will oversee all sales from the plant.

Total investments and registered capital for the JV is proposed at US$100,671,142 and US$29,828,486.54. Solargiga will own 37% interest in the JV with the capital injection of US$11,036,540.02.

Kaco to begin production at Ontario solar PV inverter facility; plans 330MW capacity in 2011

Another PV manufacturing company is setting up shop in Ontario to take advantage of the province's Green Energy Act feed-in tariff requirements for domestically sourced content. Kaco will soon begin full-scale production of its solar photovoltaic inverter line at its new facility in London, ON's Skyway Industrial Park. The firm, which will hire 50 full-time employees at the Canadian site by the end of the year, plans to produce its XP series 83kW and 100kW blueplanet inverters at the 25,000 square-foot plant by November and expects to bring 330MW of capacity online in 2011.

The company, which has stated a goal of reaching over 3GW of global inverter production capacity in 2011, said it will expand the London facility to more than 40,000 square feet next year.

Satcon signs strategic manufacturing agreement with GCL; expects 2GW annual worldwide capacity

Satcon Technology and GCL Solar Systems signed a manufacturing agreement to boost production of Satcon's 500kW PowerGate Plus solar PV inverters in the Asia Pacific market. GCL will develop a manufacturing facility in Nanjing, China, which they expect will produce over 500MW of the inverters in 2011. Satcon will supply GCL with the manufacturing processes and technologies for the PowerGate Plus in order to complete final assembly at the GCL solar plant.

GCL will purchase from Satcon the capacity to produce a minimum of 300MW per year at the Nanjing facility with the intention for the inverters made at the facility to be sold by GCL into the Chinese solar PV market and used on the company's worldwide funded utility solar developments. Production at the new facility is to begin in March of 2011. The companies stated the combination of the Nanjing facility and the Burlington, Ontario site would increase the worldwide manufacturing capacity to 2GW annually.

Other News Focus

Dutch start-up partners with Roth & Rau and Day4 Energy on advanced integrated c-Si production plant

Netherlands-based Alinement B.V. (ABV) has bold plans to become a major integrated PV module manufacturer in Europe. Under the terms of a tri-party memorandum of understanding, ABV will start production in the first quarter of 2012 in an 80MW factory, using advanced heterojunction cell technology and turnkey manufacturing lines from Roth & Rau and module manufacturing technology from Day4 Energy. It also said it plans to increase production to 500MW at a single location in the Netherlands, as well as 2.5GW globally. The site for the integrated wafer, cell and module plant was not disclosed.

Little is known about ABV. In a joint statement, ABV was described as a 'group of solar experts with a proven track record of bringing new products and production methods to market.' ABV was also said to be a prospective Day4 solarSYSTEMS partner. Jac Hanssen, CEO of Alinement, was formally a director of Solland Solar, also based in the Netherlands.

SEMI forms PV automation standards committee

SEMI has created the new PV Automation Standards Committee, located in both Japan and Europe. The Europe committee is co-chaired by Tino Korner of Q-Cells, Eberhard Teichmann from the Peer Group and Martin Zenning of Jonas & Redmann. In Japan, the PV committee is co-chaired by Terry Asakawa from Tokyo Electron and Emi Ishikawa from Atelier Ishikawa. The new committee's preliminary focus will be on efforts related to equipment-to-equipment communication, cell transport carriers and single- substrate tracking while the existing PV committee will handle non-automation matters.

Currently, the PV automation committee has two task forces: the Carrier Task Force and the PV Equipment Interface Specification Task Force (EIS). The Carrier Task Force will focus on standardization of equipment load parts and transport systems, which lead to direct and indirect cost savings in the supply chain, fewer risks during ramp-up and less energy for the integration of production lines. The EIS task force will be looking at reducing costs where software interfaces subsists between different pieces of equipment.

As the automation of PV manufacturing process continues to evolve, costs for solar cells and panels should be reduced. Automation is said to increase throughput, improve product quality and yields while requiring less maintenance and operational expenses.

Pfeiffer Vacuum to acquire Alcatel-Lucent's Adixen vacuum technology unit

Pfeiffer Vacuum Technology has revealed its intention to acquire Alcatel-Lucent's Adixen vacuum technology unit, headquartered in Annecy, France.

Fab & Facilities Special Feature

REC reveals fully-integrated manufacturing cost-per-watt roadmap

At a lengthy investor and analyst seminar being held in Singapore, coinciding with the grand opening of the €1.3 billion-plus integrated module production facility, REC's enigmatic CEO Ole Enger claimed the company was on track to deliver a company-wide all-inclusive cost of €0.97/W by the fourth quarter of 2011. Excluding equipment and building depreciation at the new plant, the cash cost target for next year would be €0.74/W.

Part of the €3 billion-plus capital expenditure program is for the polysilicon and silane capacity expansions involved in the build-out and ramp of its low-cost, fluidized bed reactor (FBR) technology in North America. The company's polysilicon achieved a fully-inclusive cost of US$42/kg in the third quarter and has a target of US$31/kg by the fourth-quarter 2011, as production reaches 16,000MT per annum, according to REC.

Enger noted that REC demonstrated a cash manufacturing cost for the FBR-processed polysilicon of US$18/kg. With the ramps under way and a period of optimization and de-bottlenecking planned for 2011, REC is confident that it has the manufacturing cost structure to compete with anyone in the industry, not least the low-cost Tier 1 producers in China.

Rather than just claim such cost competitiveness or leave out key costs such as raw materials, a series of presentations gave one of the most detailed and transparent analyses of REC's manufacturing cost structure ever. The company highlighted further capacity expansion plans and operational goals that were intended to show its longer-term cost competitiveness to investors, financial analysts, and sceptics alike.

REC plans to further leverage investments in infrastructure at the Singapore site to increase module production to 800MW by 2012, exceeding the nameplate capacity by approximately 35%. Importantly, this was claimed to be achievable without further significant capital cost. Indeed, the plant in Singapore is at the heart of its claims for longer-term cost competitiveness. The highly-automated plant uses a skilled workforce but employs less than 50% of the number typically found in Tier 1 plants in China.

Although the upfront cost of highly-automated module plants and heavy tool depreciation costs can prove challenging to compete with the cost structures found in China, REC highlighted that cell breakage in Singapore was already as low as 0.4% using a standardized 180μm wafer thickness. Silicon consumption from ingot to module is expected to be down to 5.6g/W by the fourth quarter of 2010.

Wafer quality has also been a key factor in REC's cost-competitive roadmap. Erik Lokke-Owre, senior VP of operations in Singapore, noted in his presentation that the plant had already achieved a 0.2–0.3% wafer quality improvement that contributes to an overall annual cost reduction cycle of an expected 10% per annum.


Source: REC Solar

Cell production at REC Tuas, Singapore.

The plant also includes eight advanced cell lines, each with a nameplate capacity of 70MW, giving REC a total of 550MW. Near-zero defects and perfect manufacturing flow dynamics were at the core of its competitive position, Lokke-Owre added.

Average cell efficiencies were pegged at 16.8% without further planned enhancements and process optimization, while current yields have exceeded 94%. The use of advanced process control (APC) and statistical process control (SPC) systems and protocols would ensure quality cells at a world-class level, he said.

Solar module costs were said to be on target to fall to €1.05/W by the fourth quarter of 2011, down from €1.49/W in the third quarter of 2010, representing a 30% decline over five quarters. REC executives also noted that sales demand is expected to be strong in 2011, giving the company confidence in achieving full capacity for its FBR silicon and Singapore plants.

Negotiations on the purchase of the companies, patents and licenses belonging to this unit have been largely finalized with Pfeiffer Vacuum's supervisory board consenting to the acquisition on November 3rd.

The purchase price for the unit will total approximately €200 million on a debt/cash-free basis and will be fully financed through a bank loan. Pfeiffer Vacuum intends to reduce a portion of the acquisition financing by selling treasury shares and through a capital increase from authorized capital in the amount of up to 10% of its share capital. Prior to the signing of the contract, a hearing of employee councils of the Alcatel-Lucent group is required. The acquisition is planned to take effect on December 31st.

Pfeiffer Vacuum and Alcatel team members discuss acquisition terms.

Teamtechnik opens new production facility in Jintan, China

Teamtechnik has inaugurated its new 1,500m² production facility in Jintan, China. The new location is expected to increase the amount of local contacts for customers in China and to ensure short delivery times as well as efficient response from the service teams.

Attending the opening ceremony, CEO Stefan Roßkopf (pictured, centre) said, "We now have a presence close to where 60% of Chinese photovoltaic production takes place."

Teamtechnik's Stringer TT1200 system is currently only produced at the company's headquarters in Freiberg, Germany. The first stringer systems for the Chinese market are expected to be shipped from the Jintan facility as early as May next year.

Combined with the new sales centre in Suzhou, Teamtechnik's Chinese workforce will total 50 by the end of 2011. The majority of the employees will receive technology training in Germany. Teamtechnik also has production sites in Poland and the U.S.

Opening celebration at the new Teamtechnik site in China.

Every solar cell is an original: laser marking of silicon solar cells yields new opportunities in quality control

Peter Wawer, **Uli vom Bauer**, **Jörg Müller** & **Daniel Paul Schreiter**, Q-Cells SE, Bitterfeld-Wolfen, Germany

ABSTRACT
A major challenge for the solar industry over the next few years is the reduction of production costs on the road to grid parity. Capacity must be increased in order to leverage scaling effects, production and cell efficiency must also be enhanced, and the industry must focus on intensified process optimization and quality control. Laser marking can make a key contribution to fulfilling these requirements. As hard physical coding, laser marking is applied to the raw wafer at the start of the manufacturing process, making each solar cell traceable along the entire value chain and over its whole lifetime. This paper presents Q-Cells' laser-supported process for coding each individual solar cell (European patent pending), which will require transition work at the laboratory stage before the company's innovation is ready for mass production.

Traceability by means of a data matrix code

Laser marking as a means of identifying raw silicon wafers was first used in the semiconductor industry around 35 years ago. Early markings comprised characters that were legible by humans, and in the mid 1980s, a method using bar codes was developed. According to a study conducted by the Fraunhofer Institute for Solar Energy Systems (ISE), the method employed in the semiconductor industry to mark products involves a two-dimensional matrix code in line with the Semi T2-0298E standard. In solar cell manufacturing, however, the use of laser bar codes on wafers would require a somewhat larger area in comparison with dot matrix codes. Since the code is to be written on the front of the cell, it would encroach on the finger grid.

The new code is a two-dimensional industry standard data matrix code called Data Matrix ECC200, which is a highly robust de facto industry standard. Reed-Solomon error correction allows for around 25% redundancy in a matrix in which the outer lines of the code are required for better code identification by the reader. Typical matrix sizes are 8 × 32, 14 × 14 or 12 × 26. The actual data content is scrambled and strategically distributed over the whole area to achieve a high level of robustness against missing dots, disturbance or code corruption. The capability and structure of error correction is particularly important in the solar industry (for example, if solar cell fingers are printed over the code).

This tiny code on the front of a solar cell ensures that each cell can be recognized by machines and is, therefore, traceable. The code remains readable even when the cell is integrated in the finished solar panel and survives all processing steps such as texturizing, the application of anti-reflex coating and firing. Unlike laser bar codes on semiconductor wafers, which require dedicated areas to be left free to accommodate them, the marking can be applied in the active area of the solar cell without impairing the solar cell's power generation capability. This fundamental difference represents a huge leap forward and is a massive benefit to the photovoltaic industry.

> "The marking can be applied in the active area of the solar cell without impairing the solar cell's power generation capability."

Dot matrix codes can not only be written and read easily and reliably, but can also store a huge volume of data. This makes them ideal for ensuring traceability, something that has been proven as vital time and again in the mass production of literally millions of wafers over the past few years. Alternative methods include laser marking at silicon ingot level, which creates patterns on the edge of the wafer, or wafer identification through the unique surface characteristics of each multicrystalline wafer.

Ingot marking, for example, is an extremely simple method of marking wafers. In this process, wafers are marked at the beginning of the process and the wafer position in each ingot can be determined, even if the ingots or blocks have been sliced. This is achieved through the application of a bar-code-like pattern on the side of the block. Once the wafers have been sliced, the edge of each wafer bears a unique pattern. To enable this data to be reliably read out during mass production, either all four sides of a block need to be marked or reading equipment must be installed at each edge of the wafer since wafers turn through different positions as they pass through various wet benches and manufacturing processes.

Since the data volume is much less than that of data matrix codes, it is impossible to assign a unique serial number to each cell in order to achieve end-to-end traceability over a solar cell's lifetime; an ingot index is used instead, which is a simple method of allowing wafers to be traced back to their ingots and their position therein. Determining whether ingot marking can help to trace solar panels and whether the markings can be read out reliably will require further serious investigation. Since the marking is applied to the extremely fragile edge of the cell, however, Q-Cells has chosen not to continue developing this process for mass production in order to minimize the breakage rate – a must for high-yield solar cell production.

Another method of identifying and tracking solar cells is to exploit the unique surface characteristics of each wafer, a similar method employed by face or iris recognition equipment in modern airports. Since the pattern on adjacent sliced wafers is very similar, an extremely high picture resolution would be required. In turn, this would require a much larger volume of data to be stored in comparison with the far easier process of reading a number encoded in a dot matrix code. Another reason this method has not been further developed for mass production is that it is unsuitable for monocrystalline wafers because, with their homogenous surface, they do not offer any meaningful distinguishing characteristics to enable unique identification.

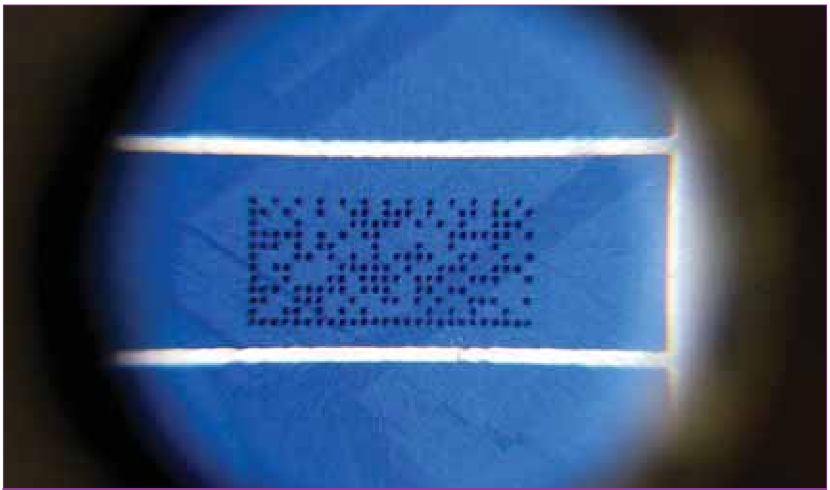


Figure 1. Laser marking on solar cells.

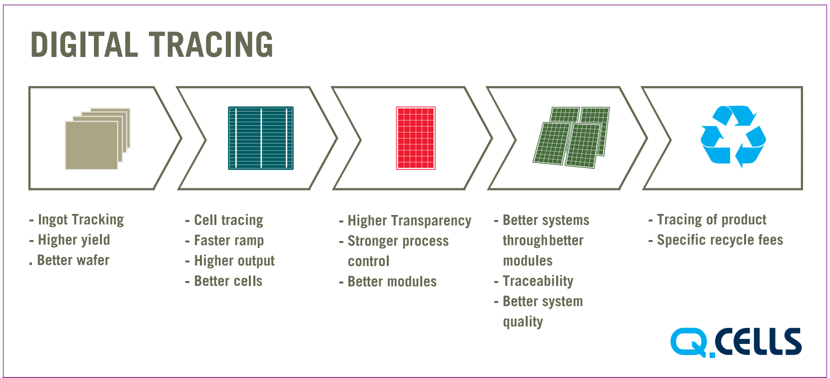


Figure 2. Digital tracking by laser marking across the entire value chain of the solar industry, from raw wafer to PV recycling.

In short, factors such as cost, throughput, convenience, reliability, the volume of data they can hold as well as the availability of both reading and writing equipment make dot matrix codes, applied to the front of cells, the ideal solution.

Laser marking: benefits for the PV manufacturing chain

Laser marking has proven to be a highly effective means of enhancing quality and achieving process stability. The digital marking of each individual solar cell allows maximum traceability across large sections of the photovoltaic value chain – from the silicon raw wafer to solar modules and systems – meaning that production steps can now be tracked in great detail. The process increases the transparency of each step, thereby enabling employees to know exactly which raw materials and manufacturing processes were used.

Laser marking allows manufacturers of silicon solar wafers to obtain information about the wafer and the ingot from the parameters of a solar cell. The findings from analyses of the production materials and processes used are directly implemented in subsequent optimization measures, thereby enabling a higher yield and higher-quality wafers. Tracking the solar cell manufacturing process provides information on the machines and procedures used during production. The learning effects achieved enable cost efficiencies and a quicker ramp-up phase at new production sites. Ongoing process control and quality optimization not only results in a higher production yield for manufacturers of solar cells and solar modules, but also improves overall system performance.

Application of the marking to the front of the cell, in particular, allows for the tracing of cells in modules even after they have been laminated, machined or even installed in a solar power plant. In the spirit of developing an environmentally-friendly range of products, laser marking data can provide useful information about recycling solar panels; even decades after the recycling of these cells and modules, this marking can identify exactly which materials were used in the production of the cells.

Application of laser markings on crystalline solar cells

A key aspect of laser marking is a clearly defined process for writing the data matrix code. The precise placement of the laser marking code can greatly improve readability. Of course, the placement of the code in relation to the finger layout (see Fig. 2) is extremely important, but the active area in which the laser writes the code and the field of view in which the data matrix reader can reliably detect the code also need to be taken into consideration. The best results have been achieved by placing the code near the centre of the solar cell, taking into account bus bar and finger layout.

> "Great care needs to be taken to ensure that laser markings do not affect the electrical parameters of a cell."

Great care needs to be taken to ensure that laser markings do not affect the electrical parameters of a cell, for example through the effects of shunts that could occur if the laser markings are 'burned' too deeply into the silicon wafer rather than being written within a specified range of permitted depths at surface level. For this reason, parameters such as laser power, wavelength and duration of writing need to be precisely defined and verified by means of practical testing. Also, despite the fact that the laser markings should preferably be rather shallow, they should still be deep enough to resist wet bench processes in solar cell production. The best results have been achieved with Nd:YAG lasers operating at a wavelength of, for example, 1,064nm with pulse durations of between 20ns and 50ns, power of between 5W and 30W, and creating dots 100µm in diameter and between 10µm and 30µm deep (before etching). Tests (see Fig. 3) have confirmed that without an optimized writing process, the readability of laser markings falls short of mass production requirements, which far exceed 90%.

Equipment for reading laser markings

To achieve the highest possible reading rates, optimized laser markings are essential. Various experiments have been conducted involving inspection systems and light sources from different suppliers. As solar cells move along the production line, their surfaces change in response to the etching, oxidation and heating processes that they undergo, which meant that, in this case, the reading equipment needed to be optimized. While the light source in conventional dot

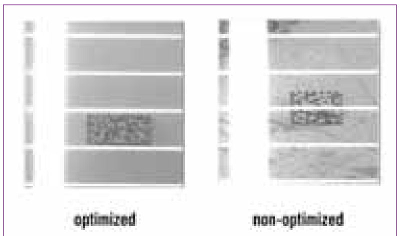


Figure 3. Optimized and non-optimized code writing laser markings with different laser parameter.

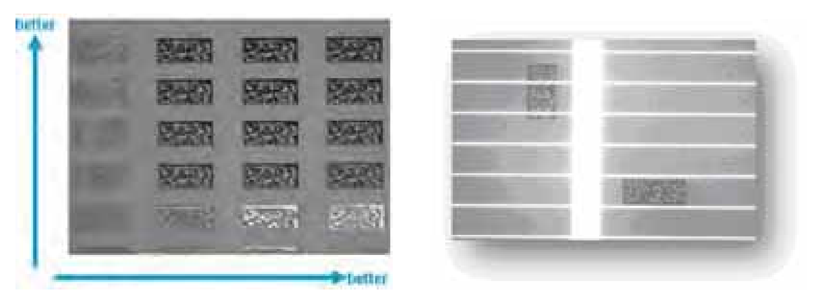


Figure 4. a) Impact on readability through specifying the right process for *writing* laser marking code; b) impact on readability through specifying the right process for *reading* laser marking code.

matrix readers (DMR) was provided by a blue LED, it was discovered that the reading rate could be improved by using a red LED, particularly downstream of wet bench processes. Readability was further improved by optimizing the shutter speed in order to regulate the exposure time. Figs. 4a and 4b illustrate the huge difference in readability following optimization of the write process (Fig. 4a) and the read process (Fig. 4b) for laser markings.

The readability of laser markings depends on the optimisation of write and read processes – and it is clear that both measures are essential in order to achieve the best possible results in industrial mass production. Readability was further improved by optimising the shutter speed in order to regulate the exposure time. Optimization is achieved through iterative learning, a process that improves as the production volume increases.

Mechanical stress test

Another key advantage of implementing laser marking technology in industrial mass production is not only the stability of the process during high-volume production, but also the fact that the technology has zero impact on the product itself. Great care has been taken to ensure that this new technology does not affect cell handling, cause any breakages or microscopic cracks or have any impact on production yield. Tests were conducted in which wafer stacks containing between 100 and 300 wafers each were examined for microscopic cracks following both manual and automatic handling. The wafers were carried and moved around in an actual mass production environment along with their non-laser-marked counterparts. Following an initial examination for microscopic cracks, the wafers were transported and handled in such a way as to simulate the stress levels they would be subjected to during regular production. A 'twist test' carried out with around 70% of the force of a pre-determined breakage force was also performed to identify any microscopic cracks.

> "Any cracks that did occur were not due to the laser marking because they occurred between the individual markings rather than across them."

Further investigations were conducted by the independent Fraunhofer CSP institute, which used the 'ball-on-ring' method to test solar cell samples with a thickness of 160µm and different marking depths (see Fig. 5). It was evident from these tests that any cracks that did occur were not due to the laser marking because they occurred between the individual markings rather than across them. This confirmed that the laser markings do not have any significant effect on breakage strength in their vicinity. Fig. 6 shows the distribution of the force required to break a solar cell, in relation to the depth of the laser markings.

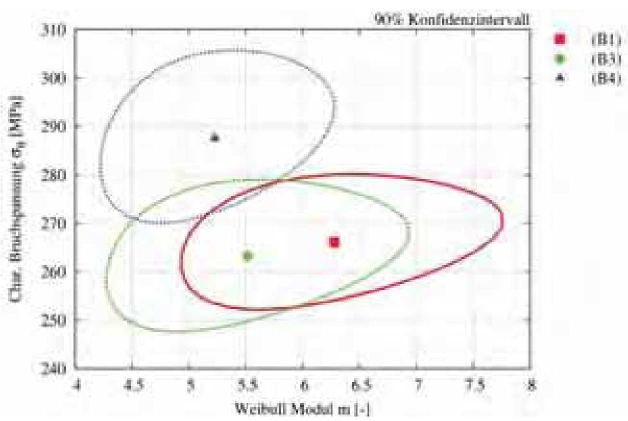


Figure 6. Investigation of solar cells' stability. The force required to create breakage shows no correlation with laser marking. Red: no marks; green: flat marks; blue: deep marks.

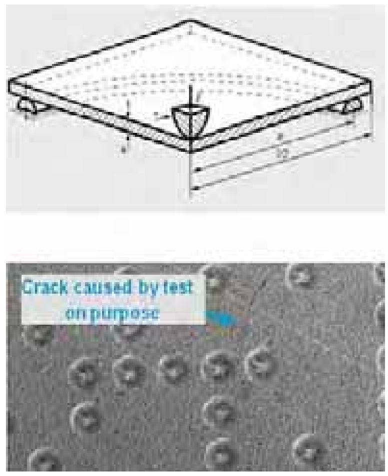


Figure 5. Investigation of solar cells' stability. The 'ball-on-ring' test provided evidence that breakage cracks have no correlation with laser marks.

Data matrix code

The new code is a two-dimensional industry standard data matrix code called Data Matrix ECC200, which is a highly robust de facto industry standard. Reed Solomon Error Correction allows for around 25% redundancy. In a 14 × 14 data matrix, 12 × 12 dots are reserved for data. The outer lines of the code are required for better code identification by the reader. Typical matrix sizes are 8 × 32, 14 × 14 or 12 × 26. The actual data content is scrambled and strategically distributed over the whole area to achieve a high level of robustness against missing dots, disturbance or code corruption. The capability and structure of error correction is particularly important in the solar industry (for example, if solar cell fingers are printed over the code).

Fig. 7 shows the new IOSS reader along with its analysis software. The red dots indicate the readability status of the code on the screen. As the code is available in various sizes (e.g. 14 × 14, 12 × 26 or 8 × 32), the system was chosen on the basis of various parameters such as the finger pitch of a solar cell, its capability to store different volumes of data, the time required to write the code and possible space constraints. To achieve the best possible results in mass production, Q-Cells conducted a number of experiments to determine the optimum size and placement of the code on the surface of the solar cell. Fig. 9 shows

Figure 7. Example of an industrial type data-matrix reader from IOSS GmbH (left). This reader has adjustable light and camera parameters in order to optimize readability, which is indicated by the red dots in the right-hand image.

an example of an actual implementation of ID laser marking. The encoded information can contain information such as the producer identifier, check digit, year/week, marker and running number.

Success story

Fig. 10 shows one actual example of a scenario where improvement of the diffusion process was brought about in Q-Cells' production. Sheet resistance is usually the control parameter used to check that the emitter definition is correct. However, as pictures a) and b) in Fig. 10 show, there is no indication of any efficiency dependence over the boot position. Only information gained at the cell tester can enable the engineers to develop improved recipes with higher efficiency and therefore maximum cell performance by creating a closed feedback loop, helped in this goal by laser marking. Although the ability to link cell tester data without laser marking is theoretically possible in the ideal IT production environment, the process either does not yet exist, is unaffordable or requires considerable testing. This would entail extra manpower, precisely specified reference material, and disruptions to ongoing production. Thanks to laser marking, however, such

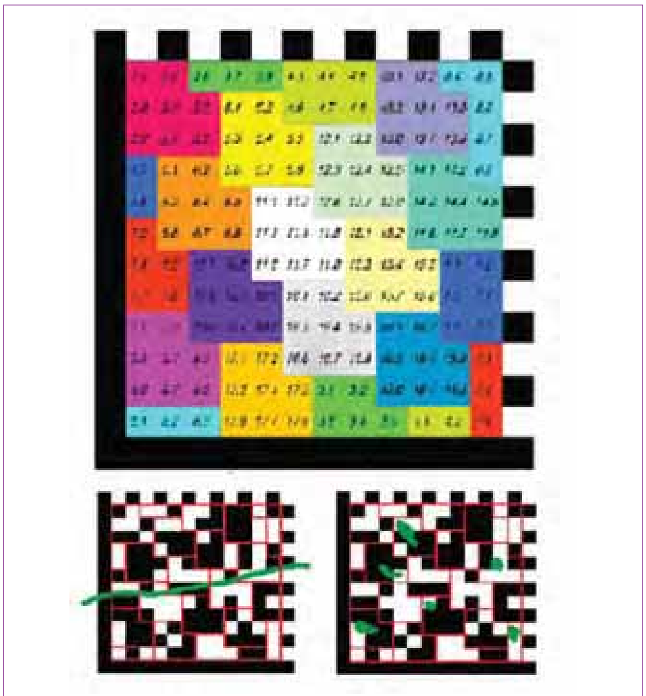


Figure 8. Distribution of the data matrix code. Top picture shows distribution of data across the data matrix for best reliability and recovery. The lower two pictures are examples of correctable and non-correctable code.

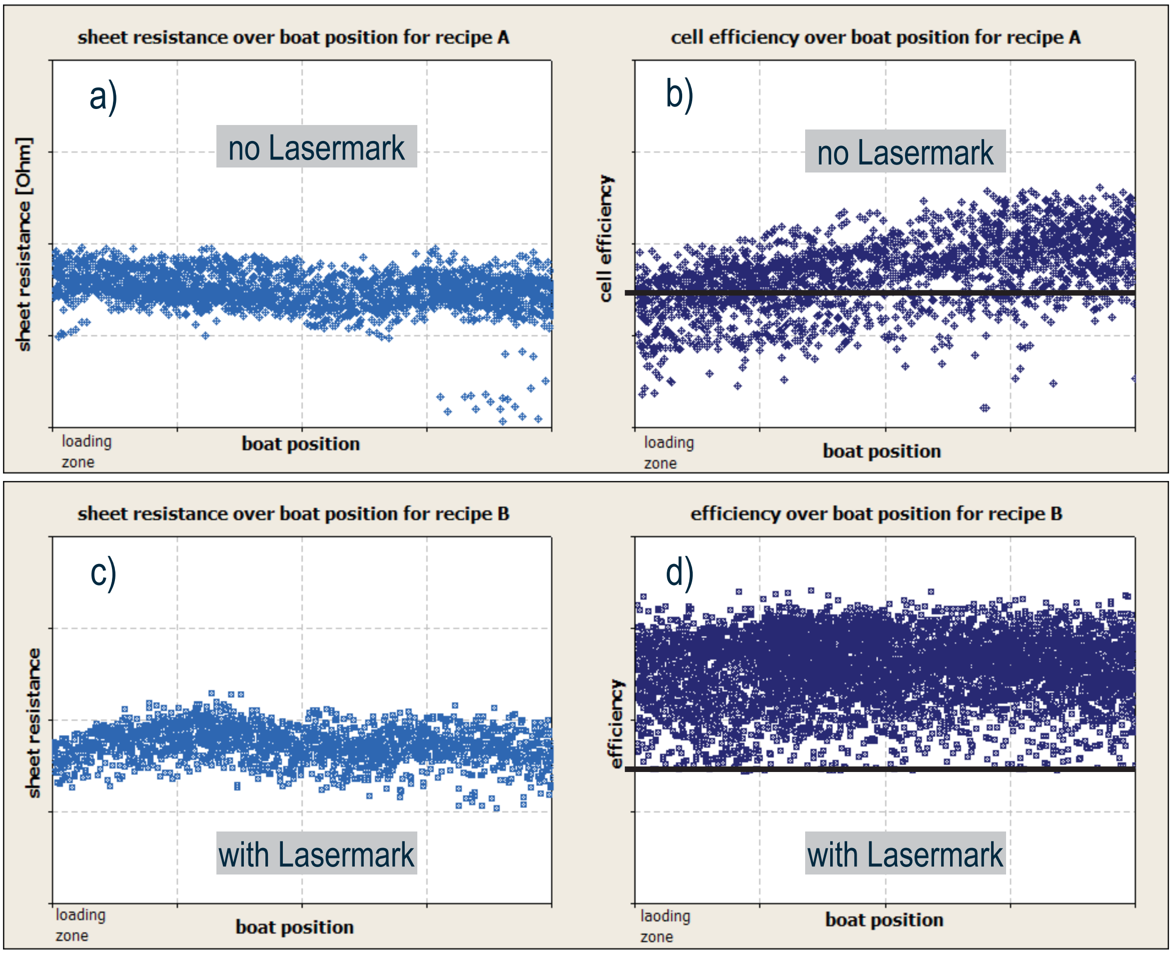


Figure 10. Improvement of the diffusion process at Q-Cells using laser marking.

Figure 9. Example of the content of a data matrix.

improvements can be achieved much more easily by using equipment from different lines in parallel with a much greater degree of statistical reliability and without disrupting ongoing production.

Processes for increasing sustainability in the PV industry

The laser marking of solar cells with a unique signature is an unprecedented step forward. The process makes a valuable contribution not only to automation and cost reduction, but also to ensuring sustainable environmental protection in the industry. It also allows end-to-end traceability, which has long been standard in other branches (e.g. the automotive sector). Containing the manufacturer ID and the product specifications, laser markings also help speed up the active recycling process of reusable solar components. The unique numeration of each solar cell offers additional advantages for customers too. For example, manufacturers can offer a guaranteed and verifiable quality standard. It also prevents product forgeries and allows complaints to be processed more quickly and efficiently.

Laser markings on solar cells – hard codes as unique numbers permanently embedded in the silicon over the entire product lifetime – not only allow manufacturers to offer products of superior quality, but also underline the sophisticated technological approach of cell suppliers in the PV industry.

About the Author

Peter Wawer studied electrical engineering at the TU Berlin, focusing on lifetime measurements of silicon crystals, and completed his Ph.D. work on thin crystalline silicon solar cells. In 1997, he began a career as a development engineer at Siemens Semiconductors in Dresden, progressing to the Infineon AG headquarters in Munich in 2004, where he held various positions predominantly in the area of technical management. Since November 2008, Peter Wawer has been responsible for the overall development activities in the core business of Q-Cells SE and is member of the board of Solarvalley Saxony-Anhalt e.V.

Enquiries

Q-Cells SE
OT Thalheim
Sonnenallee 17-21
06766 Bitterfeld-Wolfen
Germany

Tel: +49 (0) 3494 66990
Email: presse@q-cells.com
Web: www.q-cells.com

Cost-of-ownership forecasting for photovoltaic production equipment

Matthias Zapp, Fraunhofer IPA, Stuttgart, Germany

ABSTRACT

The recent decline in module market prices is the most telling sign of a need for continuous reductions in PV production costs. With this in mind, the cost efficiency of production processes is, next to stable product quality, a vital objective in the planning of production facilities. In this paper, the lessons learned in the area of cost-of-ownership (COO) forecasting methodologies for manufacturing equipment will be analyzed and evaluated for their potential application to investment decisions in the PV industry. This paper will analyze the cost structure of the PV industry with the aim of underlining the importance of a systematic cost-of-ownership approach.

Mature industries like the automotive industry have continuously optimized their cost structure during the last decades. Their ongoing success illustrates the tremendous cost saving potentials of photovoltaic manufacturers, who are still in an 'early stage' of mass production. Further development will require the adaptation and implementation of proven concepts and methodologies from other industries.

To depict the cost-saving potentials in PV manufacturing, a high-level cost structure for the crystalline PV supply chain is shown in Fig. 1. The short lifetime of production equipment, which is caused by rapid technological progress, leads to a large share of depreciation costs (approximately 20% for an assumed equipment lifespan of five years). Reducing the initial cost is, therefore, a promising cost-saving measure, especially since these costs are transparent and can be easily compared by every investor.

Nevertheless, the initial costs only account for a minimal portion of the overall costs throughout the equipment lifetime. The less tangible subsequent costs of the equipment, which occur during the operation phase and the further utilization phase, make up 80% of the total costs. Among these subsequent costs, the expenses for intermediate products (metallurgical-grade silicon, polysilicon, wafers and cells) represent the largest fraction. Besides, the consumption of further resources like energy, water, chemicals, pressured air and slurry represents another major portion of the total costs. For example, the electricity costs in the production of monocrystalline ingots account for approximately one third of the overall production costs.

Some subsequent cost items like energy consumption are highly dependent on equipment, and the selection of premium equipment may lead to considerable cost savings during the lifetime of the process. Achieving a high degree of transparency on all cost items is therefore a prerequisite for any systematic investment decision, and any subsequent costs need to be assessed in relation to this investment decision.

Any comparison of alternative equipment requires that the initial and subsequent cost items be made tangible. A better availability and comparability of the equipment data is beneficial to both the end user and the machine builder, who seeks to justify premium prices for the high-quality equipment. The subsequent costs need to be forecasted based on various planning assumptions. More precisely, the (future) production environment needs to be defined. Production planning data such as the production program, electricity prices or the labour costs may vary greatly between different production facilities and locations. Detailed cost analysis of equipment can only be conducted in consideration of a set of (likely) usage scenarios and the future production environment.

"Detailed cost analysis of equipment can only be conducted in consideration of a set of (likely) usage scenarios and the future production environment."

In synthesis, the subsequent costs are – as in most industries – the dominating cost drivers in the life cycle of PV equipment. At the same time, these cost items are less tangible than the initial investment costs, and are therefore often not considered appropriately in investment decisions. To enable manufacturers to take better decisions during the facility planning process, a life cycle-orientated and holistic cost management approach is beneficial.

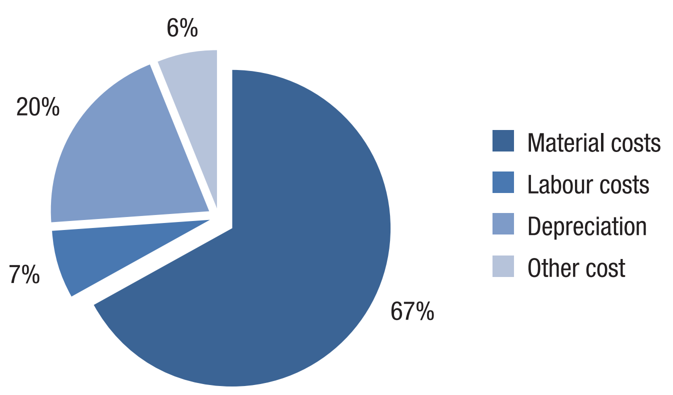


Figure 1. Exemplary cost structure of a crystalline PV supply chain (Fraunhofer IPA).

The concept of life cycle costing

Total cost of ownership (TCO) refers to the total cost of acquiring, installing, using, maintaining, changing, and getting rid of an item over an extended period of time, a concept that was initially developed for IT software and hardware [1]. The term life cycle costing (LCC) is more commonly used in relation to industrial goods such as machinery.

The life cycle costing approach classes the equipment or even the entire facility as a product of sorts which undergoes a number of life cycle phases (initiation phase, planning phase, implementation phase, operational phase, disposal/

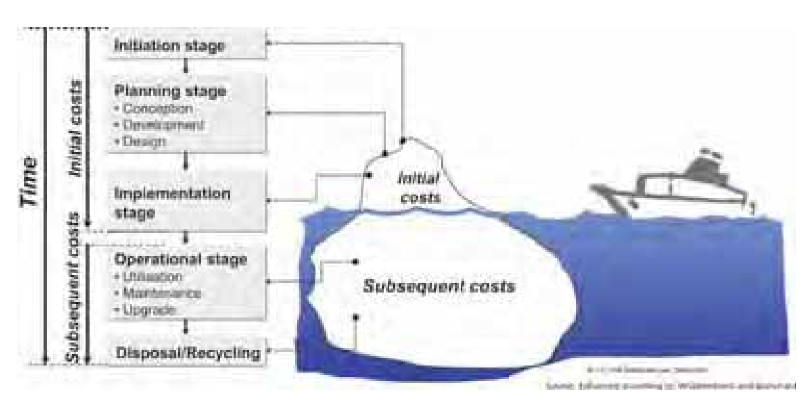


Figure 2. Life cycle cost of an industrial product [2].

recycling phase). Each phase sees the introduction of different cost items that each depend on the assumed usage scenario. In most industrial sectors, the initial costs only account for the lesser share of the total costs; however, these costs are the most visible and traditionally play a dominant role in investment decisions (see Fig. 2).

Benefits of implementing life cycle costing

All significant cost items must be taken into account in order to enable sound investment decisions. Life cycle costing can support the gathering and analysis process by using cost breakdown structures (CBS), which define and categorize the cost items for each life cycle phase. This may cover costs for set-up, various process materials, unscheduled downs, maintenance and energy. Due to the different characteristics of production equipment, the applied cost structures need to be flexible and easily extensible. Table 1 shows some of the benefits for end users and machine builders that can be gained by applying life cycle costing [3].

On the one hand, end users benefit from a higher transparency on the future production costs, which in turn allows for a more comprehensive cost assessment of production equipment and production lines. As a consequence, the risks of an investment decision like the need for a higher-performing power connection can be mitigated at an early planning stage. The gathered data can then be used as the foundation for service contracts, e.g. for determining the optimal maintenance interval. During the equipment's operating time, the life cycle data collected can be considered from the perspective of capacity and cost planning.

> "Life cycle costing enables machine builders to quantify and communicate the capabilities of their products in a structured way."

On the other hand, life cycle costing enables machine builders to quantify and communicate the capabilities of their products in a structured way. The gathered life cycle cost data can be used during the product design process, allowing for analyzing and prioritizing of future design changes in cooperation with customers and suppliers. Furthermore, the usage modalities and further requirements from the end users allow the machine builder to better plan service contracts.

In industrial sectors like the automotive industry, there appears to be a strong tendency towards a life cycle view on equipment costs. Machine tool builders, for example, are obliged by OEMs to forecast and guarantee the subsequent costs of the machine in question for a defined lifetime under certain operating conditions [4], thereby offering alternatives that can easily be assessed by the end user.

In summary, the life cycle costing approach leads to advantages for end users and machine builders. Several industries employ this cost calculation approach which covers the initial cost as well as subsequent costs for the equipment or the production line. However, in the PV industry, structured approaches are often not applied and important cost categories are not incorporated. In order to put into effect the benefits of the holistic LCC approach, several challenges need to be addressed, as discussed in the following section.

Benefits to the end user	Benefits to the machine builder
Transparency on the costs throughout the entire life cycle	Differentiation from competitors through transparent cost structures
Mitigation of investment risks	Determination of optimization measures in product design
Improved capacity and cost planning during the equipment lifetime	Improved capacity planning for services (e.g. maintenance and repair)
Foundation for maintenance and repair contracts	Extension of service offerings

Table 1. Benefits for end users and machine builders.

Challenges for implementing life cycle costing

To implement an effective and efficient life cycle costing concept, several challenges need to be addressed and mastered [5]:

- The equipment performance data needs to be gathered and modelled by the machine builder.
- The future usage scenarios for the equipment or the production line need to be gathered and modelled by the end user.
- The life cycle cost calculations for different equipment need to be standardized to make them comparable.
- The life cycle costing approach needs to be supported by suppliers and end users.

The forecasting of all relevant subsequent cost items is a challenge for the machine tool builder. Even for such basic equipment performance indicators as the mean time between failures (MTBF), the machine builders often rely solely on expert opinions, because, even for mature products, sufficient operational performance data is hard to find. This is the result of intellectual property conflicts and a lack of a structured data gathering and analysis approach.

Secondly, the life cycle costs depend strongly on the future usage scenarios of the equipment. Such end-user planning assumptions as periods of operation, basic process parameters, the prices for resources and the expected capacity utilization of the equipment need to be defined explicitly. The subsequent costs account for a larger share of the total costs for equipment with high utilization than for equipment with low utilization. Furthermore, when considering equipment as parts of production systems, the interdependencies between the equipment and the entire system must be analyzed. The reliability of a single piece of equipment can have a strong effect on the economics of the entire production system. The positioning of equipment of low reliability at the bottleneck of a production line leads to a fluctuating

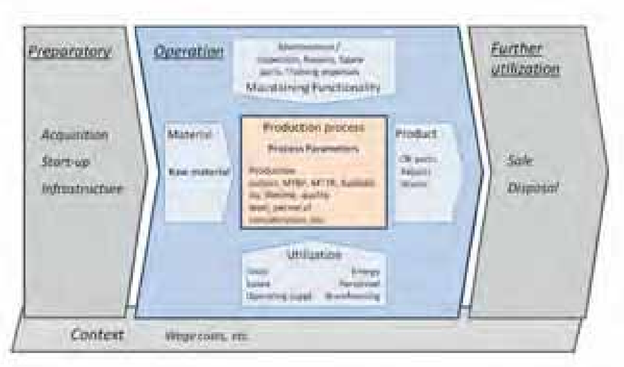


Figure 3. Forecasting model for life cycle cost (VDMA norm 34160).

material flow and thereby decreases the performance of the entire production facility. Based on the defined usage scenarios, the machine builder needs to forecast the process's Key Performance Indicators (KPIs) like yield, scrap rate, material consumption per unit as well as required maintenance intervals, which are used for the life cycle cost calculation.

Lastly, a standardized model (cost breakdown structure) for the life cycle cost forecasting needs to be applied by the different machine builders to allow the end user to compare equipments. Today, the cost specifications provided by machine builders in the photovoltaic industry are often quite diverse. In order to get the most out of a standardized life cycle costing approach, the participation of a number of market players is required. With this approach, the overhead costs implicated by manifold proprietary calculation schemes of different end users will be reduced.

Models and tools for life cycle costing

A number of proprietary and standardized models and tools for life cycle costing have been developed, with large market players in other industries such as Bosch and Daimler taking to enforcing proprietary models and guidelines for life cycle cost specifications that need to be fulfilled by their suppliers. These company-specific standards offer benefits to the OEMs themselves but result in overhead costs for the suppliers.

Industry independent models

Standardized models like the VDMA norm 34160 [6] have been developed which offer a structured approach for the forecasting of machine and plant life cycle costs. In this situation, the end user and the machine builder can issue bids and tenders in a standardized way based on the individual context conditions of the end user (see schematic in Fig. 3). The model specifies relevant production context characteristics and a cost breakdown structure. The cost items are categorized according to the preparatory, the operation and the further utilization phase and are extensible to additional detail levels and cost categories.

"Defined characteristics such as the periods of consideration and the expected resource prices have a significant influence on the life cycle costs of equipment."

The context describes the production environment of the equipment throughout its lifetime. Defined characteristics such as the periods of consideration and the expected resource prices have a significant influence on the life cycle costs of equipment, and therefore need to be carefully estimated by the end user. For the preparatory phase, the costs of the acquisition and start-up

Life Cycle Forecast according to VDMA Standard Sheet 34160							
For equipment X							
Code			**Name**	**Supplier**	**Customer**	**Value(€)**	
LCC			**Lifecycle Cost Forecast**				**3,500,000.00 €**
	E		**Preparatory Costs**				**540,000.00 €**
		E1	Acquisition costs	400,000.00 €		400,000.00 €	
		E2	Infrastructure costs	100,000.00 €	40,000.00 €	140,000.00 €	
		E3	Other costs associated with the preparatory phase	- €	- €	- €	
	B		**Operating Costs**				**2,860,000.00 €**
		D1	Periods under consideration			10	
		B1	Annual operating costs	192,000.00 €	94,000.00 €	286,000.00 €	
		IH1	Maintenance & Inspection	*30,000.00 €*	- €	30,000.00 €	
		IH2	Scheduled repairs	*22,000.00 €*	*20,000.00 €*	42,000.00 €	
		IH3	Unscheduled repairs	140,000.00 €	- €	140,000.00 €	
		RK1	Occupancy costs		*12,000.00 €*	12,000.00 €	
		MK1	Material and raw material costs		13,000.00 €	13,000.00 €	
		EK1	Energy costs		*14,000.00 €*	14,000.00 €	
		HB1	Production and process materials		- €	- €	
		EN1	Disposal costs		- €	- €	
		PK1	Personnel costs	- €	- €	- €	
		WK1	Tool costs		- €	- €	
		RU1	Set-up costs		- €	- €	
		LK1	Warehousing costs	- €	23,000.00 €	23,000.00 €	
		SO1	Other operating costs	- €	12,000.00 €	12,000.00 €	
	V		**Further utilization costs**	**- €**	**100,000.00 €**		**100,000.00 €**
		V1	Dismantling	- €	120,000.00 €	120,000.00 €	
		V2	Residual value	- €	20,000.00 €	20,000.00 €	
		V3	Other costs related to further utilization	- €	- €	- €	

Figure 4. Sample tender according to VDMA 34160 [6].

of the equipment needs to be considered; the required operation infrastructure is also incorporated in this cost category. Costs related to the processed and consumed materials, the process outcome, the maintenance as well as the machine utilization are considered for the operation phase. For the further utilization phase, an analysis is conducted of the cost and benefits for the reuse as well as the recycling of the equipment. On the one hand, the machine may require a special treatment for recycling and will therefore incur additional costs at its end of life. On the other hand, however, the machine may have a significant residual value after the period of consideration and can be re-used for other applications.

All these cost factors need to be considered prior to making the best investment decision. In real life, many cost elements are not easily available for the machine builder or the end user. Nevertheless, even estimating these cost drivers based on expert opinions is better than just leaving them out of consideration. An exemplary high-level life cycle cost calculation in alignment with the VDMA 34160 is depicted in Fig. 4, where every depicted category of the model is broken down in more detailed cost items.

When applying industry-independent standard models to particular equipment types, the degree of unintentional flexibility for the data specification and interpretation is rather high. To give an example, the production output in terms of 'units per hour' is a rather generic description for its application to different production environments like automotive assembly and solar cell manufacturing.

Industry-specific models

Industry-specific models and guidelines can ease the data exchange between customers and suppliers and can therefore reduce the overhead costs for all partners. These models provide an adjusted and more detailed cost breakdown structure. Several industry-specific standards and guidelines like the SEMI E35 norm [7] for the semiconductor, flat panel and optoelectronic industries have been developed and adapted to the specific product and processes of a manufacturing sector. These models and guidelines incorporate the specific requirements of the industrial sector and allow the market players to perform their life cycle cost calculations in a uniform way.

Characteristics of the photovoltaic industry

Most photovoltaic production equipment is designed according to the specific requirements of photovoltaic products and production processes. During the operation phase, the equipment is integral to the production lines and processes highly standardized products. Therefore, and in contrast to more flexible machine tools, the usage scenario and the most relevant cost items of the equipment can be easily forecasted. Consequently, the development and application industry-specific standard models and guidelines for life cycle costing for each manufacturing stage like crystal growing, wafer manufacturing, cell manufacturing and module manufacturing is feasible. Their application would bear additional benefits for the participating market players through well-defined cost categories and reduced overhead costs.

Life cycle cost tools to support investment decisions

Different software tools can be applied for the support of the life cycle cost calculation as part of the investment decision process. These tools support the definition of cost breakdown structures, gathering and maintaining of the basic planning

为全球顶尖太阳能制造商提供明智的解决方案：更快捷，更简便，成本更低！

“经综合评估市场上具竞争力的解决方案后，我们认为Eyelit是制造业公司可升级软件的首选”

Solyndra

2010 年6月3日

“相较于之前在其他光伏制造企业中使用过的MES解决方案， Eyelit的能力和灵活性使我印象深刻”

Ascent太阳能技术公司

2010年3月5日

“我们对各种不同的解决方案进行仔细和严格的筛选，最终认为Eyelit解决方案是我们全新晶圆厂的最佳选择”

Deutsche Solar AG

2010年2月25日

“Eyelit 为我们提供了扩大生产需要的所有功能，并在关键总体拥有成本上占明显优势”

CaliSolar

2009年2月12日

“我们需要一套既能满足我们目前成长的需要，又能在将来帮助我们实现规模化生产的解决方案”

InnovaLight

2080年7月11日

www.eyelit.com | eyelit

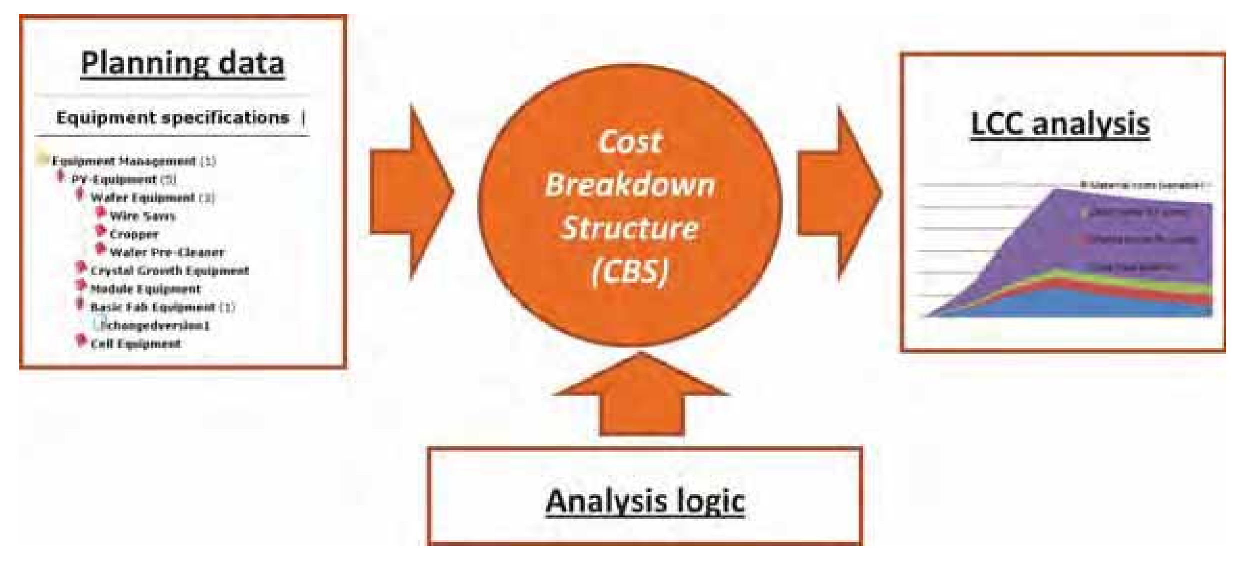


Figure 5. Principles of life cycle costing analysis tools.

data and the equipment data as well as the definition and execution of the cost analysis, as shown in Fig. 5.

Several life cycle costing tools are currently available on the market that offer the possibility of flexibly defining cost breakdown structures and the execution of customizable analysis functionalities like side-by-side comparison, net present value calculation and sensitivity analysis. While these tools are, for the most part, designed to support the product or service design process by considering different design options, many companies just apply simple proprietary spreadsheet tools. It is often the case that these tools do not obey the standard models and neglect some of the life cycle phases and cost categories described in this paper.

The integration between these life cycle costing tools, the facility planning process and the procurement process is vital to support the data exchange between all stakeholders. Any facility-planning decision may influence the selection and the configuration of particular equipment, i.e. through changing the expected throughput for equipment. On the other hand, the forecasted life cycle costs for the equipment may influence other design decisions for the facility.

In summary, software tools to support the forecasting of the life cycle cost of products are available on the market, but need to be adapted or customized to the specific characteristics of photovoltaic production equipment. Alternatively, spreadsheet tools can be used; however, regardless of the approach, standardized models and a closer integration to the facility planning and purchasing processes need to be targeted by the manufacturers.

Summary

Photovoltaic manufacturers need to maintain a strong focus on production cost reduction in order to safeguard their future competitiveness. To do so, any investment decision for production equipment or production lines need to be based on sound cost estimations, which incorporate the initial costs but also any subsequent costs during the lifetime. In general, the costs in the operation phase and the further usage phase of equipment are less tangible but account for the major share of the total life cycle costs. Therefore, these cost items need to be gathered, analyzed and incorporated in the investment decision.

In comparison with the proprietary cost calculation models and tools, standardized life cycle costing models reduce the overhead costs for the participating market players. Applying these models and guidelines can lead to a significantly improved knowledge exchange between machine builders and end users. Several industry-independent and industry-specific models and guidelines have been developed, but none of them is specifically designed for the needs and production environment in the PV industry.

Therefore, these models need to be adapted or customized to the specific production equipment and process characteristics of the photovoltaic industry, which calls for a close integration between the facility planning process and the purchasing process. Consequently, the awareness and transparency of life cycle cost during the facility planning process is improved, which contributes to the establishment of more cost-efficient production facilities.

References

[1] Gartner, Inc.: Total Cost of Ownership [definition; available online at http://www.gartner.com/6_help/glossary/GlossaryT.jsp].
[2] Fabrycky, J.W. & Blanchard, B.S. 1991, "Life cycle Cost and Economic Analysis", Englewood Cliffs, Prentice Hall.
[3] Janz, D. 2008, "Leitfaden für die Ermittlung und Herleitung von Lebenszykluskosten", in Westkämper, E. & Verl, A. 2008, *Life Cycle Costing (Durchführung der Lebenszykluskostenermittlung in der Praxis)*.
[4] Denkena, B. et al. 2006, "Life-cycle oriented development of machine tools", *Proc. 13th Cirp International Conference*.
[5] Janz, D. 2006, "Herausforderungen bei der Umsetzung der Lebenszyklusrechnung in der Praxis", in Westkämper, E. & Verl, A. 2006, *Life Cycle Costing*.
[6] VDMA Norm # 34160: Forecasting Model for Life-Cycle Costs (2006).
[7] SEMI Standard E35, "Guide to calculate cost of ownership (COO) metrics for semiconductor manufacturing equipment", [available online at www.semi.org].

About the Author

Matthias Zapp is a project manager at Fraunhofer IPA (Institute of Manufacturing Engineering and Automation). Prior to joining Fraunhofer, he studied business informatics at the University of Cologne and worked for an international IT consultancy in the areas of logistics and product costing. His fields of expertise within the photovoltaic industry are modeling and simulation of logistic processes, controlling and factory IT.

Enquiries

Fraunhofer IPA
Nobelstrasse 12
70569 Stuttgart
Germany
Email: zapp@ipa.fraunhofer.de
Tel: +49 711 970 1604

Materials

GT Solar bullish over business as revenue guidance rises

A significant increase in sales and bookings has forced GT Solar to raise its revenue guidance after reporting on its second fiscal quarter sales of US$229.3 million. This represented nearly a 70% growth over reported sales of US$135.2 million in the first quarter of fiscal 2011 and approximately 120% growth over the second quarter of last fiscal year when sales were reported at US$104.2 million. The company also reported an order backlog of US$1.16 billion, with US$544.6 million in its polysilicon segment and US$601.1 million in its PV segment.

The company increased its fiscal year 2011 revenue guidance to between US$775 million and US$850 million, up from the previously provided range of US$700 million to US$775 million.

It has also announced receipt of an order for its polysilicon production technology and related engineering services, which will be used in India's first large-scale commercial polysilicon production facility.

The company also reported a net income of US$42.8 million, approximately 160% higher than the US$16.5 million reported in the first fiscal quarter of 2011 and growth of over 350% versus US$9.4 million for the second quarter of last fiscal year. Revenue by business segment saw sales in its polysilicon segment reach US$23.3 million and US$202.8 million in its photovoltaic segment, largely due to DSS crystallization furnace sales. Revenue of US$3.2 million was attributed to its sapphire materials following the acquisition of Crystal Systems that was completed during the quarter.

Source: GT Solar

GT Solar's SDR400 CVD reactor.

Polysilicon News

GCL-Poly expects R&D project to reduce silicon production costs

GCL-Poly has won funding of RMB5 million from the National Electronic Information Industry Fund for an R&D program supporting polysilicon byproduct recycling developments. The project is aimed to further optimize its closed recycling system and reduce polysilicon production costs. Annual polysilicon production capacity at GCL-Poly reached 18,000MT in 2009 and is expected to reach 21,000 MT by the end of 2010.

Source: GCL-Poly

GCL-Poly polysilicon production facility.

GT Solar thinks big with beta testing of 650kg ingot furnaces

The technical-economic debate over ever-increasing Directional Solidification System (DSS) furnace sizes that cast multi-crystalline ingots is heating up with the news that GT Solar is beta testing with select customers its next DSS crystalline growth furnace, the DSS650. The larger furnace capacity of up to 650kg comes hot on the heels of the official launch in May, 2010 of the DSS450HP, a high-performance ingot growth furnace with a thermally optimized, second-generation hot zone that claims to have improved throughput while delivering industry-leading crystal quality.

A key limitation in moving to ever-increasing ingot sizes is the technological capability to manufacture the crucibles used in the furnace. The common industry practice is to place multiple crucibles at a time within the furnace for optimization and greater throughput.

The new system is still intended to provide an upgrade path for users of its smaller furnaces, the company said. Competitors to GT Solar, such as China-based JYT, have been developing larger furnaces for several years, though rivals had argued that ingot sizes above 600kg could lead to other equipment changes that actually add to the cost of production.

Commercial availability of the new system is expected for early calendar year 2011. Yingli Green Energy, JA Solar and Sino-American Silicon Products (SAS) are all key customers of GT Solar and approximately 85% of its business is now done in Asia. In response to this GT Solar has opened its new Asia operations, headquartered in Hong Kong. The Hong Kong headquarters is intended to serves the needs of its customers throughout the Asia Pacific region. However, GT Solar established a Shanghai, China facility last year, will continue to provide installation resources, demonstration capabilities for customers, including product training and spare parts inventory.

GT Solar reiterated that its PV equipment product development, engineering and R&D will remain in the company's corporate headquarters in Merrimack, New Hampshire, and product development, engineering and R&D for its polysilicon equipment will remain in Missoula, Montana.

Solarvalue announces creation of first solar grade metallurgical silicon ingot

During Solarvalue's annual general meeting, Dr. Christian Bornhauser, CTO of Solarvalue, announced that the company had created the first solar-grade silicon ingot, which weighed in at around 15kg during several repeated tests on different plants. He claimed that the purity levels of phosphorus and boron were less than 1ppmw and within the demanded specifications.

The company detailed that the key feature in the fundamental process is a multistage treatment for the separate reduction of phosphor, boron and other metals, which achieves the required purity levels. Simultaneously, the feedstock is permitted to differ on a larger scale making the whole process flexible when it comes to the quality of the metallurgical grade silicon.

Business News

Mallinckrodt Baker becomes Avantor Performance Materials

Effective immediately, Mallinckrodt Baker will carry out its operations under the new name, Avantor Performance Materials. This rebranding follows the company's acquisition by affiliate New Mountain Capital, the New York-based private equity investment firm, which is providing Avantor with significant financial and strategic resources to support future growth initiatives, including expansion in current markets and growth through acquisitions.

Headquartered in Phillipsburg, New Jersey, Avantor was acquired from Covidien in August 2010. Under the terms of the acquisition agreement, the Mallinckrodt name will remain with Covidien. Products sold under the Mallinckrodt product line brand name will continue to be manufactured and marketed by Avantor, but will eventually be transitioned to a new brand name which will be announced in the near future. Avantor will continue using the J.T.Baker product line brand name.

Meyer Burger makes acquisitions and strengthens U.S. operations

Meyer Burger Technology has signed a purchase agreement whereby 3S Industries USA will take over certain assets and all employees of SGS Slicing Solutions as well as SGS Machine Tool. The purchase price is remaining undisclosed with the transaction expected to close before the end of this year. Additionally, 3S Industries in Tucson, Arizona, has announced its change of name to MBT Systems Ltd and will become the new sales and service company for Meyer Burger in the U.S.

SiOnyx closes series B financing at US$12.5 million

Coherent, Crosslink Capital and Vulcan Capital have joined veteran investors Polaris Venture Partners and Harris & Harris in the series B financing round for SiOnyx. The series closed at US$12.5 million and resulted in no changes to SiOnyx's board of directors. The company's funding is going towards the commercialization of its new semiconductor processing technique, which the company claims is an advancement for smaller, cheaper, high-performing silicon photonic devices.

Other News

MEMC sees increased sales as wafer prices rise: SunEdison project pipeline tops 1GW

MEMC Electronic Materials reported a 31% sequential increase in solar materials sales, primarily from wafers, in its third-quarter results. A 20% increase in shipments and modest improvement in wafer ASPs helped sales for the group reach sales of US$503.1 million, up 12.2% from US$448.3 million in the second quarter of 2010. Its subsidiary, SunEdison, reported sales of US$21.5 million and has 1,023MW in its project pipeline, of which 155MW is under construction.

MEMC also reported a GAAP operating income of US$9.9 million for the quarter, compared to operating income of US$3.3 million in the 2010 second quarter and an operating loss of US$66.7 million in the 2009 third quarter.

The company also expects strong revenue performance in the fourth quarter since SunEdison reached an agreement to sell the

Materials Order Focus

Indosolar signs US$600 million wafer supply deal with GCL-Poly

Indosolar is making a major bid to become a leading cell producer in India with a wafer supply deal sealed with GCL-Poly amounting to 815MW and at a cost of approximately US$600 million over the next four years. The deal also highlights the rapid growth and industry acceptance of GCL-Poly as a major player, having recently reached a polysilicon production cost of US$25.4/kg in the third quarter of 2010 and wafer sales of 435MW at a manufacturing cost of US$0.58 per watt.

The companies announced at a ceremony that 209 million pieces (equivalent to 815MW) of high-quality wafers would be supplied by GCL-Poly from November 2010 to December 2014. A price adjustment mechanism was also included in the contract terms.

Located in Greater Noida, Uttar Pradesh, India, Indosolar has plans for its 300,000 square foot-facilities, which can accommodate four production lines. The cell manufacturer is planning to increase capacity to 260MW by the end of its 2011 fiscal year. According to Indosolar, Line C will have the capability to produce both multi- and monocrystalline cells with equipment and processes that have been supplied by Schmid on a turnkey basis.

Apollo lands long-term purchase agreement with solar panel manufacturer

Apollo Solar Energy has signed a five-year purchase contract with an undisclosed solar panel manufacturer. Under the terms of the agreement, Apollo will supply 5N ultra-high purity tellurium, which will have a speculated sale of around US$110 million over the five-year period.

Linde extends GCL gas supply agreement as the company increases capacity in China

The Linde Group is to expand the existing gas supply infrastructure currently held with GCL-Poly. Under the terms of the extended agreement, which will involve approximately €15 million of investment, Linde will construct production and supply facilities for high-purity hydrogen at the Xuzhou Industrial Park facility.

The two new facilities are expected to be up and running by mid 2011, doubling the existing hydrogen capacity in order to meet GCL-Poly's projected rise in demand for gases as it increases capacity at Xuzhou.

LDK Solar signs US$300 million polysilicon deal with BYD

LDK Solar has secured a two-year polysilicon deal with BYD, a China-based enterprise specializing in IT, automobiles and green energy. The new deal will see LDK supply BYD with an undisclosed volume of polysilicon, worth approximately US$300 million, over the next two years via monthly shipments that will begin in January 2011 and extend through the end of 2012.

70MW Rovigo project to First Reserve in September 2010. SunEdison has added approximately 10MW per quarter for the last four quarters to its project pipeline. MEMC noted that third-quarter segment operating profit also included US$4.5 million in ramp-related loss from Solaicx, US$0.8 million of which came from purchase accounting expenses from the previous acquisition.

PV Crystalox wafers.

LDK Solar guides higher quarterly sales: wafer capacity reaches 2.6GW

Continued strong demand in the PV market has seen LDK Solar raise its revenue and shipment guidance for its third-quarter financial results. The China-based integrated PV manufacturer said that it expects to report revenue in the range of US$610 to US$640 million, up from previous guidance of US$570 to US$600 million.

Wafer shipments, the core of the company's activities, are expected to reach between 550 to 570MW, compared to previously guided shipments of between 520 to 550MW. Modules, it newest venture, are expected to reach shipment levels of between 80 and 90MW, compared to previous guidance of 75 to 85MW.

Source: LDK Solar

LDK Solar wafer production line.

LDK Solar also noted that its polysilicon capacity at the end of September 2010 had reached a planned 11,000MT. Wafer capacity had reached 2.6GW and 120MW of capacity had been reached in solar cell manufacture. Back in April 2010 LDK Solar had projected wafer capacity to reach 2.6GW in 2011. The biggest expansion outside wafer production was modules, reaching a nameplate capacity of 760MW.

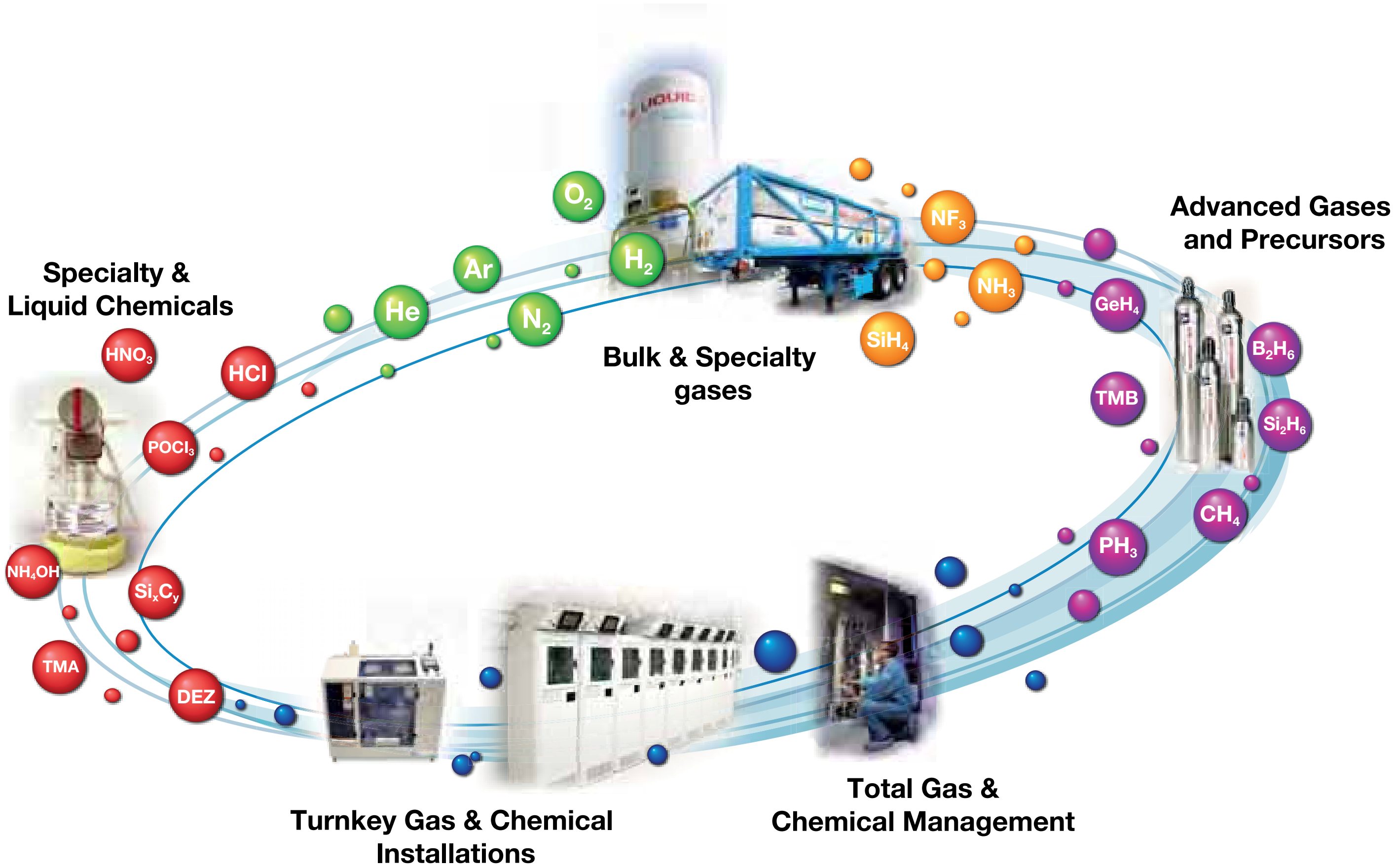
PV Crystalox targets 800MW wafer capacity by end of 2012

Sustained strong demand has led solar wafer producer PV Crystalox Solar to publicly provide a longer-range insight into its capacity expansion plans through to the end of 2012. Previously, the wafer producer had noted that plans to expand to 630MW were only under review. However, PV Crystalox said in an interim management statement that it was "actively planning the next stages of capacity expansion which will enable us to reach 630MW at the end of 2011 and 800MW at end of 2012."

Despite ramping its own polysilicon plant in Germany to an annualized rate of 1200MT per annum, which it achieved during the last three months, PV Crystalox said that has recently entered into a new five-year contract with one of its external polysilicon suppliers to support the planned wafer production expansion. The company guided full-year shipment volumes to be around 350MW, slightly ahead of the 320–340MW range previously guided, though at same levels guided in March 2010.

AIR LIQUIDE ELECTRONICS

Gases & Precursors for the Solar PV Industry



Partnering to reduce your direct & indirect materials costs per Wp

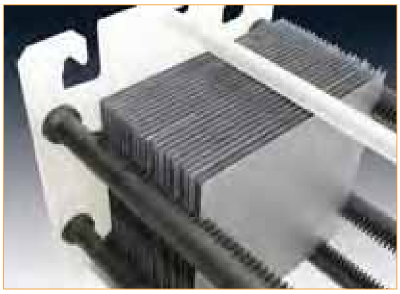
Air Liquide, the world largest gas supplier to the solar photovoltaic industry, is reinforcing its specialty gas & advanced precursor capabilities in US, China, Japan and Europe.

Air Liquide constantly provides optimized material supply solutions to its customers, helping them increase cell efficiency and fab throughput, to drive down costs per watt.

www.airliquide.com

Product Briefings

ACI-ecotec



ACI-ecotec's ecoCarrier enables transport and stocking of PV wafers and cells

Product Briefing Outline: ACI-ecotec's 'ecoCarrier' system is designed for use in raw wafer and solar cell manufacturing processes (after ingot cutting, cleaning stations/lines, texture etching, etc.). Using its special patented design, the carrier is chemically resistant and dimensionally stable for utilization in wet chemical processing.

Problem: According to ACI-ecotec, other carriers tend to deform or lose shape when exposed to extreme temperatures and fluctuations endured by most all chemical batch processes, thereby rendering the wafer slots basically useless for automated handling. Chemical agents and solutions tend to corrode other carriers and within a short time cause cracks and rips that quickly damage carrier material, often after two uses.

Solution: The ecoCarrier's special design features prevent liquid chemicals from adhering to the carrier, thus evading chemical cross-contamination and no dead spots. The drying properties also prevent chemical build-up on the wafer within the carrier (boat-marks). All six static bars as well as the removable retaining bar have high-precision toothed profiles facing each other for automatic loading of the wafers as well as perfect parallel wafer separation for drying and protection during transport. All bars feature a hermetically-sealed, thus chemically 100% resistant steel core.

Applications: Raw wafer and solar cell manufacturing processes.

Platform: The ecoCarrier consists of two lateral base plates and six specially reinforced compound bars, the whole assembly being welded for hermetical sealing, chemical impermeability and corrosion resistance.

Availability: Currently available with standard production items delivery within 6–8 weeks.

DuPont Performance Polymers

DuPont develops 'Rynite' PET grades for CPV, CSP and PV applications

Product Briefing Outline: DuPont Performance Polymers has tailored its portfolio of thermoplastic materials and design knowledge to the needs of the photovoltaic industry, including the CPV and CSP sector. The company has developed two specific grades of 'DuPont Rynite' polyethylene terephtalate (PET) that are claimed to reduce the total cost of manufacturing, assembling and installing photovoltaic systems.

Problem: In the case of CPV, modules require a housing material that withstands long-term weatherability issues and yet can be used in multiple design configurations, while lowering processing and material costs in manufacturing. Due to metal price volatility, alternative material choices that can replace such components as die-cast metals and thermosets in applications where stiffness and impact strength are required can become more cost effective.

Solution: DuPont's polymers are claimed to help increase design flexibility for greater ease of assembly and installation; provide an opportunity for functional integration (thereby reducing the overall number of components); and when produced in large numbers, offer cost-competitive methods of production through injection molding and extrusion. High-performance thermoplastics can offer a high degree of stiffness for structural strength, improved outdoor performance, corrosion resistance and good aesthetics.

Applications: Frames, inverters, connectors and junction boxes as well as bearings used in sun-tracking mirror installations.

Platform: Two specific grades are currently available from DuPont for cost-effective manufacturing of photovoltaic module frames and components: Rynite 935SUV and Rynite 540SSUV.

Availability: Currently available.

PST & Dynamic Engineering

PST and Dynamic Engineering offer largest single-train STC converter

Product Briefing Outline: Polycrystalline Silicon Technology (PST) and its alliance partner Dynamic Engineering have introduced an advanced silicon tetrachloride hydrochlorination technology for the polysilicon industry. The PST hydrochlorination converter for a 7,500MTY (metric tons per year) polysilicon plant provides the largest single-train STC converter for lower capital and operating costs.

Problem: When fewer chemical units are used in the manufacture of polysilicon, the advantages are lower capital and operating costs over plants with multiple smaller unit operations. In addition, fewer operational units mean simpler operations which can lead to lower on-site chemical buffer storage capacities and thus safer operations.

Solution: For solar- and semiconductor-grade polysilicon producers installing 10,000MTY or larger production lines, the PST 7,500MTY converter is a powerful technology advancement. It offers fewer controls, a smaller plant footprint and fewer operations personnel. The 7,500MTY converter follows the initial installation of PST's 1,500–5,000MTY hydrochlorination units between 2004 and 2008. The 7,500MTY silicon tetrachloride to trichlorosilane converter is a continuously operated in-line system which can avoid the frequent shut-downs required by thermal converters.

Applications: Polysilicon production.

Platform: The 7,500 MTY PST silicon tetrachloride to trichlorosilane (polysilicon production) hydrochlorination technology and the smaller PST hydrochlorination units are offered as standalone systems as well as being an integrated part of the full chlorosilane technologies offered by the two companies.

Availability: Currently available.

Minority carrier lifetime in silicon wafers and thin-film material

Philipp Rosenits, Fraunhofer Institute for Solar Energy Systems (ISE), Freiburg, Germany

ABSTRACT

The minority carrier lifetime is a key parameter for the performance of solar cells as it characterizes the electrical quality of the semiconductor material. Consequently, accurate and reliable methods to determine the minority carrier lifetime are of enormous interest for both practical process control and the evaluation of the potential and limitations of a specific cell concept. Due to its importance, many different lifetime measurement techniques have been developed and used over the past few decades. This paper aims to present and discuss the most common measurement methods on the one hand, while attempting to shed light on some recent developments on the other. The determination of the minority carrier lifetime of crystalline silicon thin-film (cSiTF) material is illustrated as an example of interest for those who are already familiar with standard lifetime characterization.

Introduction

Each photon that impinges on the surface of a solar cell or its predecessor, typically a 150–200µm-thick silicon wafer acting as the solar cell's starting material, will either be reflected at the front surface or enter the bulk of the cell. Roughly 75 to 90% of all incoming photons from the terrestrial solar spectrum are absorbed by a 150µm-thick solar cell (the precise fraction depends on the applied light trapping mechanisms such as anti-reflection coating, front- or back-side texturing, etc.). Virtually every absorbed photon generates an excess charge carrier pair, consisting of an excess electron and excess hole. After some time, these excess carriers disappear again, a process known as recombination. The characteristic time of this process is called excess (or minority) carrier lifetime. If the excess carriers manage to reach the front and back contacts of the solar cell within their lifetime, i.e. before they recombine, they are then of use for power generation by the solar cell; otherwise they are lost. Therefore, the higher the lifetime, the better the solar cell's performance, all other factors being equal.

> "The higher the lifetime, the better the solar cell's performance, all other factors being equal."

The minority carrier lifetime in silicon wafers destined for photovoltaic applications can vary by several orders of magnitude. Common silicon solar cell materials exhibit lifetimes between 1µs and a few milliseconds. However, for 1µm-thick polycrystalline silicon thin-film material, for instance, a few nanoseconds may be sufficient to reach acceptable cell performance. On undoped silicon wafer material, on the contrary, lifetimes exceeding 100ms have been measured [1].

The impact of the lifetime on the device performance is twofold. On the one hand, the lifetime influences the extractable voltage of the solar cell. As a very rough estimate (assuming basically an injection-independent minority carrier lifetime, low-level injection and negligible contact resistances), the relationship between lifetime and voltage is logarithmic. For typical standard solar cells, an increase of the lifetime by a factor of 10 improves the device performance by approximately 10% (an assumption based on a calculation of the implied open circuit voltage of a 1Ωcm p-type solar cell with a minority carrier lifetime of 50µs under 1 sun illumination).

On the other hand, the cell's output current is also related to the lifetime. Since the minority carriers need some time to diffuse from their place of generation to the *p-n* junction (and ultimately to the contacts), a higher lifetime enhances the charge collection probability and thus improves the extractable current of the solar cell.

In steady-state conditions, as is the case for thermal equilibrium or constant illumination, the rates of carrier generation and recombination are perfectly balanced. For an undoped semiconductor in equilibrium, the population of free charge carriers is given by the so-called intrinsic carrier concentration n_i, which is in the range of $10^{10}cm^{-3}$ charge carriers for silicon at room temperature; for doped material the majority carrier density equals the concentration of ionized dopants N_{Dop} and the minority carrier density adjusts to n_i^2/N_{Dop}. Under illumination, additional electrons and holes are generated in the semiconductor material. The density of these excess charge carriers Δn depends on the minority carrier lifetime τ and the net generation rate G, which itself depends on the incoming photon flux and its spectral distribution, the front surface reflectance and the thickness of the sample.

$$\Delta n = G \times \tau \qquad (1)$$

For example, if a typical 150µm-thick silicon wafer with a standard anti-reflection coating at the front surface and a minority carrier lifetime of 50µs is illuminated by strong sunlight (having an intensity, or irradiance, of $100mW/cm^2$ and the standard spectral distribution of AM1.5g), a steady-state excess carrier concentration of $\Delta n = 7\times10^{14}cm^{-3}$ is established in the sample, greatly exceeding the intrinsic carrier concentration. Standard industrial-type solar cells operate in the range of $\Delta n = 1\times10^{13}$–$1\times10^{15}cm^{-3}$, while high-efficiency silicon solar cells can reach $\Delta n = 1\times10^{16}cm^{-3}$ under operating conditions. Cells under concentrated sunlight may even exceed this value, and crystalline thin-film solar cells sometimes operate below $\Delta n = 1\times10^{13}cm^{-3}$.

The injection-dependent lifetime, giving a so-called lifetime curve, for a typical silicon wafer in photovoltaics is depicted in Fig. 1. One very important feature becomes immediately apparent from the graph: the value of the minority carrier lifetime is strongly affected by the range of the excess carrier density considered, also known as the injection level. Therefore, when reporting lifetime results, the corresponding injection level must always be included. Up to this point, reference has been made to a value called carrier lifetime, which in a real sample is determined by several individual recombination processes that occur simultaneously and independently of each other. The only accessible measurement quantity in lifetime measurements is therefore a so-called effective lifetime τ_{eff}, illustrated in red in Fig. 1.

The different recombination channels, which all bring their individual injection dependence into the game, include intrinsic recombination, which takes place radiatively from band to band or occurs by means of a third charge carrier (Auger recombination). Additionally, an electron-hole pair can recombine via defect levels due to impurity atoms or crystallographic imperfections of the crystal lattice, which is summarized in the term Shockley-Read-Hall (SRH) recombination. Finally, recombination can take place at the surfaces, usually quantified by a surface recombination velocity or saturation current density or expressed in terms of a fictive surface lifetime. The inverse sum of all these individual lifetimes τ_i leads to the inverse effective lifetime: $1/\tau_{\text{eff}} = \Sigma_i 1/\tau_i$. Via careful selection of the investigated injection level range, selected recombination processes can be studied explicitly, e.g. Auger recombination at high-level injection or SRH recombination at low-level injection, if the surfaces are well passivated.

Lifetime measurement techniques

There are two basic approaches to measuring the lifetime in silicon wafers. One method involves maintaining a steady-state generation of known value in the sample under investigation (e.g. by constant illumination), measuring the excess carrier density and hence calculating the lifetime. An alternative is to terminate the generation abruptly and measure the rate at which the excess carrier density diminishes. The former method is referred to as the steady-state method, the latter the transient decay method. For both cases, the following equation applies for the determination of the minority carrier lifetime [2].

$$\tau_{\text{eff}}(\Delta n) = \frac{\Delta n(t)}{G(t) - \frac{d\Delta n(t)}{dt}} \tag{2}$$

Transient decay methods are attractive because they only rely on the relative change of the carrier density with time and no additional geometric, electrical and optical sample properties (such as thickness, doping concentration, carrier mobilities, front surface reflectance, etc.) are required – which makes the determination of the lifetime relatively simple and robust. Although it is not strictly required, it is highly advisable to monitor the excess carrier density level at which the measurement takes place as a reported lifetime is only meaningful in conjunction with a specified injection level. If the lifetime depends strongly on the excess carrier density in the investigated range, a determination of the lifetime by transient decay measurements is not straightforwardly possible; however, an indicative value obtained without knowledge of the injection level is frequently found to be a useful quality measure.

In steady-state lifetime measurements, the generation rate needs to be known quite accurately. This means in practice that for every sample, the amount of photons that are absorbed within the sample has to be determined. Once the generation rate is determined, the injection level can easily be calculated. A modification of the steady-state method consists of quasi-steady-state lifetime measurements, where the excitation light intensity is substantially varied (typically up to three orders of magnitude) during the measurement with a time constant that is large compared to the lifetime of the investigated material. This method is powerful, as usually a whole injection-dependent lifetime curve is obtained within a few measurements. However, an accurate determination of the generation rate is still required.

> "There exist transient, steady-state and quasi-steady-state lifetime measurement techniques."

The spatial information that can be deduced from lifetime measurements varies considerably. Some techniques only provide a very rough spatial resolution in the range of centimetres; other methods yield a higher resolution in the millimetre and micrometre range, but spatial information of the whole wafer requires time-consuming scanning. Finally, a fast method to obtain spatially-resolved lifetime results is available by camera-based measurement techniques, where high resolution images of large sample areas can be obtained within seconds.

Table 1 presents some measurement techniques for determining the minority carrier lifetime in silicon material destined for photovoltaic applications, including three important features of the methods regarding lifetime measurements. Firstly, there is the possibility of determining injection-dependent lifetimes. It should be noted that in principle, steady-state and transient lifetime measurement methods can also provide injection-dependent lifetime curves by simply repeating the measurement for a set of different illumination intensities. With regard to measurement time and precision, this is, however, not comparable with quasi-steady-state measurement methods, where hundreds or thousands of lifetime values at different injection densities are obtained within one single measurement.

The second and third features depicted in Table 1 are the measurement mode and spatial resolution of each method, respectively. Methods that are in widespread use and techniques that have been recently developed have been selected and included, although this is not an exhaustive list and many other interesting methods exist in addition to those named in the table.

Photoconductance decay methods, and

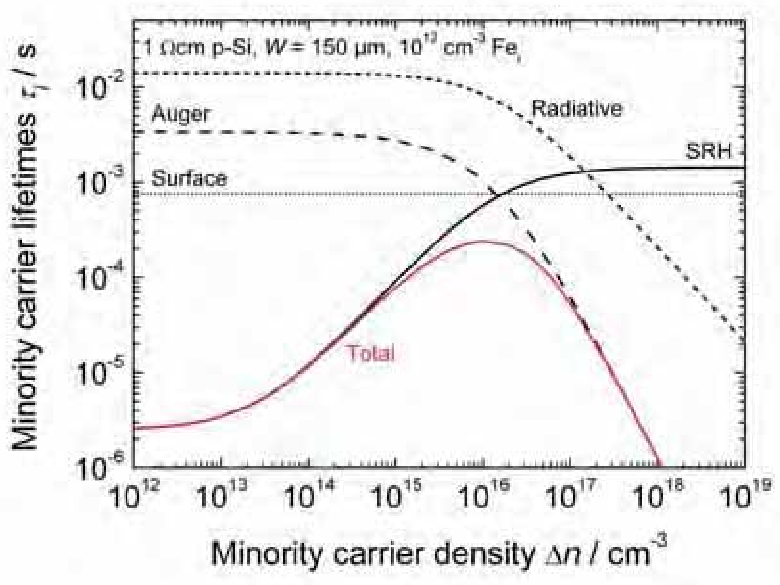


Figure 1. Simulation of the influence of different recombination channels. For silicon material, radiative and Auger recombination are typically only relevant for high minority carrier densities. Shockley-Read-Hall (SRH) recombination is modelled by 10^{12}cm^{-3} interstitial iron atoms in this example; an injection-independent surface recombination of S = 10cm/s has been assumed.

Method	Injection-dependence of lifetime?	Time domain/ Measurement mode	Spatial resolution
MWPCD	no	Transient	Local measurement, spatial information by mapping
QSSPC	yes	Transient or quasi-steady-state	Averaging over inductive coil area (~ $10cm^2$)
CDI/ILM	no	Steady-state	High, depending on camera resolution
Dynamic-ILM	no	Transient	High, depending on camera resolution
QSSPL	yes	Quasi-steady-state	Depending on diode and aperture mask
PLI	no	Steady-state	High, depending on camera resolution
TR-PLI, PLI	no	Transient	High, depending on dynamic-camera resolution
µ-PLM	no	Steady-state	Very high (~ 1µm), spatial information by mapping

Table 1. Selected measurement methods for determining the minority carrier lifetime in crystalline silicon material for photovoltaic applications.

more specifically, the microwave-detected photoconductance decay (MWPCD) methods, are very well-known and well-established techniques of measuring lifetimes in semiconductor materials. The first successful measurements date back to the late 1950s [3,4], and the technique has been the subject of continuous improvement and interest since that date (see [5–8] and references therein). In MWPCD measurements, excess carriers are generated by laser illumination and often combined with a background bias light. After switching off the external excitation, the time constant of the relaxation of the system back to equilibrium state is monitored. This is detected by the changing reflectance or absorption of a microwave signal. In practice, the length of the laser pulse and the laser wavelength may vary considerably between different measurement setups, which can influence the depth-dependent excess charge carrier profile that builds up in the sample under investigation and must be included in the analysis of the decay transient.

Another method for the determination of the minority carrier lifetime is the quasi-steady-state photoconductance (QSSPC) method, which was developed by Sinton and Cuevas in the 1990s [9]. Excess carriers are generated optically in the typical measurement setup by a polychromatic xenon flash light, and the resulting photoconductivity is determined via eddy current sensing by means of an inductively-coupled coil. The time-resolved illumination intensity is monitored by a reference solar cell, so that for a typical QSSPC measurement both the excess photoconductivity and the illumination intensity of the sample are measured simultaneously. Measurements are relatively easy to perform, and a whole injection-dependent lifetime curve is obtained rapidly. The conversion of the measurement signal into absolute lifetimes requires knowledge of the carrier mobilities and the rate of photogeneration in the sample. Transient photoconductance measurements are also possible by adjusting the decay time of the excitation source; in this case, knowledge of the exact photogeneration rate is not mandatory. While maximum illumination intensities up to a few hundred suns allow for injection densities of up to $10^{17}cm^{-3}$, low-level injection measurements below $\Delta n = 10^{13}$ – $10^{14}cm^{-3}$ are often prone to measurement artefacts such as carrier trapping [10] or depletion region modulation (DRM) [11] and have to be rejected or corrected.

Carrier density imaging/infrared lifetime mapping (CDI/ILM) is a camera-based measurement technique where the infrared absorption or emission of free carriers is detected [12,13]. It has, potentially, a high spatial resolution capability, but surface texture or lateral inhomogeneities of the optical properties may complicate the analysis. Furthermore, similar to the QSSPC technique, measurement artefacts such as trapping or DRM can be an issue in the low-level injection range. Typically, CDI/ILM is used in a steady-state mode by applying a lock-in technique with illumination switch on and off; recently, an extension which utilizes the transient parts of the switching sequence has been presented, the so-called dynamic-ILM [14]. The advantage of this technique is a calibration-free lifetime imaging of samples with arbitrary surface conditions and/or inhomogeneous doping concentration.

The electrical characterization techniques that probably experienced the most development and progress in the last five years are photoluminescence-based measurement methods. Electroluminescence [15] and photoluminescence imaging (PLI) [16] are two techniques that are currently widely used and allow for fast, spatially-resolved and high-resolution images of the minority carrier diffusion length and (effective) minority carrier lifetime, respectively. As PLI is in practice not affected by carrier trapping and similar measurement artefacts, the lifetime can in principle also

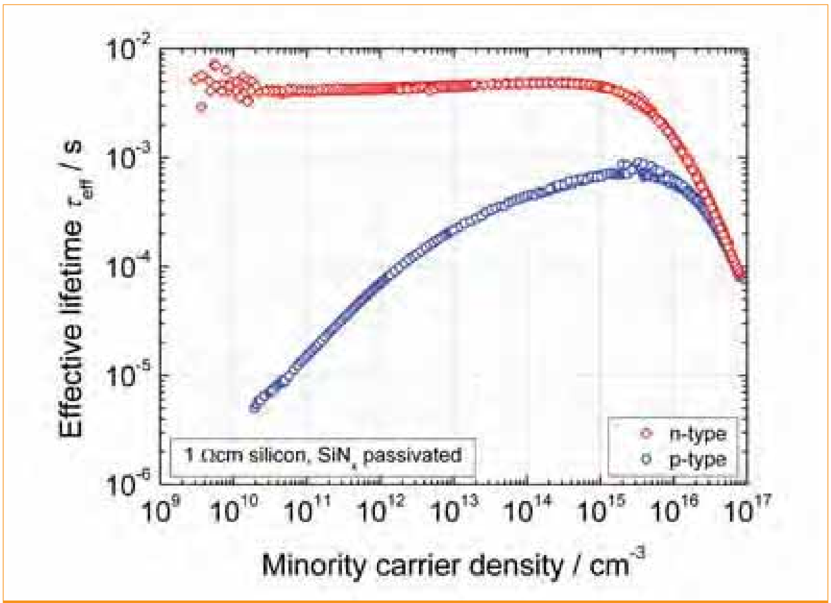


Figure 2. Effective minority carrier lifetime curves of SiN_x surface-passivated 1Ωcm p-type and n-type float zone wafers. The lifetime has been determined by means of quasi-steady-state photoluminescence (QSSPL) measurements. The injection-dependence of the minority carrier lifetime can give valuable information about the lifetime-limiting mechanisms and dominating defect parameters.

be measured reliably at very low excess carrier densities. PLI is a steady-state measurement technique, so, in order to get absolute lifetime data, a calibration of the detected photoluminescence is necessary. Different calibration methods exist – a popular approach is the calibration by integrating a QSSPC measurement [17]. Alternatively, a direct method to determine the lifetime from single PL images has also been presented [18].

> "As PL-based measurements are in practice not affected by carrier trapping and similar measurement artefacts, the lifetime can in principle also be measured reliably at very low excess carrier densities."

Apart from calibration, theoretical models for the coefficient of radiative emission and photon reabsorption are necessary, where optical properties of the sample have to be considered. In quasi-steady-state photoluminescence (QSSPL) measurements, the excitation source consists of a modulated laser or light-emitted diodes, so that the minority carrier lifetime is recorded in a broad range

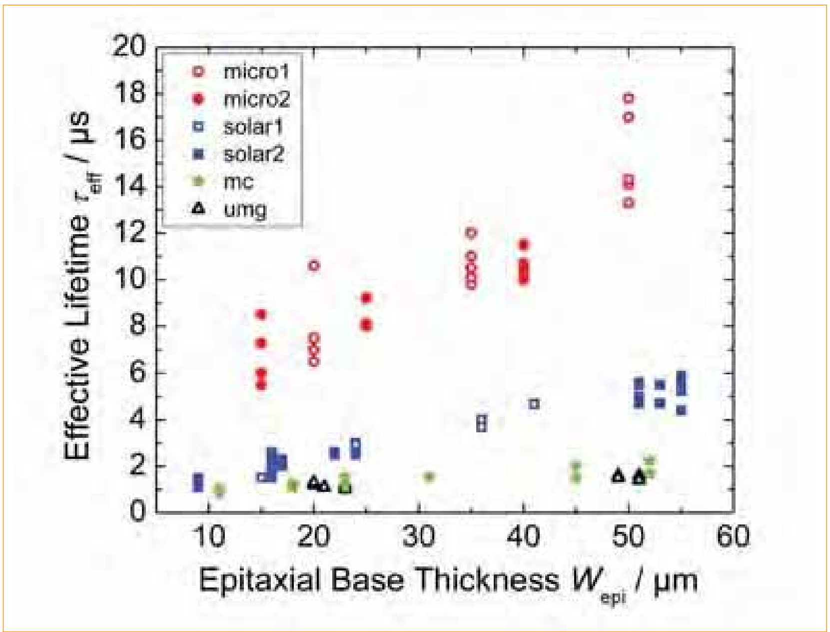


Figure 3. Effective lifetimes measured by means of microwave-detected photoconductance decay (MWPCD) on different crystalline silicon thin-film samples: monocrystalline substrates with microelectronic-grade epitaxial layers ('micro1' and 'micro2' – red circles); monocrystalline substrates with solar-grade epitaxial layers ('solar1' and 'solar2' – blue squares); standard multicrystalline substrates with solar-grade epitaxial layers ('mc' – green stars); and multicrystalline upgraded-metallurgical-grade silicon substrates with solar-grade epitaxial layers ('umg' – black triangles). The different groups exhibit clearly different effective lifetimes.

of excess carrier densities. Fig. 2 shows the lifetime curves of 1Ωcm p- and n-type SiN_x surface-passivated float zone wafers.

Two promising PL-based characterization methods that have been developed recently are the µ-PL lifetime mapping (µ-PLM)

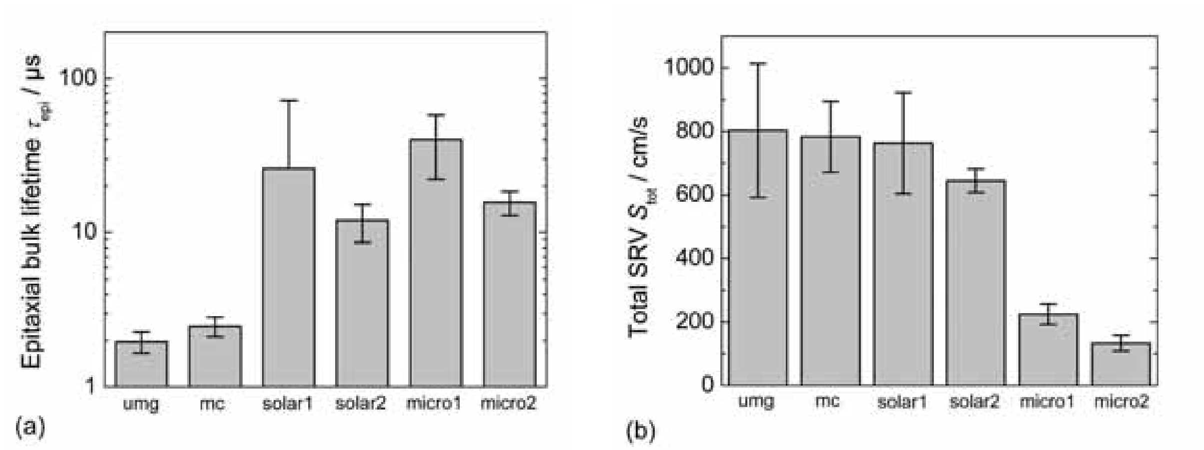


Figure 4. Epitaxial bulk lifetime (a) and total surface recombination velocity (SRV) (b) for different types of crystalline silicon thin-film material. A clear difference in the epitaxial lifetime can be observed between mono- and multicrystalline epitaxial layers, the former leading to epitaxial lifetimes in the range of a few microseconds, the latter leading to lifetimes well above 10µs. With regard to the total surface recombination velocity – which is equivalent to the effective interface recombination velocity as front surface recombination can be neglected due to high-quality silicon nitride front surface passivation – a significant difference between solar-grade (S_{tot} = 150–200cm/s) and microelectronic-grade (S_{tot} = 650–800cm/s) epitaxial samples is visible. This indicates the improvement potential for the processing of the solar-grade epitaxial layers. Error bars come from linear regression. Strictly speaking, the epitaxial lifetime of the sample set 'solar1' is not meaningful, as the error exceeds the mean value.

technique [19] and PLI techniques, which use a time dependence in the measurement, i.e. time-resolved photoluminescence imaging (TR-PLI) [20] and dynamic PLI [21]. The former enables quantitative lifetime measurements with a resolution of 1µm and can, for instance, be used for micro-PL spectroscopy, while the latter allows for fast and calibration-free lifetime images with a relatively basic measurement setup.

Application to crystalline silicon thin-film material

Exemplarily, the determination of the minority carrier lifetime in crystalline silicon thin-film (cSiTF) material and its interpretation will be presented in the following. CSiTF solar cells are an attractive and promising alternative to bulk silicon solar cells, as the former require only a small fraction of costly high-purity silicon. They basically consist of a highly-doped p-type substrate, upon which a thin moderately-doped p-type layer is deposited epitaxially via chemical vapour deposition at elevated temperatures above 1000°C. After deposition of the epitaxial layer, which acts as the solar cell's base, standard solar cell processing (emitter diffusion, front- and back-contact formation, anti-reflection coating) follows.

Measuring the lifetime in cSiTF material is challenging, because the two layers (epitaxial layer and substrate) cannot be separated physically and must therefore be measured together. (Some cSiTF concepts allow for a lift-off of the epitaxial layer from the substrate, which is not covered in this study.) In general, an influence of the substrate material is expected, as well as an influence from the interface between epi-layer and substrate. Microwave-detected photoconductance decay (MWPCD) measurements are found to be well suited to deal with the particular requirements of cSiTF material. As has been shown in a detailed theoretical and empirical analysis [22], the effective minority carrier lifetime of cSiTF material can reliably be determined by means of short- or long-pulse MWPCD.

Fig. 3 shows the lifetimes of different types of cSiTF material using mono- and multicrystalline silicon as the substrate material. The epitaxial layers have been deposited in commercially-available microelectronic-grade chemical vapour deposition (CVD) reactors or in lab-type CVD reactors specifically designed for high-throughput photovoltaic applications. The epitaxial layers of the latter type are referred to as solar-grade cSiTF material. The measured effective lifetimes are strongly dependent on the thickness of the epitaxial base, which is mainly due to the impact of the interface. Different sample groups can clearly be distinguished by their effective lifetimes.

Note that the results in Fig. 3 include measurements by short- and by long-pulse excitation and that most measurements have been performed with laser wavelengths between 660 and 980nm (a few microcrystalline samples were additionally investigated by 350 and 532nm excitation). In agreement with the theoretical predictions [22], no systematic deviation between the different measurement conditions were observed for cSiTF material. Due to a relatively small signal-to-noise ratio, a high illumination intensity was chosen, leading to excess carrier densities in the range of 10^{15} to 10^{18}cm^{-3} for the investigated samples. Further studies in this area could investigate the actual injection level.

> "The effective minority carrier lifetime could be determined on a wide range of different cSiTF materials successfully."

With a single MWPCD measurement, the effective lifetime can be determined as demonstrated. In the case of a whole sample set of thin-film lifetime samples that differ only in their epitaxial layer thickness, even more information can be extracted. Under the stringent assumption that the investigated lifetime samples within one sample set have similar electrical and optical properties, the epitaxial bulk lifetime τ_{epi} and the total recombination velocity S_{tot}, which encompasses the front surface recombination velocity (S_{front}), the loss of minority charge carriers through a net current of minority charge carriers from the epitaxial base into the substrate (denoted by S_{BSF}), and the recombination velocity at the interface (S_{int}) via crystallographic defects and impurity atoms, can be separated according to Equation 3:

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_{epi}} + \frac{S_{front} + S_{BSF} + S_{int}}{W_{epi}} \qquad (3)$$

Fig. 4 shows the results gathered by applying this analysis method to different cSiTF materials. Whereas no significant difference in the epitaxial bulk lifetime was observed between microelectronic-grade thin-film material and solar-grade epitaxial layers deposited at Fraunhofer ISE, matters are different for the total surface recombination velocity, indicating the improvement potential for the processing of the solar-grade epitaxial layers.

Finally, note that S_{BSF} can in principle be calculated by applying the theory of high-low junctions [23]. When applied to thin-film solar cells, this translates into:

$$S_{BSF} = \frac{D_{substr}}{L_{substr}\,\Phi} \text{ where } \Phi = \frac{N_{substr}}{N_{epi}} \qquad (4)$$

where the diffusion coefficient and diffusion length of the minority charge carriers in the substrate are denoted by D_{substr} and L_{substr}, and the doping concentrations of the substrate and the epitaxial layer are denoted by N_{substr} and N_{epi}, respectively. For high doping concentrations, bandgap narrowing must be included in the calculation.

Summary

This article has addressed the concept of minority carrier lifetime in photovoltaic silicon material. After the introduction of the fundamental relations, selected lifetime measurement methods have been presented, with results on crystalline silicon thin-film material showing the determination of effective lifetimes between 1 and 15µs. Additionally, under the assumption of negligible front-surface recombination and similar electrical and optical properties within one lifetime sample set, a method of separating the total recombination rate into epitaxial bulk lifetime, minority carrier loss through a net current of minority charge carriers from the epitaxial base into the substrate, and recombination at the interface has been proposed.

References

[1] Trupke, T. et al. 2004, "Effective excess carrier lifetimes exceeding 100 milliseconds in float zone silicon determined from photoluminescence", *Proc. 19th EU PVSEC*, Paris, France, pp. 758–61.

[2] Nagel, H., Berge, C. & Aberle, A.G. 1999, "Generalized analysis of quasi-steady-state and quasi-transient measurements of carrier lifetimes in semiconductors", *Journal of Applied Physics*, Vol. 86, pp. 6218–21.

[3] Ramsa, A.P., Jacobs, H. & Brand, F.A. 1959, "Microwave techniques in measurement of lifetime in germanium", *Journal of Applied Physics*, Vol. 30, pp. 1054–60.

[4] Jacobs, H., Ramsa, A.P. & Brand, F.A. 1960, "Further consideration of bulk lifetime measurement with a microwave electrodeless technique", *Proc. Institute of Radio Engineers*, Vol. 48, pp. 229–33.

[5] Kunst, M. & Beck, G. 1986, "The study of charge carrier kinetics in semiconductors by microwave conductivity measurements", *Journal of Applied Physics*, Vol. 60, pp. 3558–66.

[6] Schöfthaler, M. & Brendel, R. 1995, "Sensitivity and transient response of microwave reflection measurements", *Journal of Applied Physics*, Vol. 77, pp. 3162–73.

[7] Ogita, Y.I. 1996, "Bulk lifetime and surface recombination velocity measurement method in semiconductor wafers", *Journal of Applied Physics*, Vol. 79, pp. 6954–60.

[8] Ahrenkiel, R.K. & Johnston, S.W. 2008, "Lifetime analysis of silicon solar cells by microwave reflection", *Solar Energy Materials and Solar Cells*, Vol. 92, pp. 830–5.

[9] Sinton, R.A. & Cuevas, A. 1996, "Contactless determination of current-voltage characteristics and minority-carrier lifetimes in semiconductors from quasi-steady-state photoconductance data", *Applied Physics Letters*, Vol. 69, pp. 2510–2.

[10] Macdonald, D. & Cuevas, A. 1999, "Trapping of minority carriers in multicrystalline silicon", *Applied Physics Letters*, Vol. 74, pp. 1710–2.

[11] Bail, M., Schulz, M. & Brendel, R. 2003, "Space-charge region-dominated steady-state photoconductance in low-lifetime Si wafers", *Applied Physics Letters*, Vol. 82, pp. 757–9.

[12] Bail, M. et al. 2000, "Lifetime mapping of Si wafers by an infrared camera [for solar cell production]", *Proc. 28th IEEE PVSC*, Anchorage, Alaska, USA, pp. 99–103.

[13] Riepe, S. et al. 2001, "Carrier density and lifetime imaging of silicon wafers by infrared lock-in thermography", *Proc. 17th EU PVSEC*, Munich, Germany, pp. 1597–9.

[14] Ramspeck, K. et al 2008, "Dynamic carrier lifetime imaging of silicon wafers using an infrared-camera-based approach", *Applied Physics Letters*, Vol. 93, pp. 102104–1–3.

[15] Fuyuki, T. et al 2005, "Photographic surveying of minority carrier diffusion length in polycrystalline silicon solar cells by electroluminescence", *Applied Physics Letters*, Vol. 86, pp. 262108–1–3.

[16] Trupke, T. et al 2006, "Photoluminescence imaging of silicon wafers", *Applied Physics Letters*, Vol. 89, pp. 044107–1–3.

[17] Herlufsen, S. et al 2008, "Photoconductance-calibrated photoluminescence lifetime imaging of crystalline silicon", *physica status solidi RRL*, Vol. 2, pp. 245–7.

[18] Giesecke, J.A., Kasemann, M. & Warta, W. 2009, "Determination of local minority carrier diffusion lengths in crystalline silicon from luminescence images", *Journal of Applied Physics*, Vol. 106, pp. 014907–1–8.

[19] Gundel, P. et al 2010, "Quantitative carrier lifetime measurement with micron resolution", *Journal of Applied Physics*, Vol. 108, pp. 033705–1–7.

[20] Kiliani, D. et al. 2010, "Time resolved photoluminescence imaging for carrier lifetime mapping of silicon wafers", *Proc. 25th EU PVSEC*, Valencia, Spain [in print].

[21] Herlufsen, S. et al. 2010, "Dynamic lifetime imaging based on photoluminescence measurements", *Proc. 25th EU PVSEC*, Valencia, Spain [in print].

[22] Walter, D. et al 2010, "Determining the minority carrier lifetime in epitaxial silicon layers by microwave-detected photoconductivity measurements", *Proc. 25th EU PVSEC*, Valencia, Spain [in print].

[23] Godlewski, M.P., Baraona, C.R. & Brandhorst, Jr., H.W. 1973, "Low-high junction theory applied to solar cells", *Proc. 10th IEEE PVSC*, Palo Alto, California, USA, pp. 40–9.

About the Author

Philipp Rosenits studied physics at the Universidad de Costa Rica and the University of Freiburg, where he received his degree in physics in 2007. His diploma thesis, which he accomplished at the Australian National University and the Fraunhofer ISE, was about the characterization of electrically active defects in silicon. He is currently finishing his Ph.D. thesis, which deals with the electrical characterization of crystalline silicon thin-film material. Besides science, he is also interested in intellectual property rights and patents.

Enquiries

Fraunhofer Institute for Solar Energy Systems (ISE)
Heidenhofstr. 2
79110 Freiburg
Germany
Tel: +49 761 4588 5269
Fax: +49 761 4588 9250
Email: philipp.rosenits@ise.fraunhofer.de

Surface passivation of silicon solar cells using industrially relevant Al_2O_3 deposition techniques

Jan Schmidt, **Florian Werner**, **Boris Veith**, **Dimitri Zielke**, **Robert Bock** & **Rolf Brendel**, Institute for Solar Energy Research Hamelin (ISFH), Emmerthal, Germany; **Veronica Tiba**, SoLayTec, Eindhoven, The Netherlands; **Paul Poodt** & **Fred Roozeboom**, TNO Science & Industry, Eindhoven, The Netherlands; **Andrew Li** & **Andres Cuevas**, The Australian National University (ANU), Canberra, Australia

ABSTRACT

The next generation of industrial silicon solar cells aims at efficiencies of 20% and above. To achieve this goal using ever-thinner silicon wafers, a highly effective surface passivation of the cell front and rear is required. In the past, finding a suitable dielectric layer providing a high-quality rear passivation has been a major challenge. Aluminium oxide (Al_2O_3) grown by atomic layer deposition (ALD) has only recently turned out to be a nearly perfect candidate for such a dielectric. However, conventional ALD is limited to deposition rates well below 2nm/min, which is incompatible with industrial solar cell production. This paper assesses the passivation quality provided by three different industrially relevant techniques for the deposition of Al_2O_3 layers, namely high-rate spatial ALD, plasma-enhanced chemical vapour deposition (PECVD) and reactive sputtering.

Introduction

In high-efficiency laboratory silicon solar cells, surface recombination is very effectively suppressed by means of silicon dioxide (SiO_2) grown in a high-temperature (≥900°C) oxidation process [1]. Very low surface recombination velocities (SRVs) are in particular realized at the lightly doped rear surface, where the combination of a thermally grown SiO_2 layer with an evaporated film of Al gives – after an additional annealing treatment at ~400°C (the so-called 'alneal') – SRVs below 20cm/s on low-resistivity (~1Ωcm) p-type silicon wafers [2]. In addition, the SiO_2/Al stack at the cell rear acts as an excellent reflector for near-bandgap photons, significantly improving the light-trapping properties and, hence, the short-circuit current of the cell. One of the main reasons why high-temperature oxidation has not been implemented into the majority of industrial cell processes so far is the high sensitivity of the silicon bulk lifetime to high-temperature processes. Particularly in the case of multicrystalline silicon wafers, thermal processes above 900°C typically lead to a significant degradation of the bulk lifetime [3]. Hence, low-temperature surface passivation alternatives are required for future industrial high-efficiency silicon solar cells.

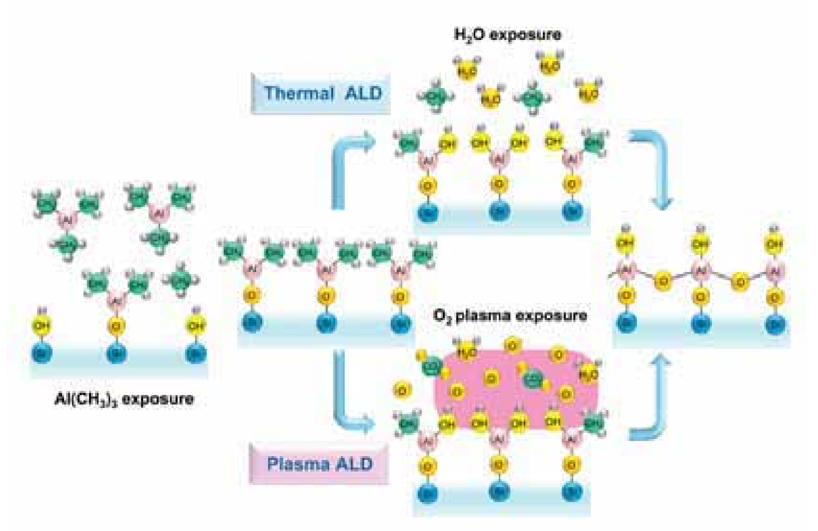


Figure 1. Schematic of one cycle of a thermal and a plasma-assisted ALD process. Each cycle consists of two half-steps: first, the trimethyl aluminium (TMA) molecules attach to the hydroxyl groups bound to the silicon surface; second, the molecules are oxidized by H_2O (thermal ALD) or an O_2 plasma (plasma ALD).

One intensively investigated low-temperature surface passivation alternative to thermal oxide is silicon nitride (SiN_x) grown by PECVD at ~400°C, which has proven to give comparably low SRVs as thermal SiO_2 on low-resistivity p-type silicon [4,5]. However, when applied to the rear of PERC (passivated emitter and rear cell)-type solar cells on a p-type substrate, the short-circuit current density is strongly reduced compared to the SiO_2-passivated cell rear [6]. This effect has been attributed to the large density of fixed positive charges within the SiN_x layer, inducing an inversion layer in the p-type silicon underneath the SiN_x. The coupling of this inversion layer to the base metal contact leads to a significant loss in the short-circuit current density and the fill factor, a detrimental effect that is known as 'parasitic shunting' [7].

"Aluminium oxide (Al_2O_3) has proven capable of providing an excellent level of surface passivation."

Fortunately, the negative-charge-dielectric aluminium oxide (Al_2O_3) has proven capable of providing an excellent level of surface passivation on low-resistivity p-type and n-type silicon wafers as well as on boron- and aluminium-doped p^+-emitters [8–21]. Al_2O_3 can be deposited by various techniques, such as ALD, PECVD and reactive sputtering. In particular, it was demonstrated that it is ideally suited to the rear passivation of

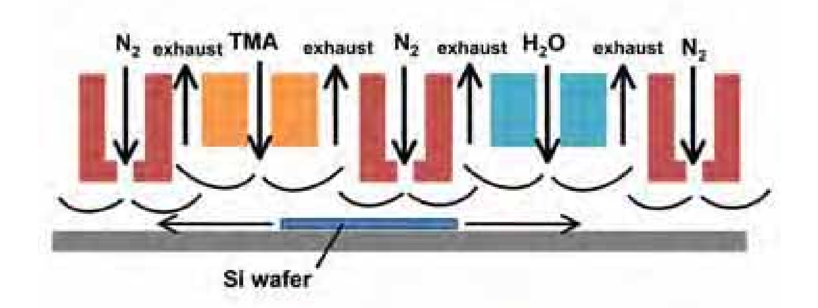


Figure 2. Schematic of the spatial ALD concept [22]. The TMA and water half-reaction zones are separated by N_2 gas bearings.

PERC solar cells, as parasitic shunting is completely absent thanks to the fixed negative charges [11]. In this contribution, we systematically compare the passivation quality of Al_2O_3 films deposited by various deposition techniques. Atomic layer deposition performed in lab reactors (plasma-assisted as well as thermal ALD) provides an outstanding surface passivation quality; however, it is limited to very low deposition rates (<2nm/min), making conventional, temporal ALD reactors unsuitable for industrial solar cell production. On the other hand, we will demonstrate that high-rate spatial ALD, PECVD, and reactive sputtering have an enormous potential for a transfer of Al_2O_3 into industrial cell production in the near future.

Atomic layer deposition

In the ALD process, one monolayer of Al_2O_3 is grown per cycle, with each cycle consisting of two half-reactions, as depicted in Fig. 1. In the first half-reaction, trimethyl aluminium (TMA) molecules react with hydroxyl (OH) groups attached to the surface. At the end of the first half-reaction, Al atoms and methyl groups cover the surface and the remaining TMA molecules in the deposition chamber are no longer able to react with the surface. After purging the deposition chamber with inert or oxygen gas, the second half-reaction of the ALD cycle starts. One can apply two different realization forms for the second half-reaction: in the thermal ALD process, water vapour is injected into the deposition chamber. The H_2O molecules react very fast with the $Al\text{-}CH_3$ complex attached to the surface. Hydrogen reacts with the methyl group to form methane, and oxygen reacts with aluminium to form aluminium oxide. In the plasma-assisted ALD ('plasma ALD') process, an oxygen plasma is ignited above the substrate, generating oxygen radicals which effectively react with the methyl groups and the aluminium at the surface. Oxford Instruments' FlexAL™ deposition system, applied in this study, uses a remote inductively coupled plasma (ICP) source, which means that the oxygen plasma is not in direct contact with the silicon wafer during Al_2O_3 deposition. This type of remote-plasma deposition technique is known to create almost no plasma damage at the surface, and is hence well suited for an excellent silicon surface passivation.

"High-rate spatial ALD, PECVD, and reactive sputtering have an enourmous potential for a transfer of Al_2O_3 into industrial cell production."

In a conventional ALD process, the separation of the half-reactions is implemented by alternate dosing of the process gases. Exposure times of only a few milliseconds are sufficient to ensure complete saturation of the growth surface. In between both precursor doses, however, the reactor chamber is purged by an inert gas and subsequently pumped to remove the residual process gas and reaction products. In order to prevent parasitic CVD processes and ensure a true ALD process, pumping times of a few seconds are required, severely limiting the growth rate to approximately 2nm/min. This renders conventional ALD unsuitable for high-throughput industrial solar cell production.

Recently, Poodt et al. proposed a high-rate ALD concept based on spatially separated ALD ('spatial ALD') [22], enabling deposition rates of 70nm/min. In contrast to the conventional sequential separation, both half-reactions are spatially separated (see Fig. 2), thus eliminating the need for intermediate pumping steps. In a first proof-of-principle lab tool developed at TNO, the spatial separation was achieved by rotating the wafer underneath a round reactor head incorporating gas inlets for TMA and water vapour, separated by gas bearing planes formed by a flow of pressurized nitrogen. Since both reaction zones are sealed off by nitrogen flow, any unintentional interaction of the process gases is prevented and the deposition can be performed under atmospheric conditions, an additional advantage concerning the industrial applicability. The spatial ALD concept has recently led to excellent surface passivation results on p- and n-type silicon wafers [23].

Note that high-throughput (up to 3,000 wafers per hour) reactors based on the spatial ALD approach are currently under development at two different companies, namely SoLayTec and Levitech, and will be commercially available in the

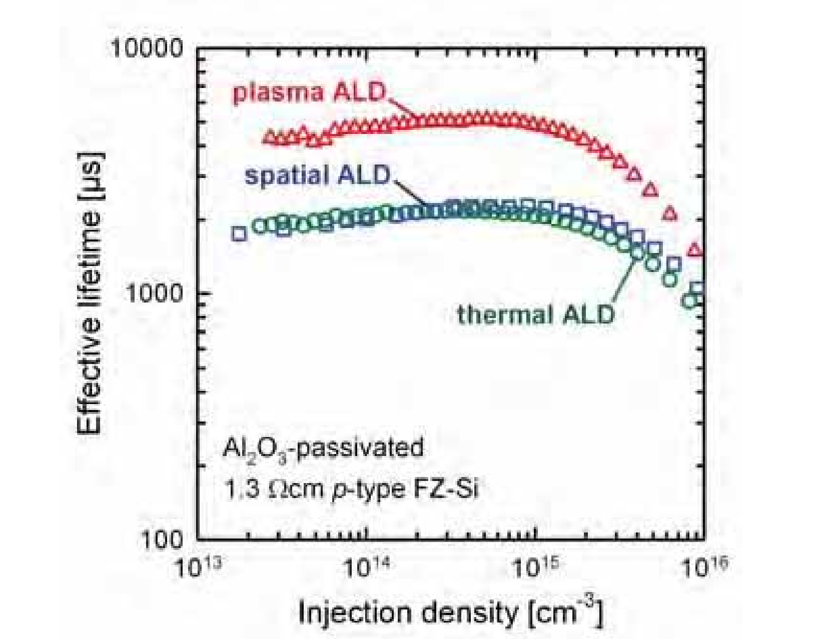


Figure 3. Effective lifetime τ_{eff} as a function of the injection density Δn measured on 1.3Ωcm p-type FZ-Si passivated by Al_2O_3 deposited by plasma, thermal and spatial ALD.

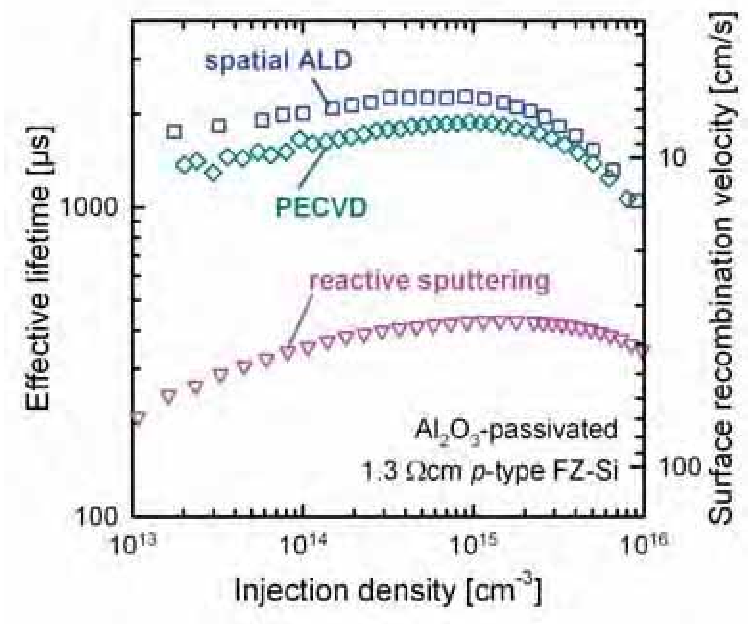


Figure 4. Effective lifetime (left scale) and corresponding surface recombination velocity (SRV) (right scale) as a function of the injection density, measured on 1.3Ωcm p-type FZ-Si passivated by Al_2O_3 deposited by spatial ALD, PECVD, and reactive sputtering.

near future with the extra option of an additional gas bearing at the wafer back side, thus enabling double-floating wafer transport in a reciprocating manner or in a single direction.

Fig. 3 shows the effective lifetimes τ_{eff} measured as a function of the injection density Δn for 1.3Ωcm p-type float-zone silicon (FZ-Si) wafers passivated using Al_2O_3 deposited by plasma-assisted, thermal and spatial ALD. Lifetimes were measured by the photoconductance decay (PCD) method using a Sinton lifetime tester. All Al_2O_3 films received a post-deposition anneal at (400±50)°C for ~15 min to activate the surface passivation [19]. As can be seen from Fig. 3, all three ALD techniques result in Al_2O_3 films of outstanding surface passivation quality, which shows an extremely weak injection dependence over the complete relevant injection range between 10^{13} and 10^{15}cm^{-3}. Al_2O_3 deposited by plasma ALD provides effective lifetimes between 3 and 4.8ms in the relevant injection range. The measured lifetime of 4.8ms at Δn = 10^{15}cm^{-3} lies well above the commonly used empirical expression for the intrinsic lifetime limit for crystalline silicon [24], indicating a nearly perfect surface passivation, even better than that previously achieved with 'alnealed' thermally-grown SiO_2. Assuming an infinite bulk lifetime, we can calculate an upper limit to the SRV S_{max} using the simple relation $S_{max} = W/2\tau_{eff}$, where W = 290µm is the measured wafer thickness. Using this relation, τ_{eff} = 4.8ms, corresponds to an upper SRV limit of S_{max} = 3cm/s. Given that the measured lifetime is above the previous intrinsic limit for silicon, the lower limit is S_{min} = 0 cm/s, and the real SRV is in between those two values – too low to be noticed by a normal solar cell. In this work, all SRVs reported are S_{max} values.

Most importantly, it can be concluded from Fig. 3 that both traditional thermal ALD as well as spatial ALD provide Al_2O_3 films with an extremely high level of surface passivation, as indicated by lifetimes of 2ms, corresponding to an upper SRV limit of S_{max} = 7cm/s, for both techniques and a practically negligible injection dependence over the relevant injection range. It is quite remarkable that the high-rate (in our example 14nm/min) spatial ALD produces exactly the same excellent level of surface passivation as the slow (< 2nm/min) conventional thermal ALD [23].

Spatial ALD, PECVD and sputtering

In addition to spatial ALD, two other techniques have recently been demonstrated to be suitable for depositing surface-passivating Al_2O_3 layers. PECVD [14,15,21] has been shown to provide SRVs of only 10cm/s on 1Ωcm p-type FZ-Si, whereas reactive sputtering [16] on comparable material has resulted in SRVs down to 55cm/s. In addition to the Al_2O_3 films deposited by spatial ALD, we have examined the passivation quality of Al_2O_3 films deposited in an in-line microwave-remote PECVD (Roth&Rau, SiNA) system and in an RF magnetron sputtering lab system [19]. The sputtering uses an aluminium target, which is reactively sputtered in an O_2/Ar atmosphere, while the PECVD uses TMA and nitrous oxide as process gases.

Fig. 4 compares the effective lifetimes measured on 1.3Ωcm p-type FZ-Si wafers passivated by Al_2O_3 films deposited using, in our opinion, the most promising industrial Al_2O_3 deposition techniques: (i) spatial ALD, (ii) PECVD, and (iii) RF magnetron sputtering. The direct lifetime comparison in Fig. 4 shows that both spatial ALD and PECVD provide S_{max}

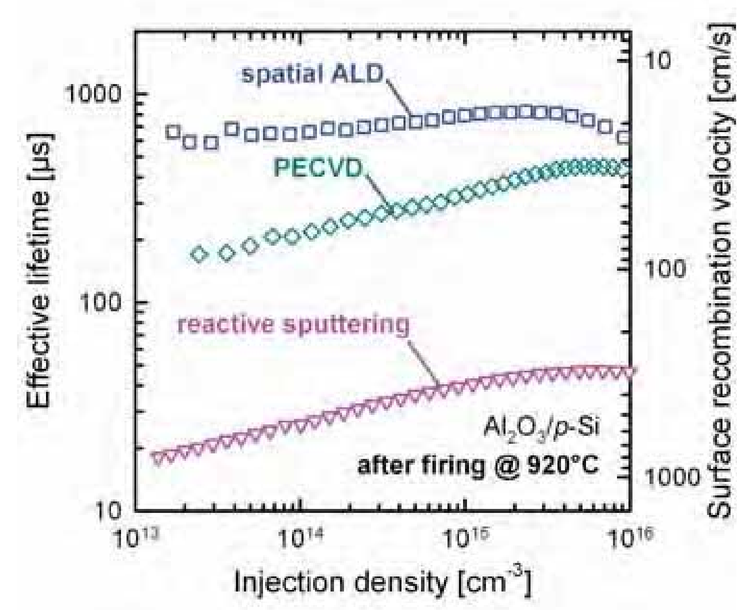


Figure 5. Injection-dependent effective lifetime (left scale) and corresponding surface recombination velocity (SRV) (right scale) after firing at a peak set temperature of 920°C (measured peak temperature ~800°C). The samples are 1.3Ωcm p-type FZ-Si wafers passivated by Al_2O_3 deposited using spatial ALD, PECVD, and reactive sputtering.

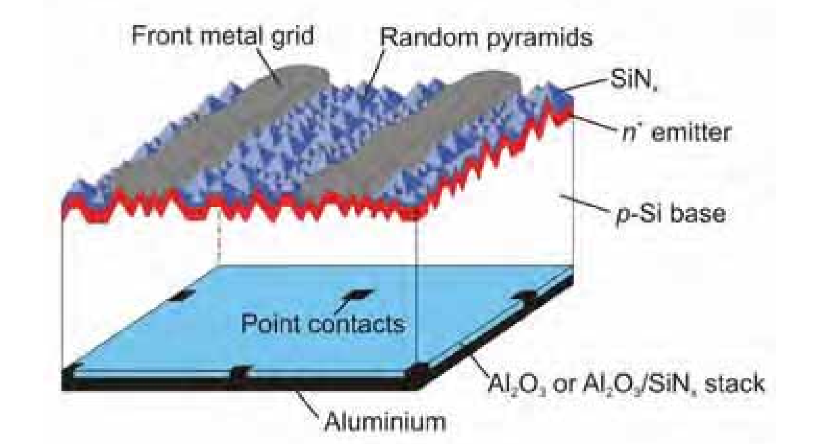


Figure 6. PERC-type solar cell structure used to demonstrate the applicability of different rear surface passivation schemes.

values < 10cm/s, clearly outperforming the sputtered Al_2O_3. Nevertheless, the sputtered Al_2O_3 passivation layer results in a surface recombination velocity between 35 and 70cm/s in the relevant injection range, which would still be acceptable for the next generation of industrial high-efficiency solar cells.

> "The PERC solar cells with sputtered Al_2O_3 as rear passivation achieve an independently confirmed efficiency of 20.1%."

Another very important property is the stability of the surface passivation during a firing step as it is typically applied in the screen-printing metallization of solar cell production lines. We annealed lifetime samples in an industrial infrared conveyor-belt furnace (Centrotherm Contact Firing Furnace DO 8.600-300-FF) at a set temperature of 920°C (measured peak temperature ~800°C). Fig. 5 shows the injection-dependent lifetimes and corresponding surface recombination velocities measured after firing. The Al_2O_3 deposited by spatial ALD shows clearly the best firing stability, providing SRVs of ~20cm/s after firing over the entire relevant injection range. The Al_2O_3 layer deposited by inline PECVD also results in a good passivation quality after firing, providing S_{max} values between 30 and 80cm/s in the injection range of relevance. The sputtered Al_2O_3 shows the strongest increase in the surface recombination after firing, leading to SRVs between 300 and 800cm/s. Obviously, the sputtered Al_2O_3 needs further optimization, while the PECVD-Al_2O_3 and in particular the spatial ALD-Al_2O_3 layers can be directly implemented in a screen-printing solar cell process.

As large-area in-line PECVD systems are already available on the market, PECVD seems to be the preferred short-term deposition technique for Al_2O_3. The preferred medium-term and long-term deposition technique might be ultrafast spatial ALD due to its reduced TMA gas consumption compared to PECVD, the absence of parasitic deposition at the reactor wall and a smaller footprint of the deposition systems currently under development. Also, ALD provides highest-quality pinhole-free Al_2O_3 films and allows conformal film deposition, which might prove useful for advanced solar cell concepts.

PERC solar cells

We have implemented our Al_2O_3 rear passivation layers deposited by plasma ALD, thermal ALD and sputtering into passivated emitter and rear cells using the process sequence described in [11]. Fig. 6 shows the cell structure featuring a PECVD-SiN_x-passivated 100Ω/sq phosphorus-diffused n^+ front emitter and a rear surface passivated by the dielectric layer systems shown in the first column of Table 1. The front grid is made by shadow-mask evaporation of aluminium and the rear is fully metallized by aluminium evaporation (~4% rear metal contact fraction) after point contact openings have been generated. Table 1 summarizes the one-sun parameters of the best PERC solar cells, as measured under standard testing conditions (25°C, 100mW/cm², AM 1.5 G). The measured open-circuit voltages (V_{oc}) and short-circuit current densities (J_{sc}) of the ALD-passivated cells are clearly superior to the V_{oc} and J_{sc} values of the cell with sputtered Al_2O_3.

V_{oc} values of ALD-passivated cells are all > 660mV and J_{sc} values are > 40mA/cm², demonstrating the huge potential of ALD for the rear surface passivation of PERC-type cells. We deposited thicker PECVD-SiO_x or SiN_x layers on top of the very thin ALD-Al_2O_3 layers, mainly to improve the internal rear reflection of the cell. The independently confirmed conversion efficiencies are 21.4% for the plasma ALD-Al_2O_3 rear passivation and 20.7% for the thermal ALD-Al_2O_3 passivation. The passivation quality of the sputtered Al_2O_3 is clearly inferior to that of the ALD-Al_2O_3 films, as indicated by an ~10mV lower V_{oc} and an ~1.5mA/cm² reduced J_{sc}. Nevertheless, the PERC cells with sputtered Al_2O_3 as rear passivation achieve an independently confirmed efficiency of 20.1% – the first 20%-efficient solar cell made using a sputtered Al_2O_3 passivation layer.

Conclusions

Despite their lower passivation quality compared to Al_2O_3 films deposited by ALD and by PECVD, we have demonstrated that sputtered Al_2O_3 layers are suitable for the fabrication of 20% efficient PERC cells, while Al_2O_3 deposited by ALD resulted on the same cell structure in efficiencies up to 21.4%. After firing in a conveyor-belt furnace, the SRV provided by Al_2O_3 films deposited by high-rate spatial ALD was found to be below 20cm/s and that of PECVD-Al_2O_3 was in the range 30–80cm/s, indicating a very good firing stability of the layers deposited by spatial ALD as well as PECVD. On the other hand, sputtered Al_2O_3 passivation layers degraded to SRVs larger than 300cm/s after firing. We conclude that spatial ALD and PECVD are already compatible with screen-printing, while the firing stability of sputtered Al_2O_3 needs further optimization, e.g. by deposition of hydrogen-rich SiN_x on top of the sputtered Al_2O_3. As high-throughput PECVD systems are already well introduced in the market, PECVD will, in our opinion,

Rear side passivation	V_{oc} [mV]	J_{sc} [mA/cm²]	*FF* [%]	η [%]
Plasma ALD Al_2O_3/SiO_x	664	40.7	79.4	21.4*
Thermal ALD Al_2O_3/SiN_x	662	40.6	76.9	20.7*
Sputtered Al_2O_3	651	39.1	79.1	20.1*

*Independently confirmed at Fraunhofer ISE CalLab

Table 1. One-sun parameters measured under standard testing conditions of the best PERC silicon solar cells with three different rear surface passivations: (i) plasma ALD Al_2O_3 (30nm)/PECVD-SiO_x (200nm), (ii) thermal ALD Al_2O_3 (30nm)/PECVD-SiN_x (100nm), and (iii) sputtered Al_2O_3 (110nm). All cells were fabricated on 0.5Ωcm FZ p-Si wafers. The aperture cell area is 4cm².

be the preferred short-term deposition technique for Al_2O_3 passivation layers. If the firing stability of sputtered Al_2O_3 layers can be further improved (e.g by using SiN_x capping layers), this could become another option for the short term. Spatial ALD might be the most interesting medium- to long-term option due to the superior overall precursor use and material properties of atomic-layer-deposited Al_2O_3.

Acknowledgments

Parts of this work have been funded by the German Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) under contract number 0325050 ("ALD").

References

[1] Zhao, J., Wang, A. & Green, M.A. 2009, *Prog. Photovolt.*, Vol. 7, p. 471.
[2] Kerr, M.J. & Cuevas, A. 2001, *Sem. Sci. Techn.*, Vol. 17, p. 35.
[3] Stocks, M.J., Cuevas, A. & Blakers, A.W. 1997, *Proc. 14th EU PVSEC*, Barcelona, Spain, p. 770.
[4] Lauinger, T. et al. 1996, *Appl. Phys. Lett.*, Vol. 68, p. 1232.
[5] Schmidt, J. et al. 2004, *Proc. 19th EU PVSEC*, Paris, France, p. 391.
[6] Dauwe, S. et al. 2003, *Proc. 3rd WCPEC*, Osaka, Japan, p. 1395.
[7] Dauwe, S. et al. 2002, *Prog. Photovolt.*, Vol. 10, p. 271.
[8] Hezel, R. & Jaeger, K. 1989, *J. Electrochem. Soc.*, Vol. 136, p. 518.
[9] Agostinelli, G. et al. 2006, *Sol. En. Mat. Sol. Cells*, Vol. 90, p. 3438.
[10] Hoex, B. et al. 2008, *J. Appl. Phys.*, Vol. 104, 044903.
[11] Schmidt, J. et al 2008, *Prog. Photovolt.*, Vol. 16, p. 461.
[12] Benick, J. et al 2008, *Appl. Phys. Lett.*, Vol. 92, 253504.
[13] Cesar, I. et al. 2010, *Proc. 35th IEEE PVSC*, Honolulu, Hawaii [in press].
[14] Miyajima, S. et al. 2008, *Proc. 23rd EU PVSEC*, Valencia, Spain, p. 1029.
[15] Saint-Cast, P. et al. 2009, *Appl. Phys Lett.*, Vol. 95, 151502.
[16] Li, T.T. & Cuevas, A. 2009, *Phys. Status Solidi (RRL)*, Vol. 3, p. 160.
[17] Schmidt, J., Veith, B. & Brendel, R. 2009, *Phys. Status Solidi (RRL)*, Vol. 3, p. 287.
[18] Dingemans, G. et al. 2010, *Phys. Status Solidi (RRL)*, Vol. 4, p. 10.
[19] Schmidt, J. et al. 2010, *Proc. 25th EU PVSEC*, Valencia, Spain [in press].
[20] Schmidt, J. et al. 2010, *Proc. 35th IEEE PVSC*, Honolulu, Hawaii [in press].
[21] Dingemans, G., van de Sanden, M.C.M. & Kessels, W.M.M. 2010, *Electrochem. Solid-State Lett.*, Vol. 13, H76-H79.
[22] Poodt, P. et al. 2010, *Adv. Mat.*, Vol. 22, p. 3564.
[23] Werner, F. et al. 2010, *Appl. Phys. Lett.*, Vol. 97, p. 162103.
[24] Kerr, M.J. & Cuevas, A. 2002, *J. Appl. Phys.*, Vol. 91, p. 2473.

About the Authors

Jan Schmidt is head of the PV Department at ISFH and professor of physics at the Leibniz University of Hanover, Germany. He received his Ph.D. degree in 1998 from the Leibniz University of Hanover. His current research interests include the analysis and manipulation of defects in silicon materials, the development of novel characterization techniques, as well as the development and evaluation of novel surface passivation methods for silicon solar cells.

Florian Werner is a Ph.D. student at ISFH. In 2009 he graduated in physics from the Georg-August University in Göttingen, Germany, where he investigated charge transport and surface properties of indium nitride nanowires. His current research at the ISFH focuses on aluminium oxide as a novel surface passivation method for silicon solar cells.

Boris Veith studied physics at the Leibniz University of Hanover, Germany, and received his diploma degree in 2010. He is now employed as a researcher at ISFH, working on the aluminium oxide surface passivation of silicon solar cells.

Dimitri Zielke is a physics student at the Leibniz University of Hanover, Germany, and is currently working towards his diploma degree in physics at ISFH. The main topic of his diploma thesis is the surface passivation of silicon solar cells using aluminium oxide.

Robert Bock studied materials science at the Christian Albrechts University Kiel, Germany, and received his diploma degree in 2006. He is currently doing Ph.D. research at ISFH with focus on n-type silicon solar cells with screen-printed aluminium-alloyed emitters.

Rolf Brendel, Director of the ISFH, completed his studies in physics and mathematics, and joined the Max Planck Institute for Solid State Research in Stuttgart following his Ph.D. work. He was appointed head of the Division for Thermosensorics and Photovoltaics at the Bavarian Center for Applied Energy Research in Erlangen. Since 2004 he has been a professor at the Institute of Solid State Physics at the Leibniz University of Hanover.

Veronica Tiba is a process development engineer, responsible for the knowledge transfer of (atmospheric) ultrafast spatial ALD of Al_2O_3 from research to industrialization at SoLayTec in Eindhoven, The Netherlands. She received her Ph.D. degree in 2005 from the Eindhoven University of Technology.

Paul Poodt is a researcher at the Materials Technology business unit at TNO Science & Industry. He received his Ph.D. degree in 2008 from the Radboud University Nijmegen, The Netherlands. His current research interests include the development of novel gas-phase deposition techniques as well as the physics and chemistry of thin-film deposition for photovoltaics and other (compound) semiconductor devices.

Fred Roozeboom is a senior technical advisor at TNO Science & Industry, and part-time professor at the University of Technology, both in Eindhoven, The Netherlands. He received his Ph.D. degree in chemical engineering in 1980 from Twente University, after which he worked on zeolite catalysis with Exxon (USA and The Netherlands) and Philips Research (The Netherlands). His topics of interest include ultrathin-film technology, plasma processing, microsystem technology, sensors and 3D integration.

Andrew Li has recently submitted his Ph.D. thesis for examination at The Australian National University, Canberra, Australia, which investigated the sputtering method for the deposition of aluminium oxide for the surface passivation of silicon solar cells. His research interests include cell design and characterization, particularly of high efficiency solar cells. He is now working for REC, Singapore.

Andres Cuevas has contributed to the development of silicon solar cell technology since 1976, first at the Universidad Politecnica de Madrid, Spain, where he obtained his Ph.D. degree in 1980 and then at ANU, where he now is Professor of Engineering. His current research interests include the characterisation and understanding of the fundamental properties of silicon, the passivation of silicon surfaces using dielectric coatings, and the development of new technologies for n-type silicon solar cells.

Enquiries

Prof. Jan Schmidt
Institute for Solar Energy Research Hamelin (ISFH)
Am Ohrberg 1
31860 Emmerthal
Germany
Tel: +49 5151 999 100
Fax: +49 5151 999 400
Email: j.schmidt@isfh.de
Web: www.isfh.de

The global photovoltaic materials market – is the future bright?

Gaurav Vyas & **Dr Leonidas Dokos**, Frost & Sullivan, Oxford, UK

ABSTRACT
Despite the financial crisis and present credit crunch, photovoltaic materials markets experienced only a temporary slide in demand in 2009, with the overall outlook remaining optimistic. This paper presents a strategic analysis review for the materials used in photovoltaic modules, essentially materials for encapsulant, frontsheet, backsheet and anti-reflection coatings. Rising concerns about the need to reduce CO_2 emissions and increase the use of renewable energy sources worldwide will stimulate the global photovoltaic market. Feed-in tariffs and politically backed targets boosting renewable energy use will provide further impetus to the photovoltaic market. This, in turn, will have a positive ripple effect on the demand for photovoltaic materials; however, depending on the market share for technology used, i.e. crystalline or thin film for PV energy, the market for materials will be influenced, in addition to advantages and disadvantages of these materials that will influence their market share. With rising awareness about green trends, the future will lie in technologies that offer enhanced energy-efficient solutions at a low cost. Manufacturers who offer products with optimum performance while remaining price-orientated will be poised to gain substantial market share.

Introduction

The solar PV market has been booming over the last few years, despite the financial crisis. Although in 2008 the PV market experienced a temporary slump, the outlook for the industry looks positive. The market is dependent to a large extent on the political volition and subsidies with the support mechanisms being specific to a country. The introduction, modification or scraping out of such support mechanisms can have a profound effect on the PV sector. At present, the global PV market is being driven by the financial incentives offered by the federal and state governments. In addition, the optimization of production costs coupled with technological advances and research and development initiatives are also assisting in the expansion of the sector. The integration of PV systems in the grid or off grid is illustrated in Fig. 1.

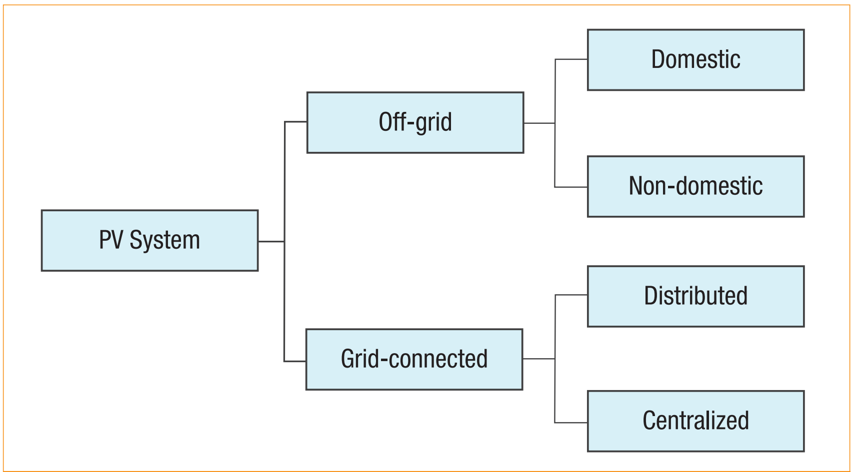


Figure 1. Schematic of a PV system integration in the electric supply chain.

Outlook for PV modules

The PV technology that is used for the production of electricity determines the usage of various materials. Crystalline silicon technology is material intensive but provides many opportunities for the material suppliers. Thin-film technology is a cost-effective solution that has a promising future scope for companies supplying polymers to the PV sector.

However, the major disadvantage of thin-film technology is its efficiency. The development and supply of materials with improved efficiency at a competitive price will assist the thin-film modules market to exhibit a higher growth rate in comparison to crystalline silicon modules. Development in the use of PV modules between 2009 and 2016 is illustrated in Fig. 2.

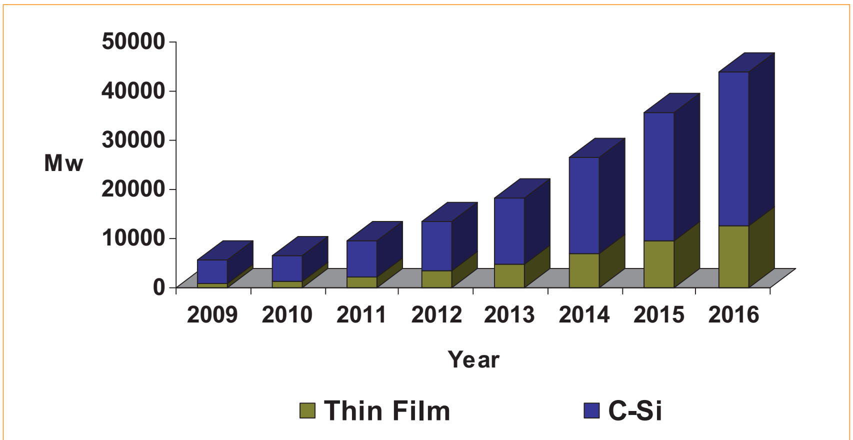


Figure 2. Outlook for photovoltaic modules (2009–2016).

PV module materials

The photovoltaic modules market has been growing rapidly on a global scale. There are several different solar cell technologies at a range of efficiency levels and various states of commercialization, as illustrated in Fig. 3.

The major goal is to get production costs down to less than $1/Watt while maintaining long-term durability. Manufacturing technologies have to become more cost effective, including innovations in materials for module components. The required functions of key component materials in photovoltaic

Solar Cell		Efficiency	State of Commercialization
Si wafer-based	Monocrystalline	15-18%	Large-scale production
	Polycrystalline	13-16%	Large-scale production
	Ribbon-based	13-16%	Small to mid-scale production
Thin-Film	Amophous Si	5-7%	Middle-scale production
	Microcrystalline Si	8-11%	Small-scale production
	CIS / CIGS	9-11%	Small to mid-scale production
	CdTe	8-10%	Middle-scale production
	$GaAs/GainP_2$	20% in lab	Small-scale production
	$InGaAs/CuInS_2$ $/CuInGaSe_2$	15% in lab	Small-scale production
Organic	Dye-sensitized	2-5%	R&D
	Organic	2-5%	R&D
	Hybrid	2-5%	R&D

Figure 3. States of efficiency and commercialization of various solar cell technologies.

modules are to provide chemical resistance, flexibility, availability and ease of process. The four key components that largely influence the functioning, longevity and efficiency of photovoltaic modules include encapsulants, frontsheets, backsheets and anti-reflection coatings (ARCs) for cover glass.

Encapsulants

Photovoltaic devices are encapsulated in polymeric materials for mechanical support and to prevent corrosion. The encapsulant represents one of the most important materials to module manufacturers for high-volume module sealing and integration. Selecting the right material not only increases the module production, but it can significantly prolong the power-generating efficiency and module durability. As the industry expands, it is critical to provide suitable materials solutions to meet the numerous requirements including performance, price, throughput and global availability.

> "The encapsulant represents one of the most important materials to module manufacturers for high-volume module sealing and integration."

The undisrupted performance necessary for photovoltaic modules to perform over a lifespan of 20–25 years requires every module component and the entire assembly to be long-lasting without substantial degradation. A testing procedure for 20–25 years is neither feasible nor economically viable when a period of 2–5 years is required for the development and launch of new encapsulation materials, processing methods, or both. As a result, artificial accelerated exposure (AET) testing plays an important role in addressing this challenge.

Typical polymers used in encapsulants are ethylene vinyl acetate (EVA), polyvinyl butyral (PVB), silicone, ionomers, polyethylene terephthalate (PET), polyolefins, thermoplastic polyurethane (TPU), polymethylmethacrylate (PMMA), and polycarbonate (PC). The market split of various polymers used in the manufacturing of encapsulants in 2009 is illustrated in Fig. 4. The 'others' group includes polymers such as TPU, PET, PMMA and PC.

Encapsulants for solar cells must have excellent adhesion to backsheet, cells and glass; high light transmission over the lifetime of the module; weatherability; good moisture barrier; high flexibility and fire resistance. Since the early 1980s, the encapsulant used in almost all PV modules has been made of EVA, representing

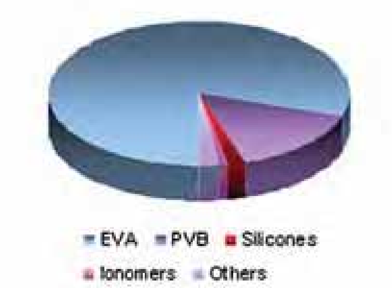


Figure 4. Market split of polymers in encapsulants.

the industry standard because of its transparency and refractive index, which reduces reflection. As EVA is not naturally UV stable, it has to be treated with various additives in order to make it suitable for photovoltaic applications.

Despite EVA's having both glass and melting phase transitions at temperatures experienced under environmental exposure, its low cost and good optical transmission made it the most preferred material for PV modules. These transitions, however, cause EVA to become brittle at low temperatures (approximately -15°C) and to be very soft at high temperatures (greater than 40°C). For modules to have a long lifespan, one would prefer a material that is relatively unchanged under a wide temperature range, as it would ultimately produce a more reliable system. These concerns are likely to become more important as silicon-based cells become thinner.

> "There have been more module failures in recent years due to the use of alternative materials with limited track records."

There have been more module failures in recent years due to the use of alternative materials with limited track records. TÜV Rheinland has been looking at the IEC standards and requirements for polymers in photovoltaics including delamination, electric arc damage and local heating spots. Laboratory tests have been developed ranging from UV preconditioning and thermal cycling to damp heat tests.

Various polymers have been developed for the marketplace. However, the lack of track record and higher costs has restricted their uptake. PVB is the preferred material for thin-film technology. In addition, when high aesthetic and high durability are required, silicone and ionomer encapsulants are the preferred choice. Silicone encapsulants are UV stable, durable, increase light transmission (and therefore efficiency), and the liquid process is less labour-intensive and more cost-effective.

Building-integrated photovoltaics (BIPV) offer great potential as innovative materials. PVB has been used for many years as an interlayer in automotive glazing and more recently in thin-film PV applications, and has great potential in the BIPV market.

The global market for encapsulants was valued at over US$2 billion in 2009, a figure that includes the laminates market for all applications such as automotive, construction, solar and others. While the solar market is currently the smallest, it exhibits the fastest growth. The global market for photovoltaic encapsulants

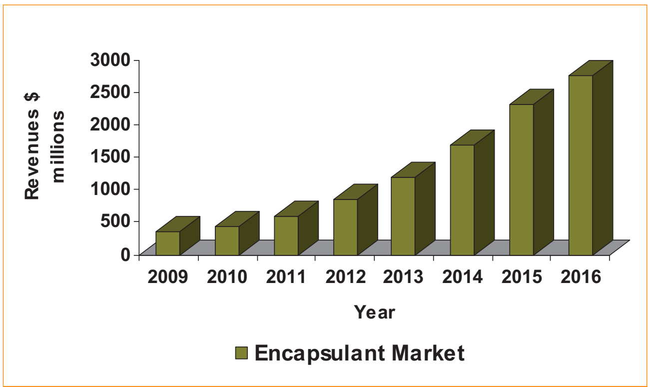


Figure 5. Revenue forecasts for PV encapsulants.

was valued at US$354.2 million in 2009 as illustrated in Fig. 5. The photovoltaic encapsulant market is mainly dominated by the EVA encapsulant that serves a larger end-user base in terms of MW value. As a result, the EVA market will continue to benefit from the increase in demand for photovoltaic energy.

Technology trends in the end-user market will directly influence the market for photovoltaic encapsulants. For instance, EVA that is preferred in the case of C-Si cells may be negatively affected if thin-film cells gain more importance. This trend can, however, positively affect the market for PVB that is traditionally preferred in thin-film cells.

Backsheets

Photovoltaic modules comprise a transparent protective superstrate and rear sheet called backsheet. In the case of crystalline silicon technology, the front panel and backsheet encapsulate solar cells and protect them from adverse weather conditions. In the case of thin-film technology, amorphous silica may be deposited on a rigid transparent layer, such as glass, and bonded to a backsheet with a transparent adhesive.

Photovoltaic backsheet materials protect photovoltaic modules from ultraviolet rays, moisture and adverse weather conditions, while also insulating the electrical load of modules. These functions are essential for the functionality and longevity of photovoltaic modules as well as the safety of people who work with and near these modules.

The backsheet comprises a laminated structure based on glass or a thermoplastic polymer, such as polyvinyl fluoride, ethylene vinyl acetate, polyvinylidene fluoride and other. The backsheet laminates are highly customizable. However, this laminated structure is not fully impervious to moisture. As a result, over time, the power output and/or useful life of photovoltaic modules made with this kind of backsheet material is reduced, due to electrical shorting resulting from absorbed moisture.

The prime requirement of a backsheet laminate is to have excellent adhesion with the encapsulant when the components are laminated together in a thermoforming process.

PET is the most preferred material with excellent water vapour resistance and relatively lower cost, but is vulnerable to degradation from exposure to environmental influences, such as UV radiation, IR radiation, and ozone. PET is mostly protected by the use of Tedlar polyvinyl fluoride (PVF) films, which are tough, photo-stable, chemically resistant and enduring against moisture exposure. They also adhere well to encapsulants and have good resistance to water vapour. As a result, the lamination of Tedlar film and PET provides an excellent backsheet material.

Polyvinylidene fluoride (PVDF) can also be used in place of PVF and is gaining more market share because of its relatively lower cost and good adhesion to PET in comparison to PVF. Other polymers used for this purpose include EVA and ethylene propylene diene monomer (EPDM); however, these polymers are rarely used because they lack some of the physical properties that are required in harsh environments.

These constructions can suffer from the drawback of poor adhesion of the PVF to PET. Backsheets formed from PVDF and

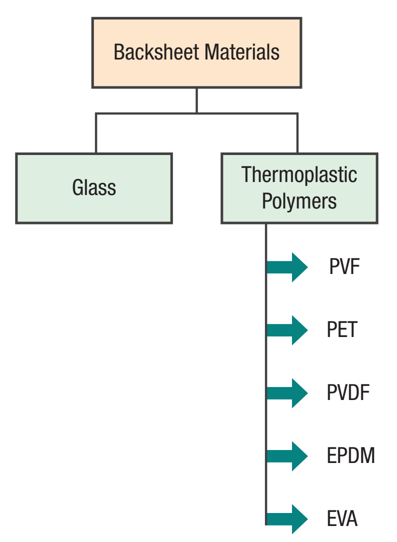


Figure 6. Types of backsheet materials.

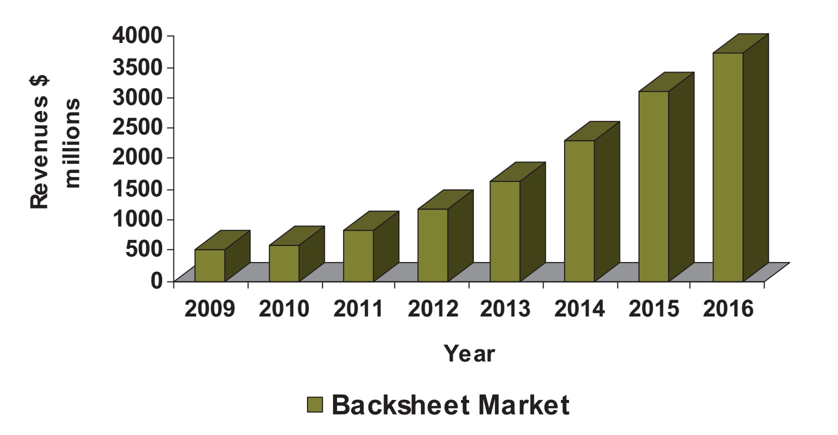


Figure 7. Revenue forecasts for PV backsheets.

PVF copolymers and PVF blends can take advantage of the properties of PVDF to overcome this issue of harsh environments.

The photovoltaic industry, which has been focusing on crystalline silicon solar cells, has recently experienced an increased interest in the field of thin-film cells. Therefore, glass, which is predominantly used as the backsheet material in thin films, is likely to witness a high growth rate in the future. While the market for glass as a backsheet material was valued at US$47.5 million in 2009, the global market for PV backsheets was valued at US$493.3 million in 2009 as illustrated in Fig. 7. This market size represents backsheets provided after laminating the individual polymer layer.

The PV industry is seeking non petroleum-based chemicals for use in photovoltaic modules. Resins from renewable sources have been developed over the past as substitutes for conventional resins due to the fluctuating prices and availability of petroleum feedstock and concerns for the environment. Some resins like polylactic acid (PLA) resins, which are produced from corn or other renewable feedstock, have been considered for use in backsheets. However, these resins from

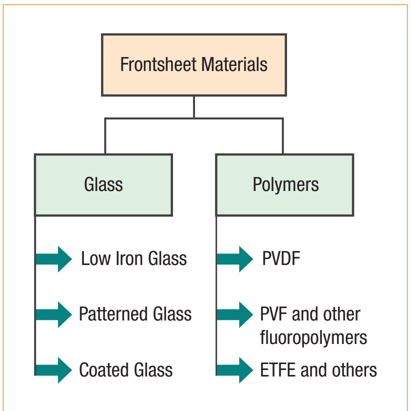


Figure 8. Types of PV frontsheet materials.

renewable or sustainable resources have not been previously considered for such applications, either because of relatively poor material properties or processing challenges. Nevertheless, there is a need to provide a useful laminate film for use as a photovoltaic module backsheet from a renewable or sustainable source.

Frontsheet

The primary role of a frontsheet in PV modules is to ensure their structural stability. In addition, frontsheets are designed to facilitate the lamination process (adhesion of encapsulant on frontsheet), maximum transmission of light into the module as well as to improve the aesthetic parameters of a module. Recent growth in the solar market has created a good demand for frontsheet materials. While an array of materials is used in solar module manufacturing (see Fig. 8), certain end-user groups prefer specific types of frontsheet materials. The main criteria include cost and efficiency, which are directly related to the spectrum of light transmitted.

Glass is the most commonly used frontsheet material, and several types of glass are used for this purpose. With changes in solar technology and a growing demand for flexible photovoltaics, the need has arisen for non-glass materials, such as polymers. Fluoropolymers and ethylene tetrafluoroethylene (ETFE) cater for the need for flexible photovoltaic modules.

Tempered glass is the basic glass type used in the solar market. Tempering involves toughening the glass in order to provide maximum strength and stability to the solar module, with the resulting glass used in most module types (with the exception of a-Si because of the high temperatures involved during the deposition process).

Patterned glass currently accounts for the highest revenue share in the photovoltaic frontsheets market as it presents the best mix of key functionalities. Some of its key advantages are durability, transmission capabilities and cost. Patterned glass is an extension of low-iron glass that is used in solar applications offers, besides functionality, aesthetic appeal. This factor has gained the material more importance in recent years.

"In 2009, the market for frontsheet materials used in the photovoltaic industry was valued at US$426.7 million."

The favourable cost of low-iron glass allows it to be used largely in applications that involve low investment. Coated glass, which is sold at a premium, currently has the highest transmission rating and looks set to be a significant product in the future.

Polymers such as ETFE and PVDF are mainly used in improving efficiency and offering structural integrity to thin-film cells. At present, they are not commonly used, unless the photovoltaic module has to be made flexible in nature.

In 2009, the market for frontsheet materials used in the photovoltaic industry was valued at US$426.7 million (see Fig. 9), with glass representing by far the largest market segment. Among the various glass types, patterned glass will continue to dominate the market, as it offers an ideal mix of cost, performance and aesthetics.

Changing end-user requirements need to be addressed through improvements in technology. End users demand a product with improved efficiency and reduced cost per Watt. Various technologies such as low-iron coated glass (anti-reflection coating (ARC) for c-Si and transparent conductive oxide (TCO) for thin films) are being evaluated to facilitate these improvements.

Moreover, in the thin-film segment, the need for portable/flexible PV modules has resulted in an increasing demand for fluoropolymers. As transparency affects transmission, companies have developed an efficient fluoropolymer (mainly PVF/PVDF) that can match the efficiency and lifetime of glass frontsheets. However, the

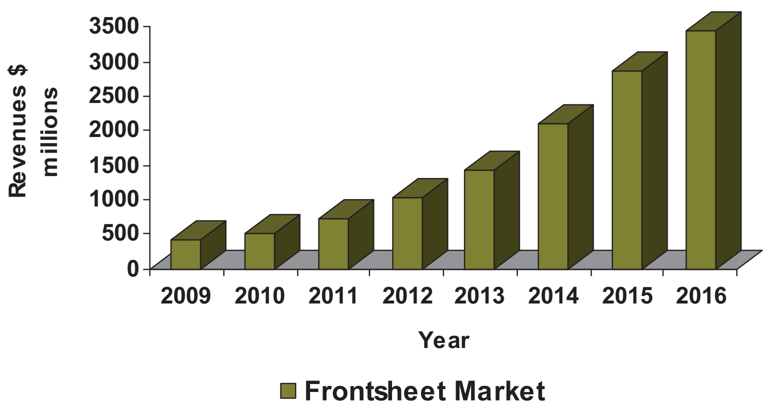


Figure 9. Revenue forecasts for PV frontsheets.

market for value-added glass is poised to dominate the photovoltaic frontsheets market in the next 10 years.

Anti-reflection coatings for cover glass

ARCs are used on the surface of glass and other optical devices to reduce reflection. These coatings are predominantly used to improve the efficiency of the system by reducing the amount of light lost due to reflection.

Conversion efficiency of a PV module is the measure of the amount of sunlight converted into electrical energy. Typically, front glass cover reflects some of the sunlight before it reaches the solar cell, thereby reducing the photovoltaic

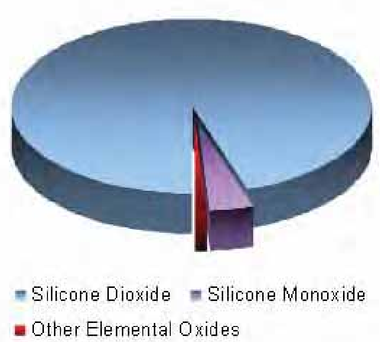


Figure 10. Market split of anti-reflective coatings.

module's conversion efficiency. On a daily basis, between 4% and 15% of sunlight is lost due to reflection from the cover glass, resulting in a reduced conversion efficiency of the module. To increase the transmission at cover glass, an anti-reflection coating is applied, which increases the amount of sunlight absorbed by the cells as well as the power generated by the module. Commercially-available photovoltaic modules convert 12–20% of the absorbed sunlight into electricity; using an anti-reflection coating can increase the efficiency of PV modules by 0.4–0.7%.

The application of ARCs over cover glass is a relatively new concept, and its success will largely depend on the efficiency gained. The changing dynamics in the energy market will play a major role in determining the extent and pace of developments related to ARCs.

Considering the cost component, glass manufacturers have already started producing ARCs in order to accelerate development in this area and manufacture new products. The market for ARC is dominated by silicone dioxide, as shown in Fig. 10.

The market for ARC is segmented into merchant markets, comprising those companies that supply ARC to module manufacturers and cover glass manufacturers as a value addition, and the captive market, namely, glass companies that have in-house manufacturing capabilities to produce ARC and use it in their products.

The market for the ARC merchant market sector was valued at US$12.6 million in 2009, which presents a huge potential for market penetration in frontsheets by 2016.

Conclusion

The photovoltaic sector witnessed a temporary slow-down during the global financial crisis. The deceleration in the demand for photovoltaic energy made material suppliers wary of increasing their manufacturing capacities. However, the future of the photovoltaic industry is very promising. Innovation in photovoltaic materials will continue to drive the market as improvements made in the efficiency of photovoltaic modules must involve direct improvement of the efficiency of materials used. Material suppliers understand this requirement, and are continuously pursuing innovation in order to remain competitive. The future lies in new technologies that offer energy-efficient solutions at a low cost.

About the Authors

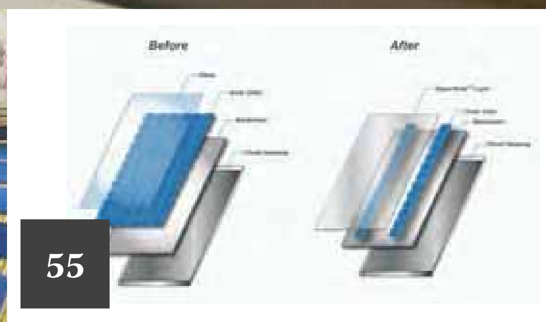
Dr. Leonidas Dokos is global programme manager in the Chemicals, Materials and Food practice at Frost & Sullivan. Leonidas has over 10 years' experience as a research fellow and an industry analyst of the materials sectors. His present focus lies on chemicals and materials used in construction and utilities, especially in renewable energy applications and green buildings.

Gaurav Vyas is research analyst in the Chemicals, Materials and Food practice at Frost & Sullivan. He holds an engineering degree in polymer science & chemical technology with a post-graduate qualification in business economics.

Enquiries

Tel: +44 (0) 1865398685
Email: leonidas.dokos@frost.com

Cell Processing



News

Yingli Green expects Panda module sales to reach 1GW in 2011

One of the key low-cost PV module manufacturers, Yingli Green is also fast becoming one of the largest suppliers of high-efficiency modules. According to Liansheng Miao, chairman and CEO of Yingli, Green Energy, its Panda cell technology is in such strong demand that the company has already entered into supply agreements totalling 721MW for 2011 and expects that figure to rise to 1GW by the end of next year.

At 18.5% cell efficiencies in volume production, Yingli Green expects efficiencies to reach 20% in 2012. Verified by the Fraunhofer Institute for Solar Energy Systems (ISE) in Germany, Yingli Green has already produced Panda cells on its pilot lines of 19.5%.

The company is currently adding 700MW of new capacity, which is expected to come on stream in the middle of 2011, which would take Yingli's nameplate capacity to 1.7GW in late 2011. This suggests that its Panda cell technology would equate to well over half its production capacity by year-end.

Miao also noted that due to continued strong demand, Yingli Green has raised its PV module shipment target to the estimated range of 1,020MW to 1,040MW. Previously, the company had guided shipments of between 950MW and 1GW for fiscal year 2010.

This means that shipments are expected to have increased 94.2% to 98.0% compared to 2009. The company guided net revenue for 2010 to be in the range of US$1.78 billion to US$1.81 billion, having reached sales of US$490.9 million in the third quarter, a 25.2% quarter-over-quarter increase. Gross profit in the third quarter was US$163.6 million, an increase of 20.9% from the second quarter. Gross margin was reported at 33.3%, compared to 33.5% in the second quarter.

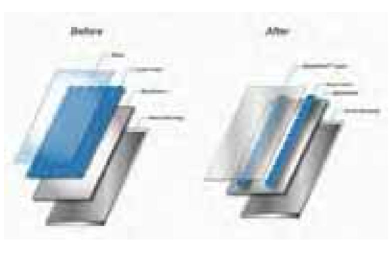
Yingli Green Panda module.

News

R&D News Focus

HyperSolar claims 'breakthrough technology' to increase solar cell power output

HyperSolar's development team has found that new design models are showing potential magnification of 300%. Using a thin and flat light magnification layer, thousands of small light collectors take the light into a light routing network, which then transmits the light to a smaller output area on the bottom where a solar cell can be attached. HyperSolar said that only one solar cell is needed under a 300% HyperSolar layer.



HyperSolar cell production diagram.

Source: HyperSolar

DEK Solar presents latest advances in PoP technology to ECN delegates

DEK Solar's senior process development specialist, Tom Falcon, presented a paper on the latest advances in print-on-print (PoP) technology to assembled delegates at a metallization workshop organized by the Energy research Centre of the Netherlands (ECN). Falcon outlined the findings of a major research project conducted by DEK, along with associated opportunities for solar cell metallization.

The paper describes the development of a PoP process for high aspect ratio front-side conductors, with in-depth results spanning the testing of various screen types, aperture widths, emulsion thickness, paste types and process parameters to empirically determine optimization. Among the conclusions reached was the fact that paste choice is critical to maximize performance and that quality screens are essential for alignment. Finer meshes and moderate emulsion are identified as delivering optimal prints while screen life is proven to stand at around 7.5K wafers. DEK Solar also found that an approximate increase of 40% in conductor aspect ratio is possible and sustainable in high volumes over a single print.

imec presents large-area silicon solar cells with conversion efficiency above 19%

imec has revealed several large-area silicon solar cells with conversion efficiency above 19%. The two main types of cells exhibited comprise Ag-screen-printed contacts which were up to 19.1% and plated Cu-contacts which obtained 19.4%. The results were achieved on large-area cells (148cm^2) with 170µm thickness, demonstrating the industrial viability of the process.

"The fact that such efficiencies can be obtained by metallization schemes based on screen-printed Ag contacts enables compatibility with present industrial metallization practice in the solar cell industry. The Cu-based front-side metallization is a step towards higher sustainability and lower cost, substituting Ag with Cu in future industrial production of crystalline silicon solar cells," said Dr. Joachim John, team manager of industrial solar cells at imec. "These exciting results were obtained in the new solar cell process facilities recently set up in imec."

"High efficiency, low cost, and sustainability are the main drivers in imec's research on crystalline silicon solar cells, eventually targeting cells that are only 40µm thick with efficiencies above 20%. We expect further improvements towards efficiencies of up to 20% for large-area silicon solar cells. This achievement is a major step forward towards industrial manufacturing of sustainable, low-cost, thin silicon solar cells with high efficiency," said Dr. Jef Poortmans, director of imec energy and solar program.

The results were achieved within imec's silicon solar cell industrial affiliation program (IIAP), a multi-partner R&D program that explores and develops advanced process technologies alongside reduced silicon usage, whilst increasing cell efficiency and further lowering the cost per watt peak. imec's record efficiency silicon solar cells feature rear-side passivation, laser ablation and, local aluminium back-side field and screen-printed contacts or Cu-plated contacts on advanced emitter schemes.

Arise looks at expanding its production lines; investigates commercialization of silicon technology

Arise Technologies signed a non-binding letter of intent (LOI) with an undisclosed turnkey supplier for the purchase of two 60MW PV cell production lines, which will be added to its German plant. The LOI gives Arise four weeks to complete the definitive purchase agreement and acquire the required debt, equity and government funding necessary to buy the new production lines.

Once the two new production lines are installed, Arise will have an annual capacity at its Bischofswerda plant of 205MW with customer shipments from the third and fourth lines beginning in the second and fourth quarter of 2011, respectively.

Additionally, Arise has begun advanced discussions with a private European-based alternative energy company for a purported arrangement to commercialize Arise's 7N+ silicon SiRF technology. Executives at both companies have come to the decision to continue with the final technology sign-off and the business terms of the commercialization arrangement.

The agreement has a proposed use of both cash and right-to-use components. Arise anticipates the deal to be completed by the end of the year once final technology evaluations conclude.

Cell Production News

Motech surpasses 1GW capacity in October

Motech Industries' consolidated solar cell shipments reached 102MW at the end of October 2010. This figure was accomplished after achieving 1.15GW capacity through Q3'10. This places Motech as the first Taiwan-based solar cell manufacturer to have reached over 1GW capacity and to have shipped over 100MW in a single month.

Hareon Solar optimizes solar cell production with Applied's manufacturing automation software

Hareon Solar has selected Applied Materials' SmartFactory manufacturing automation software with the aim of improving productivity across Hareon's solar photovoltaic cell manufacturing operations in China. The company will install Applied's software at its cell subsidiaries Jiangyin Hareon Solar Technology and Altusvia Energy.

LDK Solar completes first production line of solar cells at Xinyu City facility

LDK Solar has successfully completed the installation and trial runs of the first production line of solar cells in its newly installed manufacturing facility in Xinyu City. The solar cell manufacturing line has a present annualized capacity of 60MW; however this figure is expected to reach 120MW by the end of the third quarter of 2010.

LDK Solar cell production line.

Source: LDK Solar

News

Source: SunPower Corporation.

SunPower's Fab 3 facility in Malaysia.

AUO and SunPower's Fab 3 kick-starts solar cell production with 22.2% efficiencies

In a bid to expand capacity and become cost competitive with their rivals, AUO and SunPower's Fab 3 facility in Malaysia has fabricated its first 100 solar cells, yielding a minimum conversion efficiency of 22.2%. Due to the successful initial run, the partners expect commercial production to ramp up later this year. Construction and manufacturing ramp at Fab 3 was reiterated is still expected to continue through 2013.

Business News

Solargiga begins purchase agreement for Sino Light Investments

Solargiga Energy Holdings has begun the process for acquiring Sino Light Investments by entering into a sales and purchase agreement with the company. Solargiga has conditionally agreed to buy 100% of Sino Light's issued shares at a consideration of HK$835,200,000. This total amount will be completed in full once convertible bonds, at a conversion price of HK$1.92 per conversion share, are completed and will total 435,000,000 conversion shares issued.

Solargiga has decided to pursue the issuance of convertible bonds for consideration of the purchase as it will not significantly demand withdrawing from the company's cash resources. The final approval for the issue of the consideration shares lies with the shareholders who will make their decision during Solargiga's extraordinary general meeting.

Sino Light possesses all the issued share capital of Jinzhou Huachang Photovoltaic Technology, which manufactures silicon solar cells. Its current annual production capacity lies at 100MW, but after a planned expansion is completed by the end of this year, production capacity should be raised to 200MW.

1366 brings in US$20 million during Series B financing round

1366 Technologies has closed its Series B financing round securing US$20 million, bringing the grand total raised by the company to US$37.55 million. Returning investors North Bridge Venture Partners and Polaris Venture Partners were joined by Ventizz Capital Fund and Hanwha Chemical, who will also become a 1366 direct wafer customer for the round. 1366 advised that with the close of the financing round, it plans to take its direct wafer technology into production.

DOE awards US$57 million in new small business grants; three solar PV companies get US$4.6M

The U.S. Department of Energy (DOE) has announced US$57 million in new grants to support small business technology commercialization projects in the clean energy sector, as part of DOE's Small Business Phase III Xlerator program. Among the 33 renewable energy, advanced vehicle, efficiency, smart grid, clean fuel, and other companies receiving awards are a trio of firms working to advance solar PV technology and manufacturing – Applied Nanotech, Microlink, and Ultrasonic Technologies – that garnered a total of US$4.6 million in DOE grants.

These Phase III Xlerator awards, all given to small businesses in partnership with universities, national labs, and large businesses, are a first for DOE and build on its existing efforts under the Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) programs.

Previously, the SBIR and STTR programs through the DOE have only been funded through Phase II. Companies that had previously received DOE SBIR or STTR funding were eligible to apply for the Phase III grants.

The awards range from US$500,000 to US$3 million and will provide small innovative companies with the "staying power" they need to develop the processes that are necessary to reduce the manufacturing costs for their products and enable manufacturing at scale, according to DOE.

Solarfun signs three-year licensing deal with Innovalight for nanosilicon ink solar cell process

Solarfun has joined JA Solar and Yingli Solar to become the third Chinese crystalline-silicon PV cell manufacturer to sign a licensing agreement with Innovalight for the Sunnyvale, CA-based company's proprietary performance-enhancing nanosilicon ink process. Financial terms of the three-year commercial deal were not disclosed.

Solarfun has said it plans to convert its cell manufacturing capacity to higher efficiency products through the introduction of selective emitter technology. The company will license a solar cell process and buy silicon ink from Innovalight for the production of high-efficiency cells on monocrystalline silicon substrates.

Neo Solar signs seven-year polysilicon supply contract with Hankook

Neo Solar Power has signed a polysilicon supply contract with Hankook Silicon, which will provide them with 11,600 tonnes of polysilicon between 2011 and 2017. The agreement not only provides Neo Solar Power with a stable long-term polysilicon supply but also reinforces the strategic alliance between the two companies.

Neo Solar Power's 2011 orders exceeded its capacity and agreements with Hankook and other suppliers will help to stabilize its silicon supply and also meet the increasing demand from its customers.

Turnkey project delays and cancellation hit Roth & Rau

In releasing preliminary nine-month financial figures, PV equipment supplier

Roth & Rau saw sales and profits impacted by several delays in turnkey projects and a probable cancellation of turnkey projects in India, which were not detailed in a statement. Roth & Rau said that it would probably achieve total revenue of €189.2 million for the period, compared to €159.5 million in the same period a year ago. Earnings before interest and taxes (EBIT) are expected to be only €3.0 million, compared with €13.1 million in the previous year.

Roth & Rau stated that the turnkey project delays related to two customers in Spain, without giving further details. However, revenue guidance for the year was said to be unchanged at approximately €285 million.

News

Source: Roth & Rau

Roth & Rau's solar cell manufacturing facility.

Cell Processing Order Focus

JA Solar supply agreements top 1.2GW in 2011

New supply agreements with multiple customers have pushed JA Solar's 2011 delivery commitments past 1.2GW. The cell and module manufacturer said it had secured an additional 600MW of new product orders, all with delivery dates in 2011, and had received prepayments associated with these customer orders.

Singulus supplies cell manufacturer with Linea texturing, inline coating machine

Stangl, the subsidiary of Singulus, has delivered one of its Linea texturing and inline coating machines to an unnamed European solar cell manufacturer. This order marks Singulus' first installation of a front-end system, with the combination of phosphor cleaning and anti-reflective coating.

This installation and commissioning of a combined Singulus and Stangl production machine for silicon solar cells is an important integration step for the automation and cost reduction of modern cell manufacturing.

Tempress Systems receives US$20 million in new orders

Amtech Systems' solar subsidiary, Tempress Systems, has received US$20 million in new solar orders for its diffusing processing system. The orders stem from two new customers along with several existing customers and brings its third-quarter 2010 results to US$35 million and 2010 fiscal year total to US$118 million.

BP Solar starts using solar cells from JA Solar

BP Solar has further solidified its outsourced manufacturing strategy by awarding JA Solar a monocrystalline and multicrystalline cell supply contract exceeding 185MW. The new supply deal will see 100MW of cells shipped to BP beginning in the first quarter of 2011. JA Solar noted that a separate agreement, made earlier this year with BP Solar, was worth than 85MW. The majority of cells have already been delivered, with the remainder to be shipped through the fourth quarter of 2010.

Peng Fang, CEO of JA Solar, has said he expects JA Solar to ship approximately 1.35GW of cells in 2010 and could not meet expected demand. The company is also rapidly ramping its latest next-generation cell technology, Secium, with average conversion efficiencies of 18.5% using selective-emitter technology.

Intevac to deliver Lean Solar deposition system for new customer

Intevac has received an order for a Lean Solar deposition system for shipment in the first quarter of 2011. Kevin Fairbairn, president and chief executive officer of Intevac, said, "Our Lean Solar thin-film deposition system is capable of depositing both metal and transparent conductive oxide films, enabling high cell efficiencies and low costs per watt."

Tempress gains US$33 million in diffusion equipment orders

Tempress Systems, a solar subsidiary of Amtech Systems, has obtained US$33 million in new solar orders from numerous Asian customers. The customers, both new and existing for the company, ordered Tempress's diffusion processing systems this October.

BTU collects US$16 million order for solar cell processing equipment

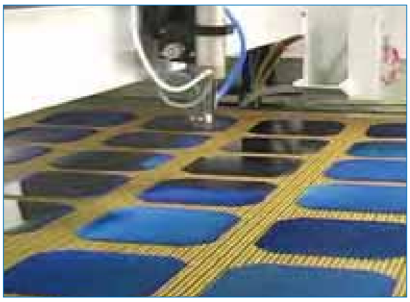
BTU has recently received a US$16 million order for solar cell processing equipment. BTU offers processing equipment for both silicon and thin-film PV applications. Recognition of this new revenue will be started in the fourth quarter of 2010 and continue through the first half of 2011.

centrotherm photovoltaics receives first upgrade order from Taiwanese customer

Through centrotherm photovoltaics' research and development strategy, three turnkey crystalline-silicon solar cell production lines owned by an unnamed Taiwanese customer are being retrofitted with a selective-emitter technology upgrade package.

Product Briefings

Ultrasonic Systems, Inc.



PV360 from Ultrasonic Systems offers highly uniform and thinner cell coating deposition

Product Briefing Outline: Ultrasonic Systems, Inc. (USI) has released its third-generation PV360 for PV wafer coating applications. The PV360 uses nozzle-less ultrasonic technology for highly uniform, thinner coating deposition of solar cells when compared to conventional spray technologies. Optimized for high-volume in-line manufacturing, the system can process up to 4,300 wafers (125mm-sized wafers) per hour.

Problem: For most photovoltaic manufacturing processes, the amount of dopant applied to a silicon wafer is in the range of 0.0002 to 0.002ml/cm^2 of liquid. This translates to a wet film thickness in the range of 2 to 8µm, which is very challenging considering that surface roughness is about 5µm for many photovoltaic wafers.

Solution: The PV360 delivers liquid coating with transfer efficiency of 95–99%, utilizing a traversing 'Ultra-Spray' blade head for greater control of film thickness down to the sub-micron level. Plus, it offers the versatility to handle the transfer of phosphoric/boric acid and phosphoric oxide dopants, as well as other proprietary coatings. The PV360 also features a wafer dryer system, dual metering pump liquid delivery system, and state-of-the-art control system with touch-panel interface.

Applications: Precision coating of various dopants such as phosphoric/boric acid and phosphoric oxide for crystalline solar cells, including laser-doped selective emitter processes.

Platform: The system can be operated in-line or as a standalone process. The conveyor width is 914mm and can accommodate up to six rows of 125mm wafers.

Availability: Currently available.

InnoLas

InnoLas's ILS TT laser processing system offers versatile c-Si volume production applications

Product Briefing Outline: The InnoLas ILS TT laser processing system is designed to execute a variety of laser processing techniques such as selective emitter, contact opening, junction isolation, LFC, EWT and MWT to achieve improved cell efficiencies. Designed for production-scale manufacturing as well as pilot line research and development, the system is equipped with a high-speed turntable and custom tooling to fit specific processing steps.

Problem: The production of premium crystalline silicon solar cells is facing several challenges: new techniques, to increase the efficiency and performance of photovoltaic solar cells, have to be developed and transferred into industrial mass production while also minimizing processing time.

Solution: The InnoLas ILS TT laser system makes state-of-the-art laser processing technologies available to large-scale production. A highly flexible machine tool, it meets the high production demands of the PV industry with respect to throughput, accuracy, productivity and reliability. All machine concepts can be used in pilot or mass production environments, allowing a direct progression from development and process optimization into new or existing production lines.

Applications: High-speed laser processing of mono- and multicrystalline silicon solar cells.

Platform: The system offers the ability to integrate two laser sources in the same system for processing two individual cells simultaneously or to allow subsequent processing with different laser sources or wavelengths if two different laser sources are selected. This allows maximum flexibility and high throughput depending on the application (up to 3600 cells per hour maximum).

Availability: Currently available.

Montech

Montech offers conveyor system for breakage free loading and unloading of wafer carriers

Product Briefing Outline: Montech has developed a conveyor system for loading and unloading of wafer carriers that ensures soft and easy handling. A key feature is that the unloading conveyor is made up of just a pair of belts and a drive, thus offering a cost-effective and efficient solution for loading and unloading.

Problem: The use of thinner wafers to reduce the cost per watt requires better wafer handling techniques and a complete elimination of manual handling to limit wafer breakage. Compared to conventional carrier loading and unloading solutions based on handling components, wafers are carried more accurately and softly with an unloading conveyor.

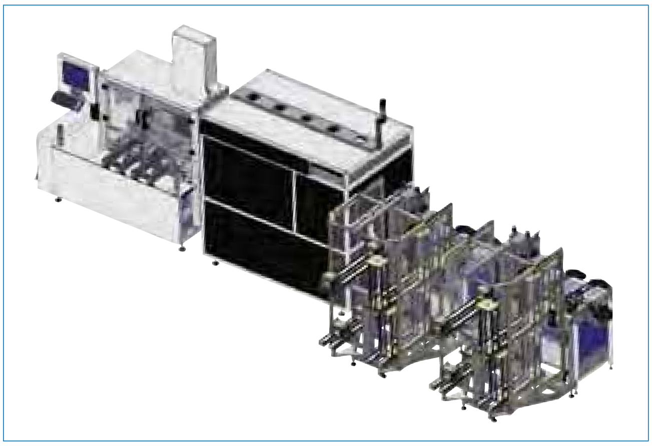
Solution: The belt conveyor's modular concept allows it to be tailored to the specific needs of each user in terms of length and width. The distance between the wafers in the carrier is leveraged optimally, as the idle roller diameter in the sliding section is just 8mm. The unloading conveyor is a double-belt system including a fixed section and a sliding section with 160mm stroke. This sliding section is driven into the carrier by a pneumatic cylinder.

Applications: Loading and unloading of wafer carriers.

Platform: In its standard configuration, the unloading conveyor is available in 125 × 125mm and 156 × 156mm versions. The drive unit can be placed in the middle, on the right or left as needed. The drive roller has a diameter of 30mm; the sliding section has a total thickness of 9.6mm and a total width of 100mm.

Availability: Currently available.

Hennecke Systems



Hennecke's wafer inspection tool offers improved quality control and reduced cell production costs

Product Briefing Outline: Hennecke Systems, a subsidiary of the Meyer Burger Technology Group, has launched specialized measuring tools for wafer inspection. The 'Module HE-WI-04' measures mono- and multicrystalline wafers using only non-contact measurement methods. Transport is done at a constant speed to minimize the stress on the wafer. The specialized system comes with a loading device that un-stacks wafers softly with a speed of one wafer per second and transports them into the measuring unit.

Problem: Improving wafer inspection for incoming wafers into the cell line could reduce production costs and downtime if wafers are initially inspected for a wide range of faults and quality issues before processing begins. Correct handling and high throughput also eliminates unnecessary wafer breakage.

Solution: The measuring unit in its standard configuration inspects the wafers for their thickness, TTV, resistivity and lifetime as well as micro cracks. The accurate inspection of each wafer is claimed to help to save up to €400,000 per year, mainly because collateral damages caused by broken wafers are minimized. As an option, the new system can be extended with proven and tested measuring modules for saw marks, stain, edge defects, geometrical properties, bending and grain size. The system is also capable of processing slurry and diamond wire sliced wafers. After quality control, the wafers can be sorted according to predefined criteria into carriers or polystyrene boxes, which ensures that a cell producer only processes A-quality wafers, and yield and uptime of the production are optimized.

Applications: Measures mono- and multicrystalline wafers from 125mm × 125mm up to 210mm × 210mm (rectangular or pseudo-square).

Platform: Hennecke Systems uses an infrared-based technology to detect microcracks and SiC inclusions. A tailor-made illumination can be used to detect stains on polycrystalline wafer surfaces for 100% quality control. Top and bottom surface are inspected for higher cell efficiency. The system is capable of a throughput of 3,600 (156-size) wafers per hour.

Availability: Currently available.

Op-tection

OSIS Sorter EL-1800 system from Op-tection offers high throughput

Product Briefing Outline: Op-tection has developed a brand new solar cell sorter to meet the demand for increasing cell sorting needs in terms of speed and automation. The OSIS Sorter EL-1800 system inspects and sorts solar cells automatically based on user-defined quality parameters.

Problem: The performance of any solar module is dependent on the weakest cell in the assembly. Wet-chemical processing, coating, and screen printing can cause strong tension, resulting in silicon bulk defects that are not visible on the outside of the cell. Even if the I-V test shows the efficiency is high enough, microcracks, shunts and edge isolation imperfections have long-term effects and can cause a dead cell in modules over time.

Solution: The OSIS Sorter EL-1800 system inspects and sorts solar up to 1800 cells per hour. The operator loads the cells into the system using four input boxes containing up to 150 cells each. The cells are fed into the system automatically and placed on conveyor belts, which transport the cells within the sorting system. The solar cells move through an inspection station, which spots defects using electroluminescence and AOI and flash-testing (optional). After inspection, the cells are sorted by quality into five different sorting boxes. The recorded EL images are analyzed using software and defects are classified and marked, after which the cell gets a quality grade that is based on user-definable criteria.

Applications: Solar cell sorter for inline inspection.

Platform: The sorter can be equipped with many of the OSIS systems for wafer and cell inspection that are also available for inline inspection. When configured as cell sorter, electrical performance can also be tested with an optional I-V tester

Availability: Currently available.

Rehm Thermal Systems

Rehm's Solardryer offers advanced thermal control and high throughput

Product Briefing Outline: Rehm Thermal Systems has introduced an advanced new series of drying systems, the Solardryer RDS 2100 and RDS 3000, for solar cell metallization processes. These systems are said to offer a range of advanced process features and thermal control that give PV manufacturers higher efficiency and yield.

Problem: Increased productivity and low energy consumption within smaller footprints are necessary for inline c-Si solar cell equipment to meet the lowest cost of ownership as a part of cost-per-watt reduction strategies. Improved thermal control can also lead to improved cell efficiencies and higher yields.

Solution: The Solardryer RDS 2100 and RDS 3000 drying process consists of a combination of five IR zones and one central convection zone, offering temperature profiling that can be adjusted for both precision and flexibility. These horizontal throughput systems guarantee a safe transport through the oven either via mesh belt or with pin chain of up to three lanes. In the mesh belt systems, the conveyor of the heating zone can be separated from that of the cooling zone. Consequently, no latent heat is carried into the cooling area, which offers a higher cooling gradient and a shorter oven. At belt speeds of up to 6m per minute, the RDS Series provides high throughputs of up to 5700 wph.

Applications: Solar cell metallization processes.

Platform: The new systems are also available with Rehm's Condensate Residue Management System, which controls the buildup of unwanted paste solvent and vehicle residue in the process chamber and extends the maintenance intervals. The oven opens from the front and comprises removable sheets that can be easily removed for cleaning.

Availability: Currently available.

Trumpf

Trumpf's new laser markers offer shorter marking times

Product Briefing Outline: Trumpf has introduced two new marking lasers – the TruMark 6030 and TruMark 6140 – to its TruMark Series 6000. Users can now choose from six high-performance machines that are available in any wavelength needed for surface processing. All TruMark Series 6000 lasers have short processing times and high marking precision.

Problem: Faster processing times are required to meet high-volume manufacturing requirements. Faster cycle-times for all process steps are required to reduce bottlenecks, one of which is the laser-marking step.

Solution: The lasers enable users to perform any marking process quickly and with a high level of quality, including tempering, engraving, depositing, colour change and foaming. The TruMark 6030 and 6140 lasers feature considerably shorter marking times when compared to other products in the TruMark Series 6000. Trumpf has increased the output of these new marking lasers by about 35%, and cycle times have been shortened accordingly. A comparison of the new TruMark 6140 with the TruMark 6130 illustrates this increased productivity. Using the same laser parameters, the same frequency and the same speed, the TruMark 6140 achieves twice the engraving depth.

Applications: Laser marking of solar cells.

Platform: The TruMark 6030 works in the infrared range of 1064nm. Its Nd:YAG laser crystal is designed for marking in the lower frequencies up to 60kHz. Users can achieve good marking results with the TruMark 6140 and its Nd:YVO4 laser crystal in the infrared range of 1064nm at frequencies starting at 40kHz.

Availability: Currently available.

Fabrication of single diffusion step selective-emitter solar cells

Ching-Hsi Lin[1], **Chien-Hua Lung**[1], **Yang-Fang Chen**[2,3], **Yu-Wei Tai**[2] and **Wei-Chih Hsu**[1],
[1]ITRI/Green Energy & Environment Research Labs, Hsinchu, Taiwan
[2]Neo Solar Power Corporation, Hsinchu, Taiwan
[3]National Taiwan University/Department of Physics, Taipei, Taiwan

ABSTRACT

A selective emitter is a doping layer that is heavily doped beneath the electrode and lightly doped in between the electrode grids. One of the disadvantages of conventional selective-emitter techniques is the need for a high phosphorus surface concentration to obtain low contact resistance and limit the shunts in the emitter. Effective emitter passivation below the contact is difficult because of the use of emitters with low sheet resistances and high doping concentrations. In this study, the selective emitter in the optimized light/light sheet-resistance combination was formed to reduce recombination under the metal contact. The fabrication of optimized light/light doped emitters was performed using a single-step diffusion process. Besides the benefit of low surface recombination for light/light combination, this approach also removes the need for a very precise alignment between the opened emitter pattern and the front screen-printed silver fingers. This work illustrates the achievement of an efficiency improvement of more than 0.4% absolute in large-scale production for selective emitter solar cells.

Introduction

Energy production using solar cells is a promising market. It is anticipated that crystalline silicon solar cells will contribute to the widespread adoption of photovoltaic applications as the primary photovoltaic technology. As research is conducted worldwide in the search for methods of improving cell efficiencies and/or reducing costs, the next few decades should see the industry become cost competitive with its fossil fuel counterpart in many parts of the world.

Further expansion of the solar cell industry will require significant cost reduction. The cost of the solar cell can be reduced by either lowering the processing fee or by further enhancing the cells' conversion efficiency while controlling expenditure. The manufacture of industrial solar cells demands the development of new solar cell structures in order to reach higher efficiencies. Successful implementation of new technologies into the cell manufacturing industry will require a keen eye on the costs involved in incorporating these techniques. This study succeeded in developing a cost-effective selective-emitter technique through a single diffusion step.

> "The manufacture of industrial solar cells demands the development of new solar cell structures in order to reach higher efficiencies."

A conventional commercial solar cell has a homogeneous emitter, which is usually formed by $POCl_3$ diffusion. An optimal emitter should have a high lateral conductivity and a low contact resistance which implies a high doping level. This, however, can induce severe Auger recombination and thus result in poorer spectral response. To achieve a high conversion efficiency, a compromise must be reached in the doping step. The other possibility is the concept of the selective emitter. A selective emitter is a doping layer that is heavily doped underneath the electrode and lightly doped between the electrode grids. Therefore, the illuminated areas are covered by a lowly-doped emitter layer. The advantages of a selective-emitter solar cell include a better short-wavelength response due to the low surface doping concentration, and a low contact resistance due to the heavy doping underneath the metal grid.

Selective emitter methodologies are of interest from the point of view of research, and tend to attract much attention throughout the photovoltaic industry. Various methods of formation of a selective-emitter on standard crystalline silicon solar cells have been developed [1-11]. Selective-emitter solar cells are usually fabricated via diffusion masking and subsequent pattern opening. There are several methods of opening the diffusion mask by use of laser ablation and application of etching paste. Ordinarily, this approach requires additional process steps compared to standard solar cell processes.

To successfully incorporate the selective-emitter technique into production, one of the requirements is that the efficiency of a selective emitter should be increased significantly compared to those conventional solar cells with uniformly-doped emitters. However, well-developed Ag pastes may limit the demand of selective-emitter techniques. The rapid developments of commercial front-side Ag pastes, which are suitable for high sheet-resistance silicon, make uniform lightly-doped solar cells possible. It is therefore necessary to develop a simple way of enhancing the efficiency at a low cost. In this study, we obtain low cost selective-emitter silicon solar cells through applying an optimized single diffusion step.

In conventional emitter cell constructs, a highly-doped emitter is present under the finger contacts, which makes effective emitter passivation below the contact quite difficult. A compromise must be arrived at between low recombination and low contact resistance. To reduce recombination under the metal contact, we implemented an effective light doping zone in the finger region. In addition, this paper explores the influences of various heavy/light doping combinations on the performance of multicrystalline silicon (mc-Si) selective-emitter solar cells. In comparison to mc-Si solar cells with a uniformly-doped 70Ω/sq emitter, an efficiency improvement of more than 0.4% absolute is achieved for selective-emitter solar cells. The selective-emitter structure was performed using a single diffusion step. Phosphorus was diffused through silicon oxide, which serves as a semi-transparent barrier. The wide lightly-doped region under the electrode removes the necessity of a very precisely-aligned Ag paste in this instance.

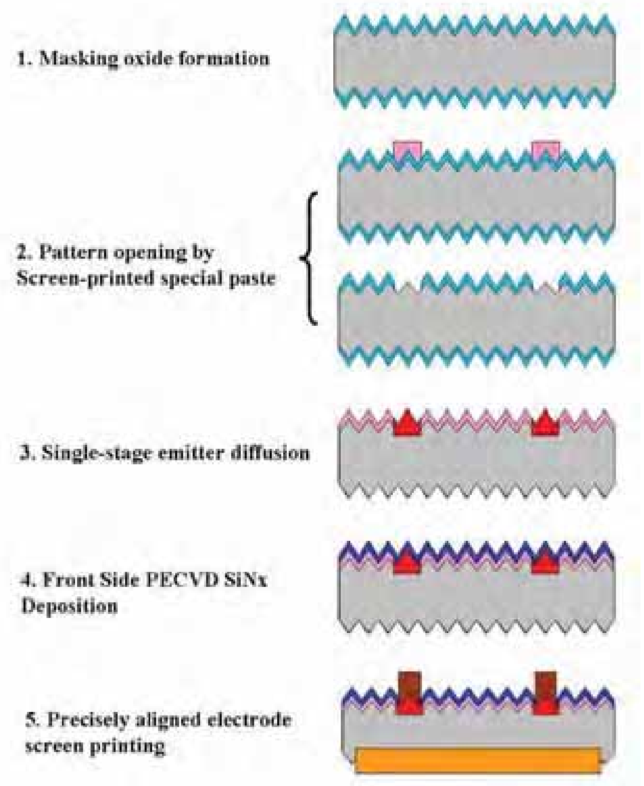


Figure 1. Major processing sequence for manufacture of 6"×6" mc-Si selective-emitter solar cells.

Experimental

The starting substrates are 6"×6", 200μm-thick industrial p-type multicrystalline silicon wafers with a resistivity of 0.5-2Ωcm from Sino-American Silicon Products, Inc. Silicon wafers were first chemically cleaned and acid-etched to remove the saw damage and randomly textured in an $HF\text{-}HNO_3\text{-}H_2O$ etching solution. An effective light doping zone was formed in the finger region to reduce recombination under the metal contact. The process sequence includes a single diffusion step and used a thermally-grown SiO_2 layer as a mask. An etching paste was then screen-printed to open the oxide barrier for the heavier doping region. After printing the etching paste, the wafers were cleaned in deionized water at room temperature. It is important that the removal of the etching paste is completed thoroughly. The measured line width after etching is about 350μm, while the open region was wider than the Ag-printed finger, which is about 110μm wide.

The dry oxide served as a partial diffusion barrier in order to perform the selective-emitter process with a single diffusion step. The sheet resistance was measured to control the diffusion through the oxide layer. To make a uniform diffusion, several oxide thicknesses were tested and various diffusion processes were performed. The emitter sheet resistances were tested in the range from 40Ω/sq to 120Ω/sq. The reference cells receive a standard homogeneous type emitter with a sheet resistance of 65Ω/sq and 75Ω/sq for mono- and multicrystalline solar cells,


FESTO
Maximise output!
The new complete wafer handling solution from Festo – the High Speed H-Portal
Maximised use of space with extremely high speed and dynamics.
For more information about the exiting H-portal contact us at solar@de.festo.com

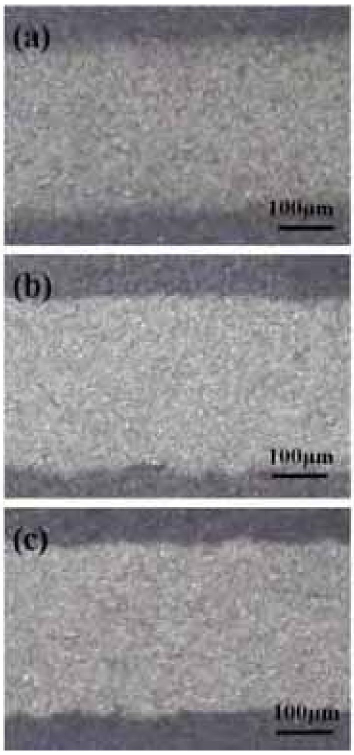


Figure 2. Optical microscopy images of the grid-line opening's coverage of etching paste on the masked oxide layer after (a) 30 seconds, (b) 60 seconds, and (c) 90 seconds of rinsing with deionized water.

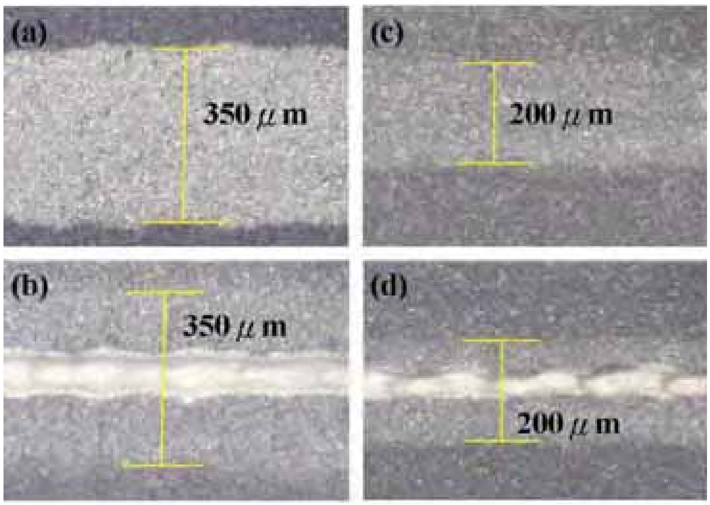


Figure 3. Optical microscopy images of (a) 350µm-wide opening of the masked oxide layer; (b) precise alignment of the electrode finger within the 350µm-wide opening of the masked oxide layer; (c) 200µm-wide opening of the masked oxide layer; (d) precise alignment of the electrode finger within the 200µm-wide opening of the masked oxide layer.

respectively. The emitter sheet resistance of the diffused emitters was measured by the four-point probe technique after the removal of the oxide in a diluted hydrofluoric acid.

The metallization was performed by screen-printing with a precisely-aligned technique and followed by co-firing using an optimized process in a lamp-heated IR belt furnace. This process resulted in simultaneous formation of an Al back-surface field (BSF) and the front Ag grid metallization. Contact patterns for the front side were carried out using a commercial paste from DuPont. The major procedures sequence for this work is shown in Fig. 1.

This study employed light beam-induced current (LBIC) and Corescan measurements to examine the finished solar cells in more detail. The Corescan is a tool developed for detailed surface mapping of the contact resistance between the emitter and the metallization grid of solar cells, while the LBIC scans the continuous wavelength of the Corescan instrument. Owing to the fact that the light used is generated by a halogen lamp, the wavelengths are relatively long and penetrate deeply. Therefore, the LBIC scan method of the Corescan mainly shows the difference in bulk lifetime over the cell. Additionally, contactless microwave-detected photoconductivity decay (µ-PCD) was used to measure the effective lifetime of the samples in this study. Spectral response and reflectance measurements were performed on the fabricated solar cells to determine the quantum efficiency (QE). Current-voltage measurements were taken under a Berger solar simulator using AM1.5 spectrum. The solar cells were kept at 25°C throughout the testing stage.

Results and discussion

In this study, thermally-grown oxides were used as a partial diffusion barrier to form the selective emitter with a single diffusion step. Dry oxidation was carried out in a tube furnace at temperatures below 900°C. The lower temperature oxidation process is suitable for use with multicrystalline silicon and does not degrade minority carrier lifetime. In the meantime, the accompanied gettering effects maintain the high quality of surface passivation. In general, the application of processes with temperatures higher than ~900°C to solar-grade mc-Si usually leads to a drastic degradation of minority carrier lifetime. An etching paste was screen-printed to open the oxide barrier for heavier doping region. This removal process was done by screen-printing the etching paste on selected areas of the masked oxide layer. Immediately after the etching step, the wafers were rinsed with deionized water for cleaning. Figs. 2(a-c) show optical microscopy images of the opening after 30 seconds, 60 seconds and 90 seconds of deionized water washing, respectively. It was found that 30 seconds' rinsing is not sufficient for cleaning, as some samples still showed traces of the etching paste. Care must be taken during this cleaning

Heavy/light doping level (Ω/sq)		J_{sc} (mA/cm^2)	V_{oc} (V)	FF (%)	Eff. (%)
40/80	Average	34.36	0.619	77.43	16.46
	STD	0.24	0.006	0.31	0.28
40/100	Average	34.39	0.619	76.82	16.36
	STD	0.19	0.003	0.32	0.22
60/100	Average	34.36	0.618	76.89	16.33
	STD	0.18	0.004	0.52	0.30
60/120	Average	34.59	0.619	76.78	16.43
	STD	0.13	0.006	0.81	0.37
Reference (40Ω/sq)	Average	33.21	0.610	77.85	15.78
	STD	0.49	0.005	0.27	0.39
Reference (70Ω/sq)	Average	34.37	0.616	76.77	16.26

Table 1. The performance of large-volume 6" mc-Si selective emitter solar cells with differing heavy/light sheet-resistance combinations. In this example, 60/100 represents diffusion which reached 60Ω/sq without oxide and 100Ω/sq through the oxide for a certain oxidation time.

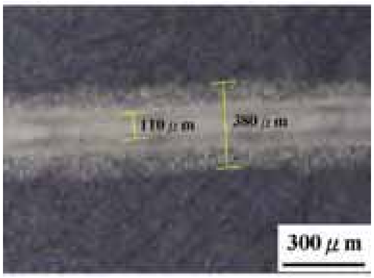


Figure 4. Optical microscopy image showing a typical precise alignment of the electrode finger within the opening of the masked oxide layer. The opened region is 380μm and the silver finger is 110μm wide.

step to ensure prevention of this residual etching paste. The cleaning time was increased and the process was optimized to a stage where the etching paste could be completely removed. In this study, various opening line-widths were also tested (see Fig. 3); however, this study concluded that the opening line-width is not a crucial issue due to the use of higher emitter sheet resistance in the opening regions.

After the single-step $POCl_3$ diffusion, Ag fingers were printed onto the heavier-doped emitter regions. Samples were observed under an optical microscope to check for correct alignment. A typical optical microscopy image, as shown in Fig. 4, reveals the precise result of the alignment between the etched regions and the Ag grids. The open region was wider than the Ag-printed finger, which is approximately 110μm wide.

To ensure a uniform diffusion, several oxide thicknesses were tested and various diffusion processes were performed. The sheet resistance was measured to control the diffusion through the oxide layer. The emitter sheet resistances were tested in the range from 40Ω/sq to 120Ω/sq. Table 1 compares the characteristics of large-volume 6" mc-Si selective emitter solar cells with different heavy/light sheet-resistance combinations. The results listed in Table 1 suggest that the difference between the sheet resistances of the heavy doping (underneath the electrode grid) and the light doping (between the grids) affects the performance of the selective-emitter solar cells.

In this study, the emitter sheet resistances were tested in the range from 40Ω/sq to 120Ω/sq. Many sheet resistance combinations were tested. A compromise must be made between low recombination and low contact resistance. Phosphorus-diffused emitters with a high sheet resistance contribute only marginally to recombination. Table 2 compares the characteristics of the best batch of 6" selective emitter solar cells with modern homogeneous solar cells. The reference cells receive a standard homogeneous type emitter with a sheet resistance of 65Ω/sq and 75Ω/sq for mono- and multicrystalline solar cells, respectively. In comparison to the control mc-Si solar cells with uniformly-doped 70Ω/sq emitter, the mc-Si selective-emitter solar cells with 75/110(Ω/sq)/(Ω/sq) sheet-resistance combination show an

		I_{sc} (A)	V_{oc} (V)	FF (%)	Eff. (%)
c-Si	SE (65/105)	8.995	0.630	78.13	18.22
	Reference (65Ω/sq)	8.946	0.624	77.53	17.82
mc-Si	SE (75/110)	8.527	0.624	77.98	17.07
	Reference (70Ω/sq)	8.438	0.617	77.52	16.62

Table 2. The average efficiency for multi- and monocrystalline selective-emitter solar cells is 17.07% and 18.22%, respectively. Here, 75/110 represents diffusion which reached 75Ω/sq without oxide and 110Ω/sq through the oxide for a certain oxidation time.

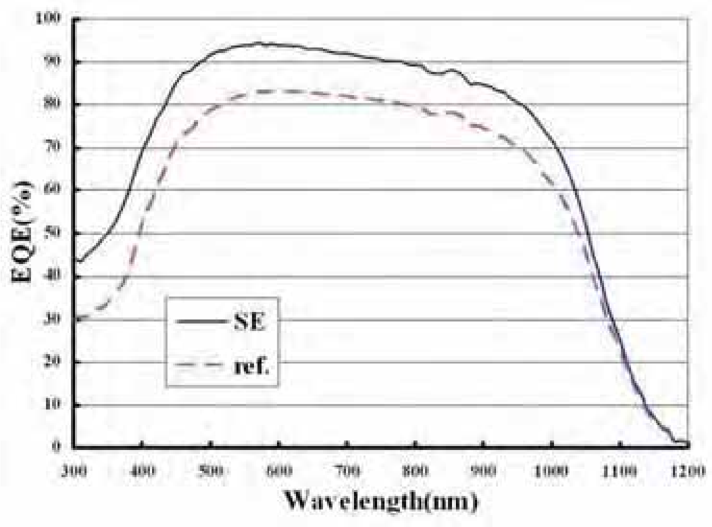


Figure 5. External quantum efficiency (EQE) response for both selective-emitter and conventional uniform-doped emitter solar cells.

average efficiency improvement of more than 0.4% absolute (in this case, 75/110 represents diffusion which reached 75Ω/sq without oxide and 110Ω/sq through the oxide for a certain oxidation time).

Similarly, in comparison to the control c-Si solar cells with uniform doping of 65Ω/sq emitter, the c-Si selective-emitter solar cells with 65/105 (Ω/sq)/(Ω/sq) sheet-resistance combination also show an average efficiency improvement of more than 0.4% absolute. The efficiency of SE cells is significantly higher for both mono- and multicrystalline solar cells.

As shown in Table 2, an improvement of about 7mV on the open circuit voltage (V_{oc}), ~0.4%-0.6% on the fill factor (FF) and about 50-100mA on the short circuit current (I_{sc}) was achieved with the SE cells compared to their homogeneous emitter counterparts. It was found that the recombination under metal contacts affects the performance of the solar cells. This work found that even though the selective-emitter samples suffer from a higher contact resistance, selective-emitter solar cells still show a better overall performance over conventional solar cells. The average contact resistances were 27mΩ/cm² and 13mΩ/cm² for selective-emitter and conventional cells, respectively. In Table 2, the increase in V_{oc} of selective-emitter cells may be primarily due to lower surface recombination as well as lower Auger recombination, as illustrated in the QE measurement results depicted in Fig. 5. The graph in Fig. 5 displays the QE as a function of the wavelength, and suggests that selective-emitter cells have a higher QE at wavelengths less than 1000nm due to the bulk and front-surface passivation.

“Even though the selective-emitter samples suffer from a higher contact resistance, selective-emitter solar cells.”

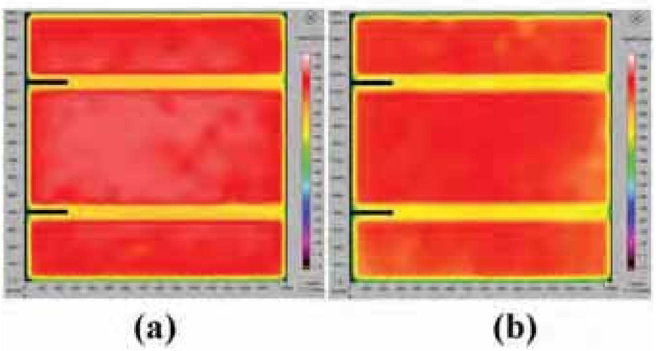


Figure 6. Light beam-induced current (LBIC) maps for: (a) selective-emitter mc-Si solar cells, (b) mc-Si solar cells with a conventional uniform-doped emitter structure. The LBIC is a scan of a continuous-wavelength light beam conducted by the Corescan instrument.

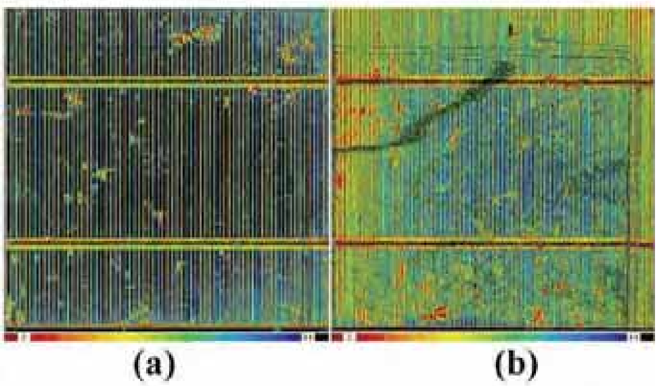


Figure 7. Photoconductance-decay (μ-PCD) maps for: (a) selective-emitter mc-Si solar cells, (b) mc-Si solar cells with a conventional uniformed-doped emitter structure.

I-V and QE results were further supported by light-beam induced current (LBIC) and lifetime measurements. The LBIC scan method is scanning of a light beam over the solar cell while measuring the resulting short-circuit current for each position. Since the LBIC scan method of the Corescan mainly shows the difference in bulk lifetime over the cell, it is clear that the selective-emitter samples fabricated in this work have higher induced current compared to those of conventional solar cells (see Fig. 6). Lifetime mapping also reveals a similar pattern. Fig. 7 shows μ-PCD lifetime mapping after solar cell fabrication.

This study demonstrates that the selective-emitter approach is still an attractive technique even in light/light sheet-resistance combination. The results show that selective-emitter solar cells can have a significant efficiency enhancement over modern solar cells with a uniform lightly-doped emitter. In comparison to mc-Si solar cells with a uniformly-doped 70Ω/sq emitter, an efficiency improvement of more than 0.4% absolute is achieved in large-scale production for selective-emitter solar cells. In this work, the average efficiency for multi- and single-crystalline selective-emitter solar cells is 17.07% and 18.22%, respectively.

Conclusions

The use of low sheet-resistance emitters in conventional multicrystalline silicon solar cells usually results in poor short-wavelength response. Heavy doping will increase Auger recombination in the emitter region and make effective surface passivation difficult. On the other hand, good quality Ohmic contact to high sheet-resistance emitters is not easy to achieve using normal commercial Ag pastes. These difficulties have focused research efforts on the selective-emitter technique for decades. A selective emitter is a doping layer that is heavily doped beneath the electrode while lightly doped in between the electrode grids. A successful industry implementation of the selective-emitter technique must be capable of displaying a significant efficiency enhancement over modern solar cells with uniform lightly-doped emitters.

The purpose of this study was to develop low-cost multicrystalline selective-emitter silicon solar cells through an optimized single diffusion step, which was achieved by screen-printing etching paste followed by screen-printing precisely-aligned normal Ag paste. The performance of the resultant selective-emitter solar cells was presented and discussed in relation to the different heavy/light sheet-resistance combinations. The results of this work suggest that the difference of sheet-resistance in between heavy doping (underneath the electrode grid) and light doping (in region between the grids) affect the performance of the selective-emitter solar cells. An efficiency improvement of more than 0.4% absolute is achievable for selective-emitter solar cells manufactured using this procedure, resulting in an average efficiency for multi- and monocrystalline selective-emitter solar cells of 17.07% and 18.22%, respectively.

Acknowledgement

The authors would like to thank the support of the Bureau of Energy and the Ministry of Economic Affairs (MOEA).

References

[1] Bultman, J.H. et al. 2006, "Ideal single diffusion step selective emitters: a comparison between theory and practice", *Proc. 16th EU PVSEC*, Glasgow, Scotland, pp.1424-1426.

[2] Ferrada, P. et al. 2009, "Diffusion through semitransparent barriers on p-type silicon wafers", *Proc. 24th EU PVSEC*, Hamburg, Germany, pp. 1897-1900.

[3] Urrejola, E. et al. 2009, "$POCl_3$ diffusion with in-situ SiO_2 barrier for selective emitter multicrystalline solar grade silicon solar cells", *Proc. 24th EU PVSEC*, Hamburg, Germany, pp. 1835-1837.

[4] King, R.R., Sinton, R.A. & Swanson, R.M. 1990, "Studies of diffused phosphorus emitters: saturation current, surface recombination velocity, and quantum efficiency", *IEEE Transactions on Electron Devices*, Vol. 37, No. 2, pp. 365-371.

[5] Okanovic, M. et al. 2009, "Influence of different laser parameters in laser doping from phosphosilicate glass", *Proc. 24th EU PVSEC*, Hamburg, Germany, pp. 1771-1774.

[6] Eisele, S.J. et al. 2009, "18.9% efficient full area laser doped silicon solar cell", *Appl. Phys. Lett.*, Vol. 95, p. 133501.

[7] Fogarassy, E. et al. 1981, "Silicon solar cells realized by laser induced diffusion of vacuum-deposited Dopants", *J. Appl. Phys.*, Vol. 52, No. 2, pp. 1076-1082.

[8] Sameshima, T., Usuzi, S. & Sekiya, M. 1987, "Laser-induced melting of predeposited impurity doping technique used to fabricate shallow junctions", *J. Appl. Phys.*, Vol. 62, No. 2, pp. 711-713.

[9] Horzel, J. et al. 1997, "A simple processing sequence for selective emitters", *Proc. 26th IEEE PVSC*, pp. 139-142.

[10] Rohatgi, A. et al. 2001, "Self-aligned self-doping selective emitter for screenprinted silicon solar cells", *Proc. 17th IEEE PVSC*, pp. 1307-1310.

[11] Porter, L.M., Teicher, A. & Meier, D.L. 2002, "Phosphorus-doped,silver-based pastes for self-doping ohmic contacts for crystalline silicon solar cells", *Sol. Energy Mater. Sol. Cells*, Vol. 73, pp. 209-219.

About the Authors

Ching-Hsi Lin received a Ph.D. degree in materials science and engineering from University of Utah, U.S.A., in 2002. Dr. Lin is currently working at the Industrial Technology Research Institute, Taiwan.

Chien-Hua Lung received a Ph.D. degree in chemistry from National Taiwan University, Taiwan, in 2002. Dr. Lung works at the Industrial Technology Research Institute, Taiwan.

Yu-Wei Tai received his Ph.D. degree in chemical engineering from National Taiwan University in 2005. He then joined the technology development at Neo Solar Power Corporation, and since 2009 has been working as deputy manager of technology development.

Yang-Fang Chen received his Ph.D. degree in physics from Purdue University, USA, in 1984. Dr. Chen is currently a professor in the National Taiwan University, Taiwan. Since 2007, he has been a technical adviser in Neo Solar Power Corporation, consulting in the field of physics, photovoltaics and thin films.

Wei-Chih Hsu received a Ph.D. degree in materials science and engineering from the National Taiwan University, Taiwan, in 2004. Dr. Hsu is currently working at the Industrial Technology Research Institute, Taiwan.

Enquiries

Ching-Hsi Lin,
Rm 402, Bldg. 78, 195, Sec. 4,
Chung Hsing Rd., Chutung, Hsinchu,
Taiwan 310, R.O.C.
Tel: +886 35913358
Email: chinglin@itri.org.tw

Yang-Fang Chen,
No. 1, Sec. 4, Roosevelt Rd., Taipei,
Taiwan 300, R.O.C.
Tel: +886 233665125
Email: yfchen@phys.ntu.edu.tw

Yu-Wei Tai,
7, Li-Hsin 3rd Rd., Hsinchu Science Park,
Hsinchu, Taiwan 300, R.O.C.
Tel: +886 35780011
Email: davidtai@neosolarpower.com

Screen printing in laser grooved buried contact solar cells: the Lab2Line hybrid processes

Dr. Alex Cole, Narec, Northumberland, England

ABSTRACT

Laser grooved buried contact (LGBC) solar cell technology is proving to be an attractive method of producing solar cells that are designed to operate at one sun and at concentration. Such technology is commercially available at Narec for applications up to 100 suns. Although LGBC cells can have a higher efficiency at one sun when compared with standard non-selective emitter screen-printed solar cells, a more complex manufacturing process is required for these cells. This paper outlines the approach taken under the FP6 EU funded project "Lab2Line", in which screen-printing and LGBC solar cell processing techniques are hybridized in order to produce lower cost, high efficiency solar cells.

Introduction

Despite the ongoing economic crisis, the global PV market could reach between 10GW and 16GW of new installations in 2010, compared to between 8GW and 12GW in the previous forecast year. While the announced worldwide PV production capacity would be sufficient to cover the expected evolution of the market in the coming five years, we could nevertheless see some temporary shortages due to possible fluctuation of demand patterns. In this scenario, Europe is leading the way with almost 16GW of cumulative installed capacity in 2009, representing about 70% of the world's cumulative PV power installed at the end of 2009 [1].

"Efficiency increases for concentrator systems can have a drastic impact on the reduction of levelized cost of energy."

It is generally accepted that the best way to continuously grow in the face of the market demand and competition from outside the EU is for a European PV manufacturer to provide high efficiency modules at low cost, in order to have the best power/price ratio. Currently, due also to the shortage of inverters, it is preferable to extract the highest power density at the lowest possible cost. At the moment, all the highest efficiency cells (and modules) are coming from producers outside of the EU (for example SunPower, Sanyo, Suntech [2–4]).

In order to obtain high efficiency, low cost cells, LGBC solar cell technology offers a route to obtain efficiencies higher than 18% on monocrystalline CZ wafers, by employing low throughput steps like sputtering and electroless chemical plating. It is also a suitable cell design for low to medium concentration due to its low front-contact shading, and its selective emitter structure.

As part of the Lab2Line project, screen-printing and LGBC solar cell processing techniques were hybridized with the aim of producing lower cost, high throughput, high efficiency solar cells processed on large-area (125 × 125mm) monocrystalline wafers using techniques scalable to industry. Two hybrid approaches have been considered: a fully screen-printed cell in which Screen-Print (SP) is applied to both the cell rear and into front-contact grooves and is subsequently cofired; and a process in which SP is applied only to the rear and then electroless plating is used to form the front contacts.

Both of these Lab2Line hybrid approaches offer high average efficiencies at one sun with a small performance distribution, with the second process showing at least a 6% relative improvement of efficiency at concentration. Efficiency increases for concentrator systems are especially important as they can have a drastic impact on the reduction of

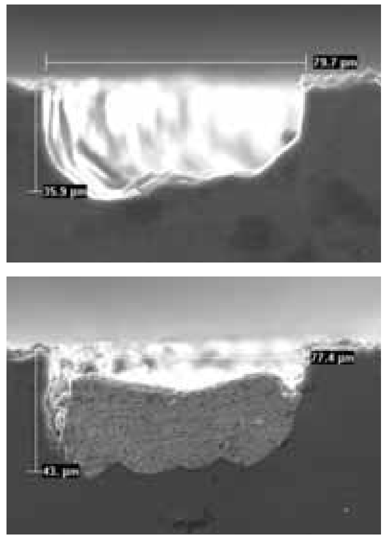


Figure 2. Scanning electron microscope (SEM) images of a front-contact groove modified to allow the application of screen print within the groove. The images show the groove prior to filling with SP paste (top) and after filling, drying and firing of the SP paste (bottom).

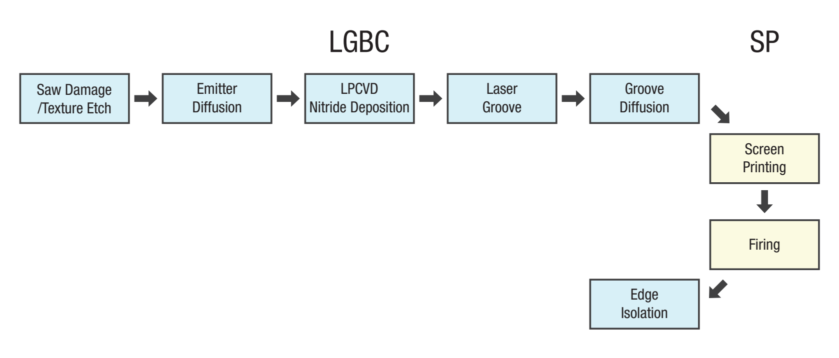


Figure 1. Outline of hybrid process 1, indicating the steps that are normally carried out in the LGBC or SP processes.

	V_{oc} (V)	J_{sc} (mA/cm^2)	FF %	Eff %
Best cell	0.625	35.08	79.2	17.34
Average cell	0.620	34.56	78.1	16.72
Standard deviation	0.002	0.38	2.0	0.51

Table 1. One sun IV parameters for cells processed with hybrid process 1.

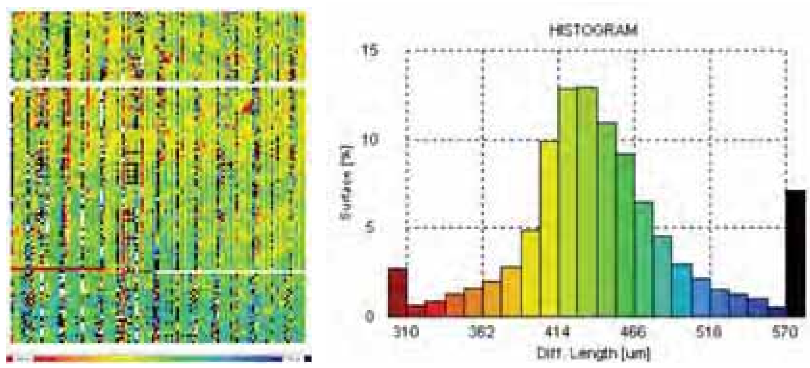


Figure 3. LBIC measurements of a wafer processed through hybrid process 1. Note that there are no centre to edge effects observed over the range of the scan (116mm), which is equivalent to the full size of the wafer measured. This would indicate that it is unlikely that there will be any issues with scaling up this process to larger wafers.

levelized cost of energy (LCOE) in areas with high direct normal incidence.

Hybrid processes

Hybrid process 1:
Fully screen-printed process

In the process summarized in Fig. 1, the SP metallization technique is used for both front and back contacts, with SP applied over the entire cell rear and only into laser grooves on the front. On the rear, aluminium compensates the back phosphorous diffusion and forms the back surface field (BSF), while silver forms the front contact fingers and busbars [6]. The major issue in this case is the laser groove filling by SP, which involves a modification of groove shape, paste rheology and front grid design to obtain low shading and a well-aligned SP/groove cell (see Fig. 2).

Hybrid process 1 results

The main issue encountered during this process is the optimization of SP inside grooves. In order to obtain complete alignment between the groove pattern and the screen-print mask, a specific front-contact grid was designed. Computer modelling with PC1D [7] was used along with in-house developed software taking into account the minimum printable finger width and the maximum number of fingers which could be effectively aligned with the SP. We obtained a grid with 66 fingers on a 125 × 125mm wafer, with each finger nominally 80µm in width, allowing effective alignment [8] with good filling and adhesion, as shown in Fig. 2.

In order to make good ohmic contact of the SP silver paste to the heavily diffused silicon in the groove, optimization of the paste dilution and the use of silver SP paste specifically designed to make ohmic contact directly onto silicon were necessary. After optimization of both printing and co-firing, a 16.70% average efficiency with best cell 17.34% was reached. The results garnered are shown in Table 1, showing an average V_{oc} of 620mV and a maximum of 632mV.

Laser beam-induced current (LBIC) measurements carried out using a Semilab WT2000 tool are shown in Fig. 3. Diffusion lengths averaging 430µm can be observed, with good uniformity over the whole area of the cell (116 × 116mm). Any observed non-uniformity appears to be random in nature and no centre-to-edge effects are observed, a result of the improved back-surface field, bulk gettering and rear-surface recombination velocity provided by Al screen-printing and firing compared to sputtered aluminium. This is an improvement over the standard LGBC process where diffusion lengths are of the order of 240–280µm.

The long wavelength performance, evaluated in terms of internal quantum efficiency (IQE), is shown in Fig. 4. Theoretically, if we optimize every step to move the average V_{oc}, J_{sc} and FF to the maximum measured at one sun, efficiencies close to 18% can be obtained with a relatively simple, high throughput and potentially low-cost process sequence.

Even though the IV parameters of cells produced by this process are good, the difficulties arising from the accuracy required for front screen-printing alignment and a small process window for a stable co-firing process could make the hybrid process 1 less appealing for an industrial scale-up. Some of these issues could be mitigated by using an ink-jet or stencil-printing approach, for example.

Hybrid process 2:
Back screen print of LGBC cells

During hybrid process 2, SP Al paste is applied to the rear of the cell only, which is then dried and fired. This avoids front-contact alignment issues or the larger shading produced by 80µm-wide screen-printed fingers. The remaining residual SP paste is then etched away and the metallization is carried out with the LGBC process's standard electroless chemical plating. This results in an LGBC front with

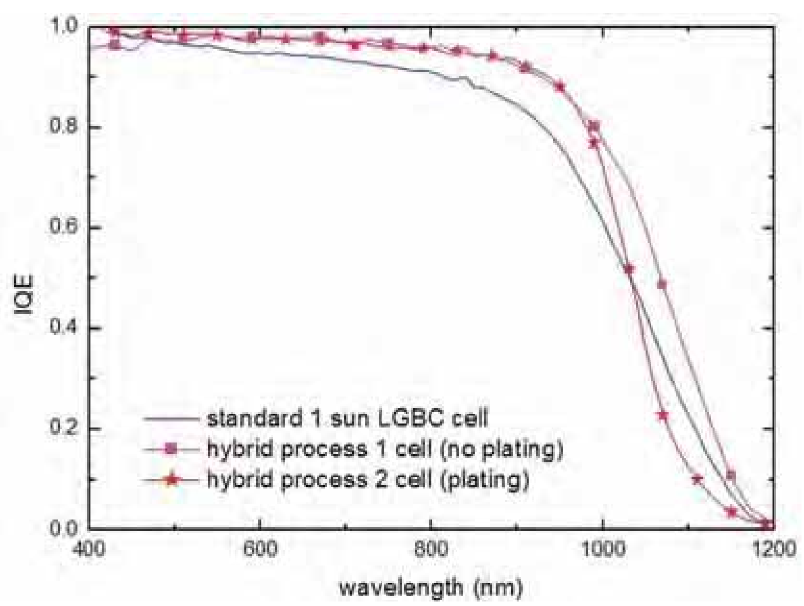


Figure 4. Internal quantum efficiency measurements for wafers processed through the standard LGBC process and hybrid processes 1 and 2.

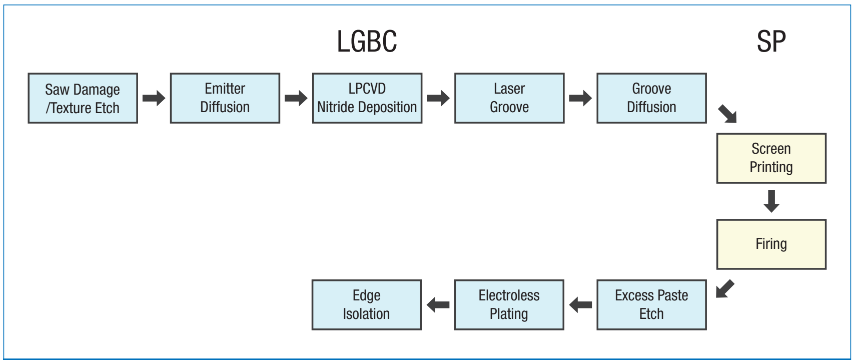


Figure 5. Outline of hybrid process 2, indicating which steps are normally carried out in the LGBC or SP processes.

low shading, low contact resistance and high conductivity and an SP rear which has a superior BSF, lower rear surface recombination velocities and improved bulk gettering properties than the traditional LGBC Al-sputtered rear.

Hybrid process 2 results

Several hundred of one sun cells have been produced using this process, the results of which are depicted in Table 2. The IQE of cells produced by both methods have been measured, and is presented in Fig. 4 with a standard LGBC cell for comparison. All cells have an excellent blue response due to the selective emitter structure produced by the LGBC process. Furthermore, the improvement in the long wavelength region is clearly appreciable for the hybrid processes. An unexpected result is the difference in behaviour between the IQEs for hybrid process 1 and 2 cells in the 950–1200nm range. However, comparing this to the cells' V_{oc} values, the comparison is surprisingly inconsistent as both processes produce very similar V_{oc} values.

Since the only difference between hybrid processes is the chemical plating, and as we have previously noted that cells with front plating or SP show similar performance under standard AM1.5 conditions [7], we can relate this effect to the metal growth on the back side. A further small batch (circa 15) of cells was processed using the hybrid 2 process with certain process steps optimized. This yielded the results shown in Table 3.

	V_{oc} (V)	J_{sc} (mA/cm^2)	FF %	Eff %
Best cell	0.631	35.60	79.7	17.9
Average cell	0.623	35.30	79.1	17.4
Standard deviation	0.004	0.15	1.1	0.33

Table 2. One sun IV parameters for cells processed with hybrid process 2.

Introduction to concentrator photovoltaics (CPV)

One route to reductions in LCOE from PV is by using concentrator systems. In a typical crystalline silicon one-sun module, around 80% of the cost of the module comes from the silicon solar cells. CPV systems offer a route to reduce the amount of PV material by focusing sunlight onto the cells using comparatively cheap mirrors or lenses; however, sun tracking may be required, depending on the level of concentration of incident light on the cells. As calculated in-house by Narec, in areas of high direct normal incidence (DNI), the LCOE of well-designed concentrator systems can potentially be

	V_{oc} (V)	J_{sc} (mA/cm^2)	FF %	Eff %
Best cell	0.629	36.05	0.799	18.11
Average cell	0.628	35.33	0.799	17.97
Standard deviation	0.001	0.10	0.002	0.08

Table 3. IV parameters for cells processed with hybrid process 2 using optimized process steps.

much lower than for crystalline silicon or thin-film PV modules.

Narec currently offers LGBC crystalline silicon cells suitable for low- to medium-concentration (up to circa 100×) and has supplied cells designed for various concentrations and illumination profiles to over 70 companies, institutes and universities. According to the European Commission's PV Status Report 2010, market share of CPV is still relatively small as it is still in the development phase; nevertheless, an increasing number of companies are focusing on the CPV sector, around 60% of which were founded in the last five years. In 2008 about 10MW of CPV systems were produced, and market estimates for 2009 are in the 20–30MW range, with estimates for 2010 reaching the 100MW mark. Consensus industry-wide is that CPV will be in the GW scale by 2013, most likely consisting of a mix of silicon- and multijunction-based CPV systems [9].

Application of hybrid process 2 to CPV cells

Cells were manufactured using the hybrid 2 process (produced in the same batch as those displayed in Table 2) that have a size (2cm × 1.6cm) and front contact optimized for CPV applications. These cells were optimized to work best with an illumination of 50 suns, and yielded a best cell that reached 19.6% efficiency (at 50×) and 18.9% (at 100×) on 200µm CZ wafers (see Fig. 6). This is a 6% relative improvement for the same cells manufactured on comparable wafers using the standard LBGC process. Cells of over 20% efficiency have also been manufactured following optimization for 25× with a similar design. Also, as the V_{oc} value is higher than is normally obtained with standard LGBC technology, this should result in lower performance degradation with increased temperature – a factor that could be especially important for concentrator applications.

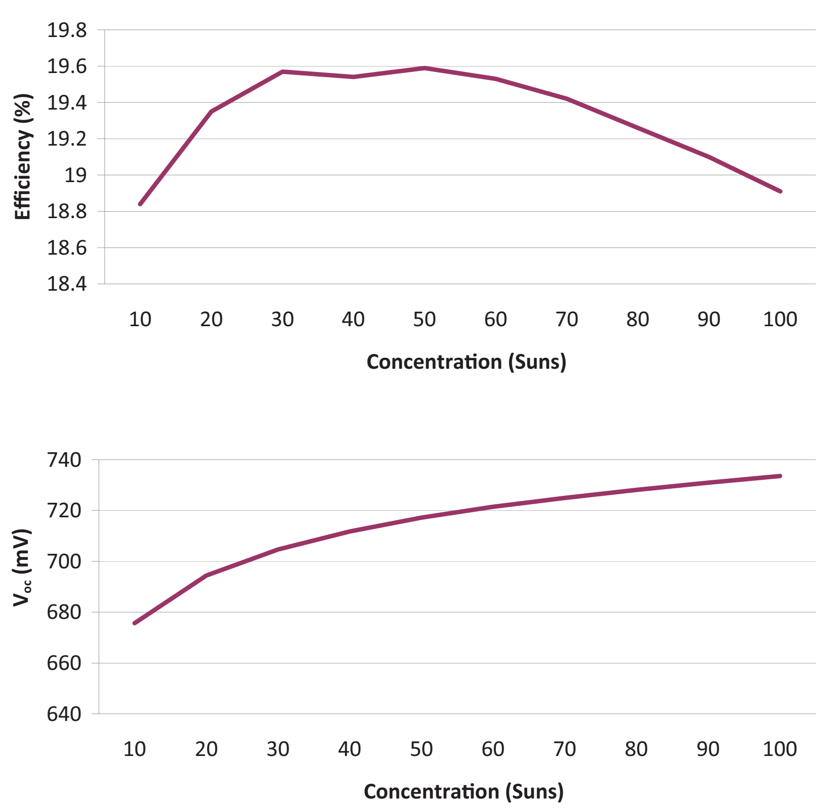


Figure 6. Efficiency and open circuit voltage (V_{oc}) as a function of illumination level. An efficiency of 19.6% is achieved at 50 suns and 18.9% at 100 suns, representing a 6% relative improvement over LGBC technology on the same wafers.

In order for CPV to be even more competitive with standard PV technology, especially as the cost of one-sun modules is falling at a rate of approximately 22% with each doubling of installed capacity, the CPV systems must show cost reductions on a similar scale. These reductions could be reached in component prices, with parts such as cells and lens tracking systems each playing a part. However, increasing efficiency effectively reduces the cost of almost every component, while land-based costs are reduced as the power density is increased.

An example of a company using silicon-based concentrator cells that is currently shipping product to high direct normal irradiance (DNI) areas is the British company, Whitfield Solar. This company can provide a point-focus Fresnel lens system that uses Narec's LGBC silicon cells at 50 suns. These lenses are manufactured from PMMA, and the system operates as an open-looped, tilt-and-roll tracking system. The efficiency of the concentrator cells is a very important factor in order to allow realization of the cost-reduction potential in any CPV system. Increases in cell efficiency lowers all cost per Wp-related costs and provides a higher power density. As the hybrid 2 cells have the same front and rear contacts as standard LGBC cells, they should act as a straight, 'drop-in' replacement for the existing cells provided by Narec.

Conclusions

This article has reported the important results of the three-year Lab2Line FP6 project. Screen-printing processes were hybridized with LGBC processes in order to enhance the efficiency of the cells at one sun and at concentration. At one sun, a cell efficiency of 17.3% was achieved with hybrid process 1 (screen printing into grooves on the front of the cell and over the entire rear of the cell) on large-area wafers (125mm). This process should prove to be immediately scalable to larger-area wafers (156mm) due to the uniformity measured by LBIC.

Using hybrid process 2, an efficiency of 18.11% was achieved at one sun on large-area (136cm^2) wafers, which could be further improved by adjusting specific process steps such as altering the plating technique or optimization of the emitter doping profile. Applying the same hybrid process 2 to concentrator cells yields a 6% relative improvement in efficiency compared to standard Narec LGBC cells when using like-for-like wafers. Other benefits include faster processing (Al sputtering is currently a bottleneck) and improved uniformity, which is also scalable to larger wafers such as 156mm pseudosquares.

We have therefore shown two processes that hybridize the screen-printing process

Figure 7. Whitfield Solar's WS:Si24 solar concentrators installed on a residential rooftop in Queensland, Australia.

and the LGBC solar cell process, which yields benefits in efficiency, process time and uniformity, especially in the application of concentrator cells. Narec hopes to offer these new hybrid cells for concentrator applications, such as for the Whitfield Solar WS:Si24 CPV system in the near future.

Acknowledgements

The authors would like to thank Lucilla Bittoni from Chimet for providing aluminium screen-printable pastes. This work is partially supported by the European Commission in the Sixth Framework Programme "Lab2Line" project; contract number DIR2/TREN/05/FP6EN/S07.66659/019902.

References

[1] EPIA 2010, "Global market outlook for photovoltaics until 2014" [available online at http://www.epia.org/fileadmin/EPIA_docs/public/Global_Market_Outlook_for_Photovoltaics_until_2014.pdf].

[2] Rose, D. et al. 2006, "Mass production of PV modules with 18% total-area efficiency and high energy delivery per peak watt", *Proc. IEEE 4th World Conference on Photovoltaic Energy Conversion,* Waikoloa, Hawaii, pp. 2018–2023.

[3] Taguchi, M. et al. 2005, "An approach for the higher efficiency in the HIT cells", *Proc. 31st IEEE PVSC*, Lake Buena Vista, Florida, pp. 866–871.

[4] Shi, Z., Wenham, S. & Ji, J. 2009, "Mass production of the innovative PLUTO solar cell technology", *Proc. 34th IEEE PVSC*, San Diego, California, pp. 1922–1926.

[5] Heasman, K.C. et al. 2007, "PC1D modelling of the efficiency of laser grooved buried contact solar cells designed for use at concentration factors up to 100X", *Proc. PVSAT 3*, Durham University, UK.

[6] Lauermann, T. 2010, "Enabling dielectric rear side passivation for industrial mass production by developing lean printing-based solar cell processes", *Proc. 35th IEEE PVSC*, Honolulu, Hawaii.

[7] Clugston, D.A. & Basore, P.A. 1997, "PC1D version 5: 32-bit solar cell modeling on personal computers", *Proc. 26th IEEE PVSC*, Anaheim, California, pp. 207–210.

[8] Cole, A. et al. 2009, "The LAB2LINE laser grooved buried contact screen printed solar cells hybrid P-type monocrystalline process", *Proc. 24th EU PVSEC*, Hamburg, Germany.

[9] Jäger-Waldau, A. 2010, "PV Status Report 2010", European Commission, DG JRC.

About the Authors

Alex Cole is Business Development Manager for Photovoltaics at Narec. He has worked in PV research for six years, during which time he has published over 25 papers. His background is in physics, having earned a Ph.D. in solid state physics as well as a degree in physics from the University of Leeds.

Luca Serenelli has been working in the field of PV at ENEA since 2005, prior to which he gained a degree in physics. His main research topics of interest are advanced screen printing and plasma processing for thin-film deposition; heterojunctions and dry-etching. His current contributions comprise approximately 40 papers, conference proceedings and patents.

Roger Bentley is head of research at Whitfield Solar. He gained a Ph.D. in solar energy from Reading University; an M.Sc. in industrial engineering from Toronto University; and a B.Sc. in general science (physics and chemistry) from Manchester University. He has worked in PV for 30 years and published some 40 papers.

Enquiries

Tel: +44 (0) 1670 357731
Email: alex.cole@narec.co.uk
Web: www.narec.co.uk

Influence of a-Si:H deposition temperature on thermal stability of a-Si:H/SiN_x:H stacks

C.C. Huang[1], **Y.T. Huang**[2], **Y.W. Tseng**[2], **W.H. Chen**[1], **T.Fang**[1], **C.C. Li**[1] & **C.C. Tsai**[2],
[1]Motech Industries, Tainan, Taiwan; [2]National Chiao Tung University, Hsinchu, Taiwan

ABSTRACT
A hydrogenated amorphous Si (a-Si:H) film, combined with a silicon nitride (SiN_x:H) capping layer and a post-deposition anneal, can hugely enhance the surface passivation on crystalline silicon wafers. In this work, the influence of various deposition temperatures of a-Si:H films on the thermal stability of a-Si:H/SiN_x:H stacks and a possible mechanism are discussed. Both minority carrier lifetime measurement and grazing-angle XRD were employed to study the thermal stability of a-Si:H/SiN_x:H stacks, and the results are interpreted in terms of dihydrides concentration and epitaxial crystallization. With an appropriate thermal treatment, the a-Si:H film deposited at 130°C and capped by SiN_x:H showed better passivation performance than 200°C-deposited a-Si:H/SiN_x:H stacks, but under an excessive thermal budget the former showed more severe degradation of carrier lifetime. The more dihydride-rich composition within 130°C-deposited a-Si:H/SiN_x:H stacks could be regarded as providing more effective intermediates for hydrogen interchanges, but on the other hand, it is also more susceptible to epitaxial crystallization.

Introduction
The goal of grid parity is leading to the development of cells with thinner crystalline-Si wafers in an attempt to reduce costs. The use of thinner cells usually results in lower efficiency because more light is able to reach the rear surface of the cell where many trapping sites exist. These trapping sites, which include defects and dangling bonds, act as recombination centres for photo-generated carriers in the Si substrate [1]. Therefore, to improve the efficiency of thin solar cells, good surface passivation is vital to reduce the surface recombination, especially for the rear surfaces. Thermally-grown silicon dioxide (SiO_2) layers provide a very good and thermally stable passivation, but they are prepared by a long and energy-intensive high temperature process, which is unfavourable for mass production [2]. Furthermore, this high-temperature process is extremely detrimental for block-cast multicrystalline silicon [3,4]. Considering quality degradation of wafer materials, a passivation layer that can be deposited at lower temperatures is preferable. Plasma-enhanced chemical vapour deposition (PECVD)-SiN_x films are typically fabricated by a low-temperature process (approx. 300–400°C). They provide very good passivation quality [5–7], but the thermal stability is not as good as SiO_2 layers. Furthermore, cells made from p-type wafers and passivated with nitrogen-rich SiN_x films typically suffer from an inversion layer which is shunted by the local contacts [8]. As the nitrogen content in the SiN_x layer was reduced to get silicon-rich SiN_x layers, the overall defect density was found to decrease. In the extreme case that nitrogen is totally removed, amorphous silicon layers should be formed with the lowest defect density [9]. This intrinsic hydrogenated amorphous silicon (a-Si:H) shows several advantages.

First of all, this passivation film is deposited by PECVD in the temperature range between 200°C and 250°C. The much lower process temperature reduces both energy consumption and degradation of wafer material quality caused by impurity diffusion. Secondly, a-Si:H films can result in the same low effective surface recombination velocity as thermal oxidation [10] and show no parasitic shunting. Therefore, surface passivation by a-Si:H is an attractive candidate for high-efficiency silicon solar cells.

> "In this work, 5-6Ωcm B-doped p-type Cz wafers were used for deposition of dielectric layers and the measurement of minority carrier lifetime."

Even though surface passivation with a-Si:H shows many advantages, it is not without its drawbacks. Quality of passivation with a-Si:H films is highly sensitive to thermal processes. Since process steps such as contact annealing or even screen-printing require a certain thermal stability of the passivation layer, many researchers prefer to focus their study on improving the thermal stability of a-Si:H films for better surface passivation. Plagwitz et al. [11] and Bentzen et al. [12] showed that depositing a silicon nitride (SiN_x) layer on top of the a-Si:H film as a capping layer can improve the thermal stability of the surface passivation. On the basis of this discovery, S. Gatz et al. [13] revealed that the thermal stability of the surface passivation by a-Si:H/SiN_x stacks can be enhanced by increasing the deposition temperature of the SiN_x layer from 300°C to 400°C because of the increasing density of the SiN_x capping layer.

In this work, several concepts to improve thermal stability of surface passivation by a-Si:H/SiN_x stacks are discussed. The SiN_x capping layer is deposited by PECVD at 450°C. The results confirmed that SiN_x-capped a-Si:H films show better thermal stability as compared with a single a-Si:H layer. The effect of deposition temperature of a-Si:H films on the thermal stability of a-Si:H/SiN_x passivation stacks is also discussed in this study.

Experimental details
In this work, 5-6Ωcm B-doped p-type Cz wafers were used for deposition of dielectric layers and the measurement of minority carrier lifetime. KOH chemicals were employed for the fabrication of shiny wafer surface and followed by diluted HF dipping prior to the film deposition. Subsequently, 27.12MHz PECVD systems with H_2 and SiH_4 as the precursor gases were utilized for the deposition of a-Si:H film, followed by the deposition of an SiN_x:H layer using precursor gases of NH_3 and SiH_4. All a-Si:H/SiN_x:H stacks were deposited on both surfaces of the samples, and SiN_x:H layers were deposited with film thickness of 80nm at a temperature of 450°C. Film thickness and deposition

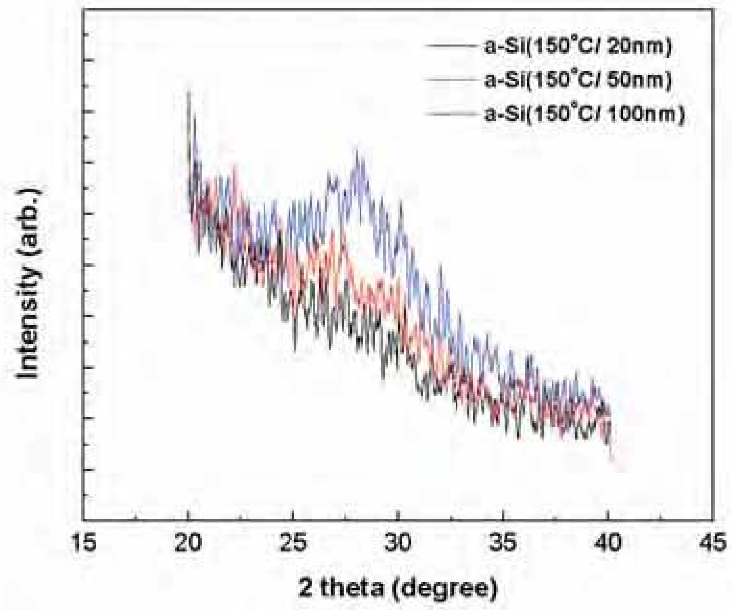


Figure 1. XRD spectra for amorphous silicon films deposited at 150°C with thickness of 20nm, 50nm and 100nm on p-type (100) polished wafers.

temperature of a-Si:H layers were varied from 20nm to 100nm and 110°C to 200°C, respectively. Additionally, in order to measure the extent of crystallinity of a-Si:H films under various thermal conditions, p-type polished wafers with equal size of 1cm^2 were used for XRD monitoring on the same film stacks.

Firstly, we measured samples with a-Si:H film thickness of 20nm, 50nm and 100nm by grazing-angle XRD to look for the sufficient signal of crystallinity. Then, with the selected sampling thickness, various deposition temperatures of a-Si:H layer and different post-deposition RTA (rapid thermal anneal) temperatures were considered to check the phase of crystallization by XRD. In the meantime, micro-PCD was employed in this work to measure the minority carrier lifetime for shiny surface-based samples.

Results and discussion

Thickness dependence on XRD

Fig. 1 shows that the diffraction signals from the crystallized orientation phase (111) of a-Si:H film at a diffraction angle of 2θ~ 28 degree were more and more pronounced with increasing thickness of a-Si:H film. The broad peaks indicate the weak crystallinity of a-Si:H film even with 100nm thickness. For subsequent tests, 100nm a-Si:H layers were used, partly due to the better XRD signal, and partly due to good passivation performance of a-Si:H of such thickness. Mitchell [14] has worked on thick a-Si:H film capped onto c-Si wafers as a passivation layer and concluded that a 200nm-thick a-Si:H layer has a deleterious effect on surface passivation, and that an a-Si:H layer with thickness around 100nm can achieve an optimal passivation property by providing more atomic hydrogen, evidenced by higher concentration of monohydrides and dihydrides in the FTIR spectra.

Temperature dependence on carrier lifetime and XRD

The evolution of crystallinity of a-Si:H films under various thermal treatments and the associated influence on thermal stability of a-Si:H/SiN$_x$:H stacks is of great interest. Wang [15] reported on an investigation into the use of the a-Si:H layer in silicon heterojunction solar cells on p-type crystalline silicon wafers. The dramatic effects of crystallinity on the SHJ solar cell's performance were summarized such that epitaxial growth of crystalline silicon will easily take place over a specific thermal budget, and low temperature deposition (<150°C for (100) and <200°C for (111)) of the a-Si:H layer is recommended for the growth of abrupt and flat interface at the heterojunction. Our measurement results of minority carrier lifetime by micro-PCD on samples with 130°C, 150°C, 170°C and 200°C as various deposition temperatures (see Fig. 2) indicate a progressively better passivation performance with lower deposition temperature, and such results are consistent Wang's findings [15]. From XRD spectra shown in Fig. 3, however, higher diffraction intensity around phase (111) of the epitaxial-grown a-Si:H layer is not observed as expected on samples with higher deposition temperature. This may indicate that a slight difference of a-Si:H crystallinity among various deposition temperatures from 130°C to 200°C cannot be readily revealed by XRD spectra.

Nevertheless, the influence of various crystallinity factors relevant to different deposition temperatures of a-Si:H films on passivation performance may not necessarily be mainly attributable to the epitaxial growth at the interface of heterojunction. More active interchanges of atomic hydrogen within dihydride-rich a-Si:H films deposited at 130°C, compared to that at 200°C, could be another dominant factor for the better passivation effects instead. Generally, dihydrides ratio for 130°C-deposited a-Si:H films estimated from FTIR results is 1.5 to 2 times as much as that for 170°C, and such dihydride-rich a-Si:H films could contain more porous Si-H bonding with which less thermal activation energy of surface

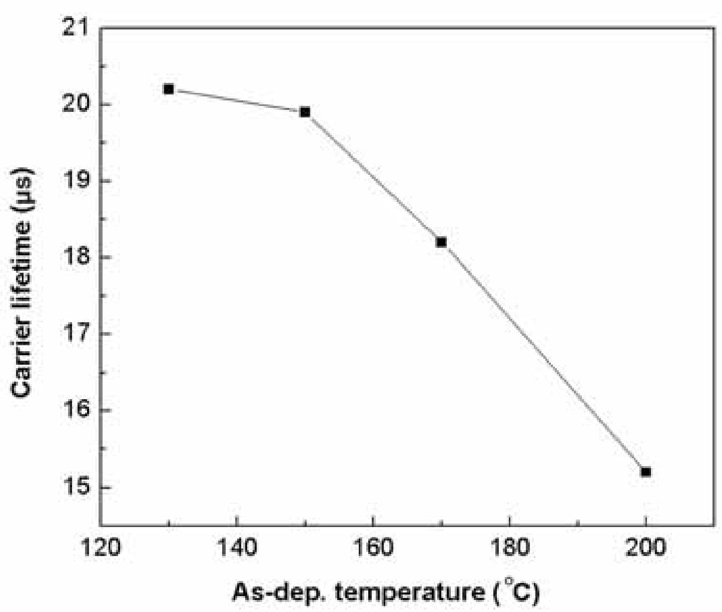


Figure 2. Minority carrier lifetime measured by micro-PCD for amorphous silicon films deposited at 130°C, 150°C, 170°C and 200°C with thickness of 100nm on p-type (100) Cz shiny wafers.

Cell Processing

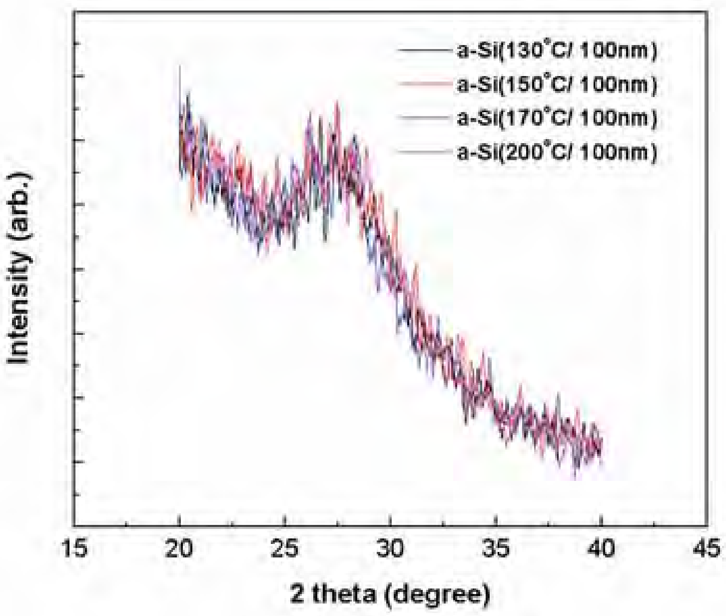


Figure 3. XRD spectra for amorphous silicon films deposited at 130°C, 150°C, 170°C and 200°C with thickness of 100nm on p-type (100) polished wafers.

passivation would be required. Mitchell [1] also reported that, based on FTIR results before and after thermal anneal, dihydrides showed potential for surface passivation since the concentration of dihydrides was reduced after an effective thermal treatment. The results imply that atomic hydrogen under thermal diffusion can interchange between the easily-broken Si-H_2 bonding and those that already exist near the interface of c-Si surface. After an effective surface passivation under thermal treatment, Si-H_2 bonding could be structurally transformed to Si-H and crystalline silicon, leading to the reduction of Si-H_2 concentration. In the case of as-deposited dihydride-rich a-Si:H films prior to thermal treatment, nevertheless, Si-H_2 bonding still plays an important role in the interchange of atomic hydrogen and behaves like intermediates for hydrogen passivation during the process of deposition.

Thermal stability of as-deposited a-Si:H

As published elsewhere [12], post-deposition thermal anneal upon passivation layers with a-Si:H/SiN_x:H structure can further enhance surface passivation performance. If one simply applies a-Si:H/SiN_x:H stacks as backside passivation layers on traditional solar cells, the degradation of cell performance caused by high thermal budget of the fabrication process is a major problem. To study this issue, post-deposition RTA with ambiance of forming gas was employed in this work to check the thermal stability.

Two deposition temperatures of a-Si:H films, 130°C and 200°C, were selected to investigate whether the as-deposited composition of a-Si:H films would account for the thermal stability of a-Si:H/SiN_x:H stacks. Effects of five-minute RTA treatment on three kinds of samples: single layer-passivated a-Si:H (130°C/100nm); dual a-Si:H (130°C/100nm)/SiN_x:H (450°C/80nm) stacks; and dual a-Si:H (200°C/100nm)/SiN_x:H (450°C/80nm) stacks are summarized in Fig. 4. Without the SiN_x:H capping layer on a-Si:H films, the carrier lifetime before and after annealing showed comparable values for 150°C anneal, but severe degradation occurred after annealing at 250°C and 350°C. This suggests that atomic hydrogen originating from a-Si:H layers not only thermally diffused toward the crystalline silicon interface but also simultaneously diffused out of the stacks to the atmosphere. When annealing over the thermal criteria of deposition temperature, out-diffusing hydrogen may dominate the interaction so that large parts of broken dangling bonds would not be passivated.

> “Post-deposition thermal anneal upon passivation layers with a-Si:H/SiN_x:H structure can further enhance surface passivation performance.”

In addition to the dependence of anneal temperature, the anneal duration is also a key factor. In our previous study, single layer-passivated a-Si:H deposited at 130°C, 150°C and 170°C with RTA of 250°C for three minutes can all achieve improvement of carrier lifetime by more than a factor of two. Even with annealing over the deposition temperature, effective thermal treatment can be achieved under the proper control of thermal budget. As a result, investigations seeking for the optimal duration of RTA shall be further included as future works.

Thermal stability of a-Si:H/SiN_x:H stacks

With SiN_x:H films served as capping layers on a-Si:H films, surface passivation effects can be enhanced due to more inward diffusion of atomic hydrogen. At anneal temperature of 400°C, which is lower than SiN_x:H deposition temperature of both samples (with underneath layers of 130°C and 200°C-deposited a-Si:H films), comparable carrier lifetime changes were evident, which is most likely due to insufficient thermal activation energy.

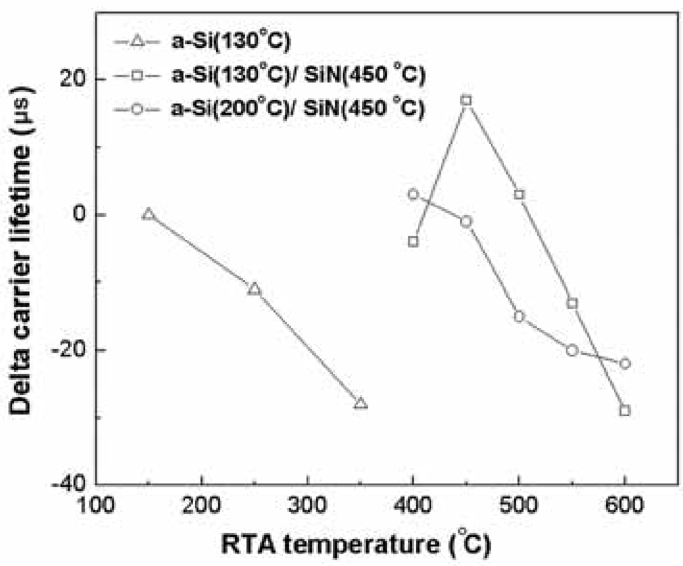


Figure 4. Minority carrier lifetime changes before and after RTA for three kinds of sample: c-Si/a-Si:H (130°C/100nm); c-Si/a-Si:H (130°C/100nm)/SiN_x:H (450°C/80nm); and c-Si/a-Si:H (200°C/100nm)/SiN_x:H (450°C/80nm).

2nd International Conference on

PV Module Recycling

25 January 2011 • Madrid, Spain

ATTEND THE ONLY CONFERENCE ON PV MODULE RECYCLING!

REGISTER NOW: www.epia.org

This event is co-organised by the European Photovoltaic Industry Association (EPIA) and PV CYCLE with the institutional support of the European Commission's Joint Research Centre (JRC), in the frame of the IEA PVPS Task 12.

EPIA European Photovoltaic Industry Association · PV CYCLE · JRC European Commission

Credits: Sunicon AG, First Solar, Beck Energy/First Solar

Cell Processing

Mitchell's study [1] about the estimation of thermal activation energy for hydrogen passivation indicated that for a single a-Si:H layer, anneal temperature near to or higher than the deposition temperature can accelerate the reaction. In this work, however, the predominant element determining the thermal activation energy of a-Si:H/SiN_x:H stacks is the deposition temperature of the SiN_x:H capping layers. The alternation of the thermal activation threshold from the deposition temperature of a-Si:H to that of SiN_x:H occurs when the process of as-deposited a-Si:H films is subsequently followed by the SiN_x:H capping process.

At anneal temperature of 450°C, 130°C-deposited a-Si:H stacks showed more carrier lifetime improvement than that of 200°C-deposited ones. The effectiveness of carrier lifetime improvement at anneal temperature of 450°C for the 130°C-deposited a-Si:H sample is, as discussed, probably attributed to the abundance of dihydrides. The threshold criteria of thermal activation for a-Si:H/SiN_x:H stacks should be, as mentioned, near the deposition temperature of SiN_x:H so that the anneal temperature of 450°C can activate atomic hydrogen within SiN_x:H films and then successively interchange with those located in a-Si:H films. As a result, for a-Si:H/SiN_x:H stacks, the effective anneal treatment should rely not only on exceeding activation criteria of SiN_x:H deposition temperature, but also on a sufficient concentration of atomic hydrogen originating from a-Si:H films.

"The abrupt drop of carrier lifetime for 130°C-deposited a-Si:H stacks with anneal temperature increasing to 600°C is apparently attributed to the formation of epitaxial crystallization."

Beyond an anneal temperature of 500°C, however, carrier lifetime of 130°C-deposited a-Si:H stacks showed more degradation with increasing anneal temperature. The XRD spectra depicted in Fig. 5 showed no obvious diffraction signals of a-Si:H crystalline phase, except for the sample of 130°C-deposited a-Si:H stacks annealed at 600°C. The XRD spectra indicated that the abrupt drop of carrier lifetime for 130°C-deposited a-Si:H stacks with anneal temperature increasing to 600°C is apparently attributed to the formation of epitaxial crystallization even though such diffraction signals are not observed at anneal temperature of 500°C and 550°C. As for 200°C-deposited a-Si:H stacks, the lifetime change from anneal temperature of 500°C to 600°C showed smoother dependence than those deposited at 130°C, which is consistent with the outcome that each corresponding XRD spectrum showed no obvious crystallization phase. As a result, the causal relationship between the lifetime degradation at an excessive thermal treatment and the formation of epitaxial crystallization can be reasonably speculated. Furthermore, regarding the role of dihydrides as intermediates of hydrogen interchanging therein, even though Si-H_2 bonding could potentially provide a better surface passivation, it is also susceptible to epitaxial crystallization under an excessive thermal budget.

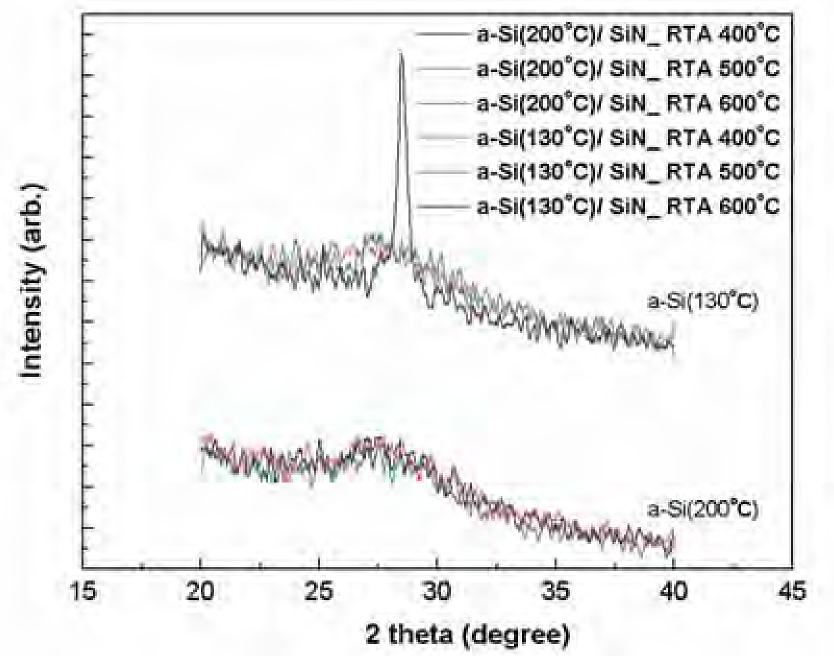


Figure 5. XRD spectra for 130°C and 200°C-deposited a-Si:H dual stacks (a-Si:H/SiN_x:H) with RTA 400°C, 500°C and 600°C.

While the results of carrier lifetime changes under various thermal treatments could be consistently interpreted in terms of the formation of epitaxial crystallization, a couple of points are worthy of further investigation in order to achieve better thermal stability of the passivation stacks. Firstly, the recipe of SiN_x:H film deposition needs to be optimized, to diminish the plasma damage upon a-Si:H film surface and to supply more atomic hydrogen with a lower thermal activation energy. Secondly, thermal profile (temperature vs. duration) of the entire fabrication process needs to be carefully designed, in order to avoid either insufficient or excessive thermal treatment.

Conclusions

For single-layer a-Si:H films, the higher lifetime improvement provided by films deposited at lower temperatures (e.g. 130°C) could be attributed to their dihydride-rich composition, supplying a higher concentration of atomic hydrogen and providing a lower thermal activation energy of hydrogen passivation. Compared with the single a-Si:H layer, the a-Si:H/SiN_x:H stack showed better surface passivation performance, and the carrier lifetime can be further improved by an adequate thermal treatment (450°C/five minutes). The more pronounced improvement for 130°C-deposited a-Si:H/SiN_x:H stacks is again consistent with the possibility that dihydride-rich structures could contribute hydrogen to enhance passivation. Furthermore, the thermal activation threshold changed from the deposition temperature of a-Si:H to that of SiN_x:H when the SiN_x:H capping layer was deposited on top of the a-Si:H films. When excessive thermal annealing (600°C/five minutes) was applied, carrier lifetime showed more severe degradation for 130°C-deposited a-Si:H stacks, and the phase signals of epitaxial crystallization of a-Si:H films revealed by XRD spectra also demonstrated the detrimental effect on surface passivation. As a result, even though Si-H_2 bonding could potentially provide better surface passivation, it is also more susceptible to the epitaxial crystallization under an excessive thermal budget.

Acknowledgements

The author would like to thank Prof. C.C. Tsai and her students, Y.T. Huang and Y.W. Tseng from the department of photonics of NCTU for PECVD systems of amorphous silicon deposition.

References

[1] Mitchell, J., Macdonald, D. & Cuevas, A. 2009, "Thermal

activation energy for the passivation of the n-type crystalline silicon surface by hydrogenated amorphous silicon", *Applied Physics Letters*, Vol. 94, pp. 162102.
[2] Glunz, S.W. et al. 2005, "Comparison of different dielectric passivation layers for application in industrially feasible high-efficiency crystalline silicon solar cells", *Proc. 20th EU PVSEC*, Barcelona, Spain, pp. 572–577.
[3] Macdonald, D. & Cuevas, A. 2000, "The trade-off between phosphorus gettering and thermal degradation in multicrystalline silicon", *Proc. 16th EU PVSEC*, Glasgow, Scotland, pp. 1707–1710.
[4] Schultz, O., Riepe, S. & Glunz, S.W. 2004, "Influence of high temperature processes on multicrystalline silicon", *Solid State Phenomena*, Vol. 95–96, pp. 235–240.
[5] Mäckel, H. & Lüdemann, R. 2002, "Detailed study of the composition of hydrogenated SiN_x layers for high-quality silicon surface passivation", *Journal of Applied Physics*, Vol. 92, pp. 2602–2609.
[6] Romijn, I.G. et al. 2005, "Passivation mc-Si solar cells using SiNx:H: from magic to physics", *Proc. 20th EU PVSEC*, Barcelona, Spain, pp. 1352–1355.
[7] Chen, F. et al. 2007, "Relationship between PECVD silicon nitride film composition and surface and edge passivation", *Proc. 22nd EU PVSEC*, Milan, Italy, pp. 1053–1060.
[8] Dauwe, S. et al. 2002, "Experimental evidence of parasitic shunting in silicon nitride rear surface passivated solar cells", *Progress in Photovoltaics: Research and Applications*, Vol. 10, pp. 271–278.
[9] Robertson, J. 1994, "Defects and hydrogen in amorphous silicon nitride", *Philosophical Magazine B (Physics of Condensed Matter, Electronic, Optical and Magnetic Properties)*, Vol. 69, pp. 307–326.
[10] Lauinger, T. et al. 1996, "Record low surface recombination velocities on 1Ωcm p-silicon using remote plasma silicon nitride passivation", *Applied Physics Letters*, Vol. 68, pp. 1232.
[11] Plagwitz, H. et al. 2006, "Amorphous Si/SiN double layers: A low temperature passivation method for diffused phosphorus as well as boron emitters", *Proc. 21st EU PVSEC*, Dresden, Germany, pp. 688.
[12] Bentzen, A. et al. 2005, "Surface passivation of silicon solar cells by amorphous silicon/silicon nitride dual layers", *Proc. 15th International Photovoltaic Science & Engineering Conference*, Shanghai, China, pp. 316.
[13] Gatz, S. et al. 2008, "Thermally stable surface passivation by a-Si:H/SiN double layers for crystalline silicon solar cells", *Proc. 23rd EU PVSEC*, Valencia, Spain, pp. 1033–1035.
[14] Mitchell, J. et al. 2005, "Electronic and structural properties of amorphous silicon on crystalline silicon wafers", *Proc. 20th EU PVSEC*, Barcelona, Spain, pp. 1004–1007.
[15] Wang, T.H. et al. 2005, "Effective interfaces in silicon heterojunction solar cells", *Proc. 31st IEEE PVSC*, Orlando, Florida, pp. 955–958.

About the Authors

Chien-Chung Huang has been with Motech Industries for a year and is currently working at the R&D division. Prior to this post, he worked for three years in TSMC's R&D division. He has an M.A. in physics from the National Tsing Hua University.

Yen-Tang Huang is a Ph.D. student at the Department of Photonics at the National Chiao Tung University. His main areas of research include a-Si thin-film solar cells and HIT solar cells.

Yi-Wen Tseng is a master's student at the Department of Photonics at the National Chiao Tung University. His main research focus is on the areas of a-Si material and HIT solar cells.

Wen-Hua Chen joined Motech's R&D division two years ago, prior to which he spent three years at TSMC's product division. He received an M.A. degree in chemical engineering from the National Cheng Kung University in 2005.

Ting Fang received her Ph.D. degree in material science and engineering from the National Tsing Hua University in 2007. She joined the R&D team of Motech Solar following her graduation three years ago.

Chi-Chun Li has a B.S. degree in physics from the National Taiwan University, and M.A. and Ph.D. degrees in electrical engineering from Princeton University. He worked for Lucent Technologies and Alcatel-Lucent from 2000 to 2008, after which he joined Motech Industries' R&D team.

Professor C.C. Tsai received her Ph.D. in physics from the University of Chicago in 1978. She is now a professor at the Department of Photonics at the National Chiao Tung University. Her research interest includes amorphous/polycrystalline silicon, solar cell and TFT-LCD technology.

Enquiries

Motech Industries
Tainan Science-Based Industrial Park
No. 2, Da-Shun 9th Rd.,
Hsin-Shi, Tainan 74145,
Taiwan
Tel: +886 6505 0789

Developing novel low-cost, high-throughput processing techniques for 20%-efficient monocrystalline silicon solar cells

Ajeet Rohatgi & **Daniel Meier**, Suniva Corp., Norcross, Georgia, USA

ABSTRACT
The workhorse of the photovoltaic industry, crystalline-silicon solar cells, continues to have additional headroom for conversion efficiency improvement as well as decreased production costs. As some companies have already demonstrated, clear pathways exist to bring about the achievement of >20%-efficient monocrystalline cells through the use of existing and novel production techniques. A newcomer to the solar cell and module sector, Suniva, has rapidly become a volume manufacturer using innovations originally developed at the University Center of Excellence in Photovoltaics (UCEP) at the Georgia Institute of Technology. This paper discusses the company's first- and second-generation production technologies, including the implementation of ion implantation as a high-volume process, as well as details of cell-making approaches in the development stage.

Introduction
Suniva was founded in August 2007 with the aim of producing high-efficiency crystalline-silicon solar cells based on technology developed at UCEP. After a little more than a year, the company's first commercial solar cell was produced at a newly constructed 30MW per annum manufacturing facility in Norcross, Georgia. The company then expanded capacity to 170MW per annum, with round-the-clock operations producing 156mm pseudosquare cells on p-type Cz wafers with efficiencies of approximately 18%. The company also markets own-branded modules made with its cells; a system equipped with the modules – a 3MW array in India – is shown in Fig. 1. Suniva's cells have also been incorporated into several >1MW ground-mount systems in Italy as well as other locations in the United States and elsewhere.

The company's goal is to produce silicon solar cells and modules with the right balance of cost and efficiency to attain grid parity with fossil fuel-produced electricity at US$0.10/kWh. Levelized cost of energy (LCOE) is a key method for judging the market worthiness of a PV technology since the metric accounts for the total installed system cost and energy production over the life of a PV system. High cell efficiency is arguably the most effective way to shrink LCOE because it reduces the cost of each link in the silicon PV value chain.

Cost modelling summarized in Fig. 2 shows that 18–20% efficient modules at a price of US$1.25/W can produce electricity at US$0.10/kWh. The Solar Advisor Model (SAM) from the Department of Energy's National

Figure 1. Part of a 3MW (DC) grid-connected solar farm, Karnataka, India, the largest utility-owned grid-connected solar project in the country.

Renewable Energy Laboratory (NREL) was used for these calculations for a residential PV system in Phoenix, Arizona, using the DOE-projected 2015 balance-of-systems cost of US$2.05/W for a 20% module. Suniva's approach to moving into the US$0.08–0.10/kWh band of grid parity is to raise cell efficiency by building simple yet effective cell structures on commercial-grade monocrystalline silicon wafers without appreciably increasing the number of processing steps and their cost.

First-generation production cells
The first-generation production cells (known as ARTisun) have a traditional

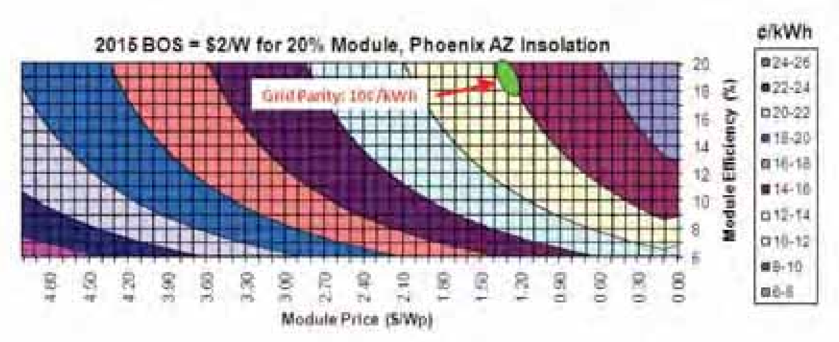


Figure 2. Contour plot of the levelized cost of energy (LCOE) for a residential solar system as a function of module efficiency and price.

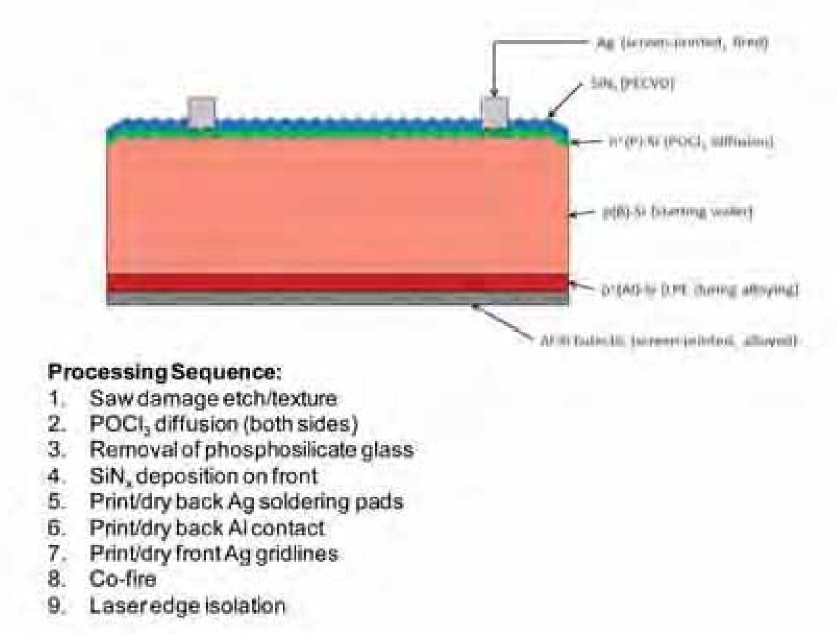


Figure 3. Structure and processing sequence for first-generation production cell ('LPE' refers to liquid phase epitaxy).

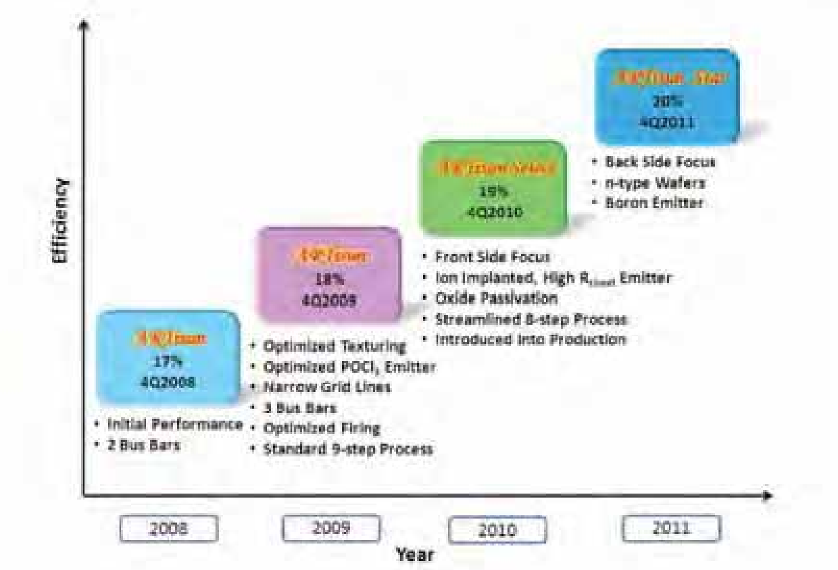


Figure 4. Suniva's roadmap progression from first production in 2008 through three major developments, culminating in 20% production cells in 2011. The first two developments (2009, 2010) have been completed on schedule.

n^+pp^+ structure, with $POCl_3$ emitter diffusion, plasma-enhanced chemical vapour deposition (PECVD) silicon-nitride antireflective (AR) coating, screen-printed and co-fired back-silver, back-aluminium, and front-silver contacts, as illustrated in Fig. 3. Cells are fabricated on 156mm Cz wafers (239cm^2), with an efficiency of approximately 18%. Nine process steps are required, where each step is associated with the wafer travelling through a distinct and major piece of equipment.

Fig. 4 shows the company's technology roadmap for driving the cell efficiency from 17% in 2008 to 20% in 2011. The roadmap calls for three technology developments in three successive years. The first development in 2009 involved optimization of each layer of the basic 17%-efficient screen-printed solar cell. Consistent with the roadmap, optimization was carried out for the surface texturing, for the emitter diffusion and sheet resistance, for the SiN_x AR coating, and for the metal pastes and single-firing cycle used to make screen-printed contacts to the cell. These process improvements reduced reflection and shading to improve short-circuit current density (J_{sc}), provided an excellent aluminium back-surface field (Al-BSF) to enhance the open-circuit voltage (V_{oc}), and produced high-quality contacts with fill-factor (FF) above 0.79. These advances raised the efficiency of the baseline cells from 17% to 18% in 2009, on schedule and at zero additional cost.

Pictures of the front and back of the first-generation production cell are shown in Fig. 5, while Fig. 6 shows the I-V curve. The high FF is characteristic of high-quality contacts and optimum grid/cell design.

Second-generation production cells

Early work at Georgia Institute of Technology resulted in a novel cell process for producing laboratory cells (4cm^2 FZ substrate) with efficiencies up to 20.1%, as measured by Sandia National Laboratories [1,2]. These devices came to be known as 'STAR' cells, an acronym for "simultaneously diffused, textured, in-situ oxide AR-coated." The arrangement for processing these cells is depicted in Fig. 7. A p-type silicon solar cell wafer (S) is located in a quartz boat between a boron source wafer (B) and a phosphorus source wafer (P). On loading the boat into a standard quartz tube, diffusion of boron into one side of the wafer and phosphorus into the other side is accomplished at an elevated temperature in an inert gas. The dopant atoms simply move from the surface of the source wafer to the surface of the solar cell wafer where they are incorporated. After a period of time, the inert gas is changed to oxygen in order to grow a thick thermal oxide for both surface passivation and antireflective coating purposes.

The appeal of this patented process is that it diffuses a phosphorus emitter and a boron back-surface field, and grows a passivating thermal oxide layer all in one thermal cycle using a standard oxidation furnace and with no diffusion glass to strip [3]. It was also found that impurities associated with the dopant coatings on the source wafers largely stayed with the source wafers and were not transported to the solar cell wafer - a sort of 'impurity filtering.' Measured reverse saturation current density (J_{0e}) values for the phosphorus emitter and its surface were quite respectable at 140fA/cm^2 for a 50Ω/sq emitter (limits V_{oc} to 680mV) and 85fA/cm^2 for a 100Ω/sq emitter (limits V_{oc} to 693mV).

Although the STAR process can produce high-efficiency cells, its implementation in volume manufacturing is difficult because the source wafers must be regenerated after each run and the source wafers occupy slots in the boat, which limits the throughput of the solar wafers. However, some of the key advantages of the STAR

Figure 5. Pictures of the front and back of a production cell fabricated from a 156mm pseudosquare Cz wafer.

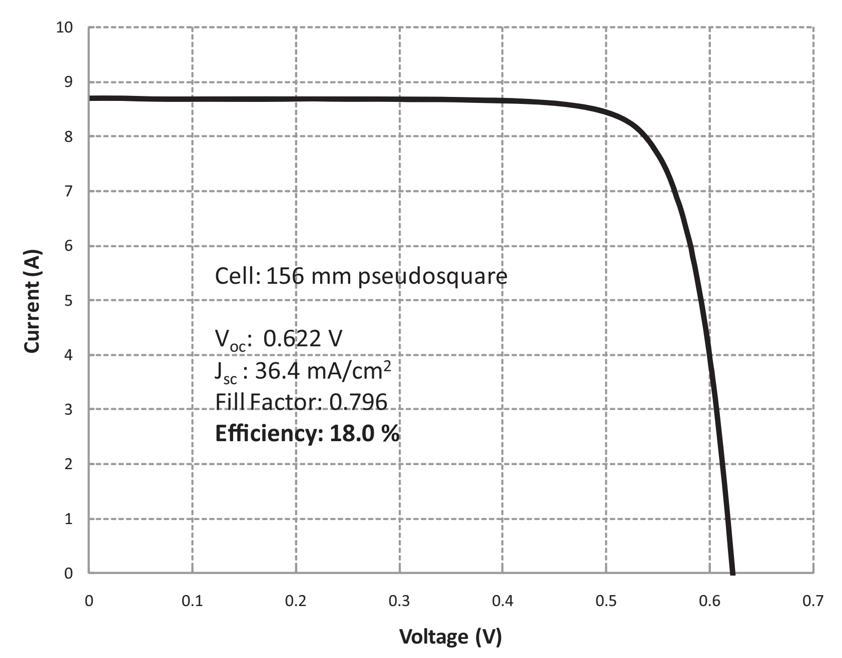


Figure 6. I-V curve for three-bus production cell (239cm^2).

process (clean flux of dopant atoms, no diffusion glass formation, in-situ thermal oxide) can be retained in the production-worthy process of ion implantation.

The company has developed a streamlined ion implantation process (known as ARTisun Select) for producing the cell structure shown in Fig. 8. Compared to the $POCl_3$ process, the novel ion implantation scheme reduces the number of process steps from nine to eight. A phosphorus implant step has been added to form a homogeneous emitter, but the phosphosilicate glass removal step and the laser edge-isolation step have been eliminated. Both steps are considered "subtractive", referring to the removal of a material layer created earlier in the process (in this case, phosphosilicate glass (PSG), and an n^+ layer that wraps from front to back of the wafer). Thus, once the saw damage is etched (an unavoidable subtractive step), all other processing steps are additive since the cell structure is built layer by layer. Note that the implant damage must be annealed (step 3), but since this is performed in an oxygen ambient, a passivating thermal oxide is obtained at no additional cost.

Several thousand cells were fabricated in pilot-scale runs prior to introducing this process into full production, with average efficiencies of approximately 19%. The I-V curve of one of the cells produced is provided in Fig. 9. The new process improved the cell efficiency by about 1% (absolute) relative to the $POCl_3$ cell, in conjunction with one fewer processing step. This improvement in efficiency can be attributed to several factors: a highly uniform emitter with elevated sheet resistance; the passivation of that emitter with thermal oxide; excellent screen-printed contacts to the ion-implanted emitter; and the recovery of active cell area by eliminating the laser edge-isolation trench. This required engineering an optimized combination of precise emitter-doping profiles along with metal paste composition and firing to capture the benefits of a lightly doped emitter (37.7mA/cm^2), while maintaining a high fill-factor (0.798), as shown in Fig. 9.

The introduction of this novel low-cost, high-throughput manufacturing process is the first instance of ion implantation being introduced into volume production of high-efficiency solar cells. The technique offers several advantages over conventional $POCl_3$ and in-line diffusion technologies including single-side dopant incorporation; in-situ oxidation for superior surface passivation; elimination of the PSG removal step; elimination of the junction edge-isolation step; precise doping control and novel dopant profile engineering by varying implantation dose, implantation energy, and implant damage annealing recipe; and patterned dopant regions for selective emitter and possibly interdigitated back-contact-type cell structures.

Attempts to use ion implantation in solar cell processing are not new: the technique was used in the 1980s to produce small-area R&D-type

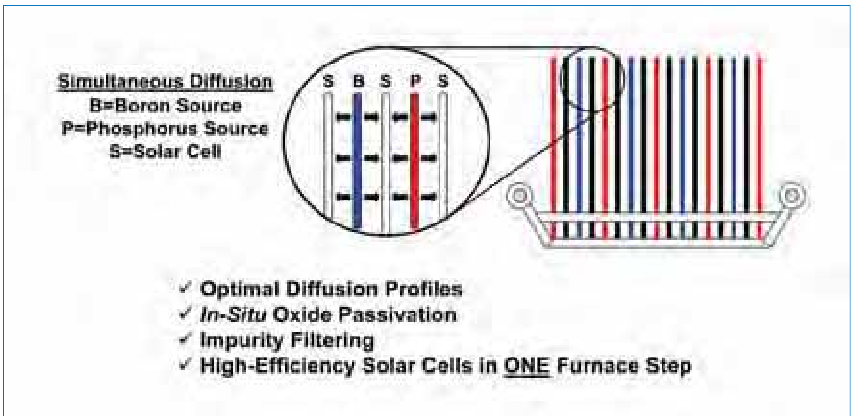


Figure 7. Original STAR process from UCEP, used to produce 20% cell efficiency (4cm^2 FZ), showing a solar cell wafer sandwiched between a boron source wafer and a phosphorus source wafer in a quartz boat.

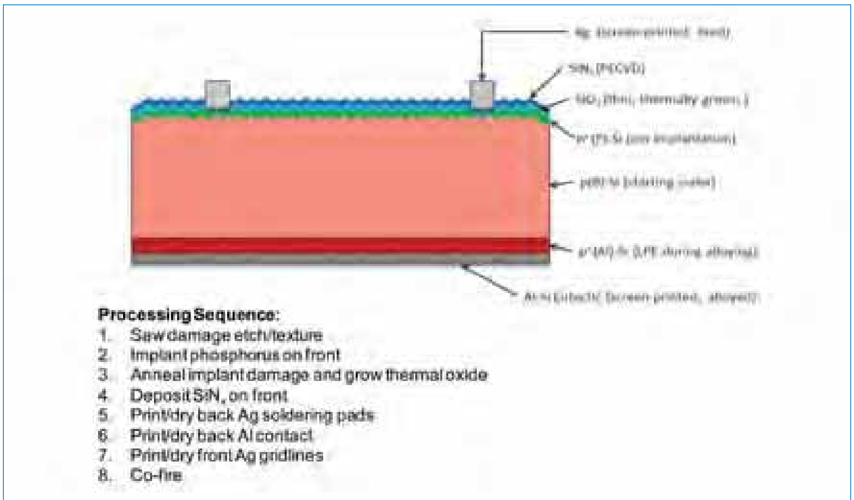


Figure 8. Structure and eight-step fabrication process for ion-implanted cell with homogeneous emitter.

monocrystalline cells [4–7]. However, implantation was abandoned for PV applications because of a common perception that it was too slow and too costly for mass production of silicon cells. Recently, interest in ion-implanted emitters has reawakened [8], with the potential of the implantation technique recognized as a way to produce advanced high-efficiency cell structures with fewer processing steps. In partnership with Varian Semiconductor Equipment Associates (VSEA), which led the development of high beam current, fast wafer handling, high-throughput implanters specifically designed for the PV industry, the potential of this enabling technology was demonstrated through innovation and volume production [9].

A screen-printed selective-emitter cell structure, as shown in Fig. 10, using two in-situ ion implants has also been successfully demonstrated. Firstly, the entire wafer is implanted with a lower dose to create the high sheet resistance field region. A proximity mask is then inserted between the wafer and the ion beam without removing the wafer, and a second implant follows. Openings in the mask define a grid-pattern of heavily doped regions to which the front screen printed contacts must be aligned. As in the case of the homogeneous emitter, the implant damage is annealed in a tube furnace similar to those used for $POCl_3$ diffusions. The process sequence is essentially the same as that for the homogeneous emitter.

In-situ oxidation also helps in contact alignment if this alignment is carried out by pattern recognition. Because the oxide grows much faster on the heavily-doped n-type regions, the grid pattern is easily visible after oxidation. Following the implant anneal, the wafers are sent through a standard PECVD SiN_x deposition step. Since the passivating oxide under the SiN_x contributes to the AR effect, a thinner SiN_x layer is needed which enhances the throughput of the PECVD machine. While most selective-emitter strategies being attempted or used in production require one to four additional steps, the same structure can be achieved with one less process step using the masked ion implantation approach.

The value of an implanted selective emitter over its homogeneous emitter counterpart is clearly seen in the short wavelength range of the internal quantum efficiency data shown in Fig. 11. However, the corresponding efficiency benefit relative to a homogeneous implanted emitter is modest at 0.1–0.2% (absolute) because of the superior ion-implanted homogeneous emitter process, which also produces ~19% cells. An increase in J_{sc} (0.3mA/cm^2) and V_{oc} (2mV) is partially offset by a decrease in FF (0.004) associated with the higher sheet resistance in the field. In the interest of higher implantation

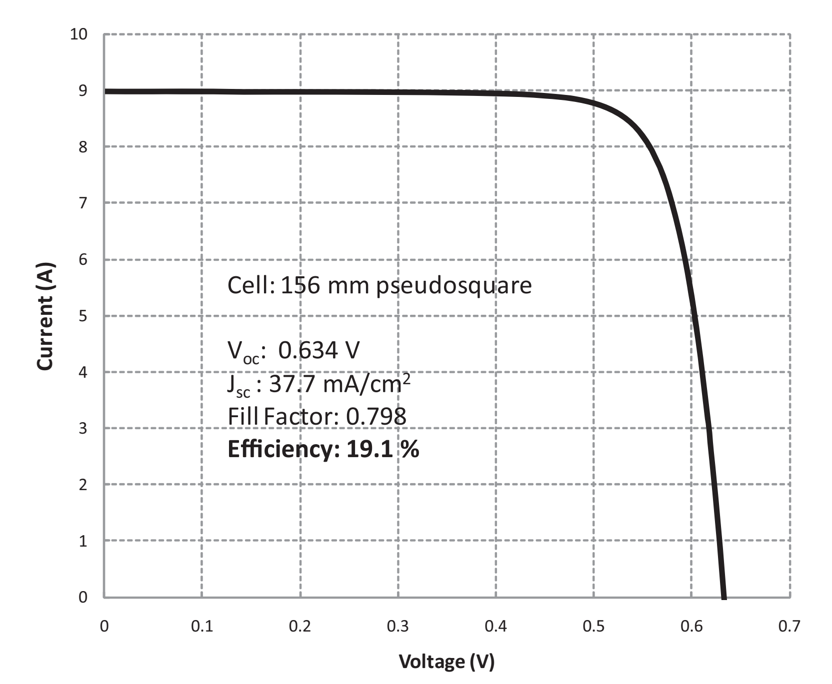


Figure 9. I-V curve of ion implanted cell (239cm^2) with homogeneous emitter.

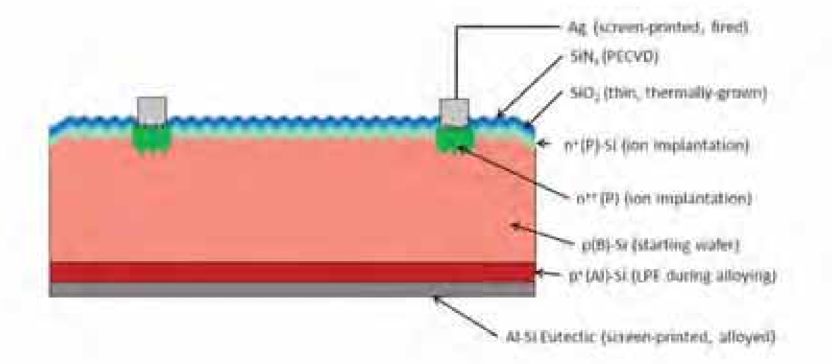


Figure 10. Cell structure with ion-implanted selective emitter instead of a homogeneous emitter.

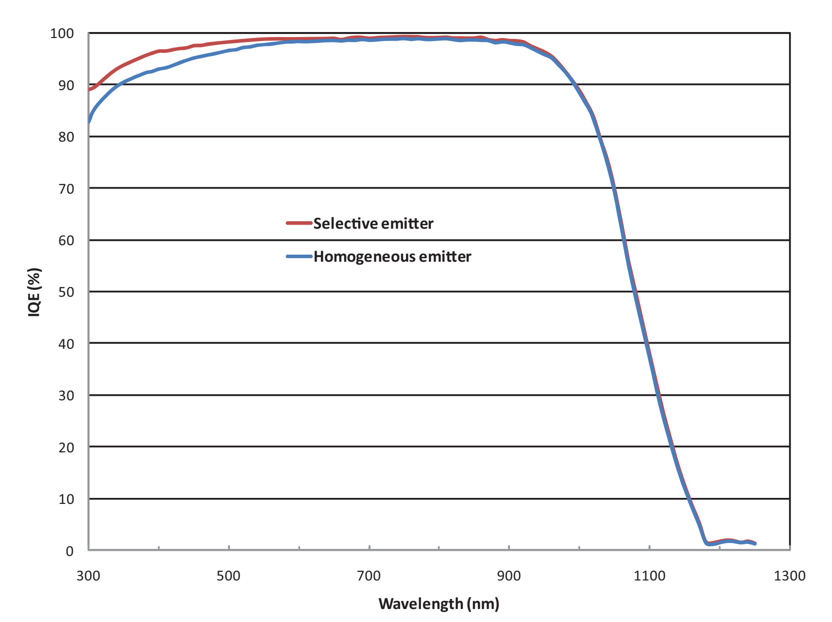


Figure 11. Measured IQE for cells having a homogeneous emitter and a selective emitter.

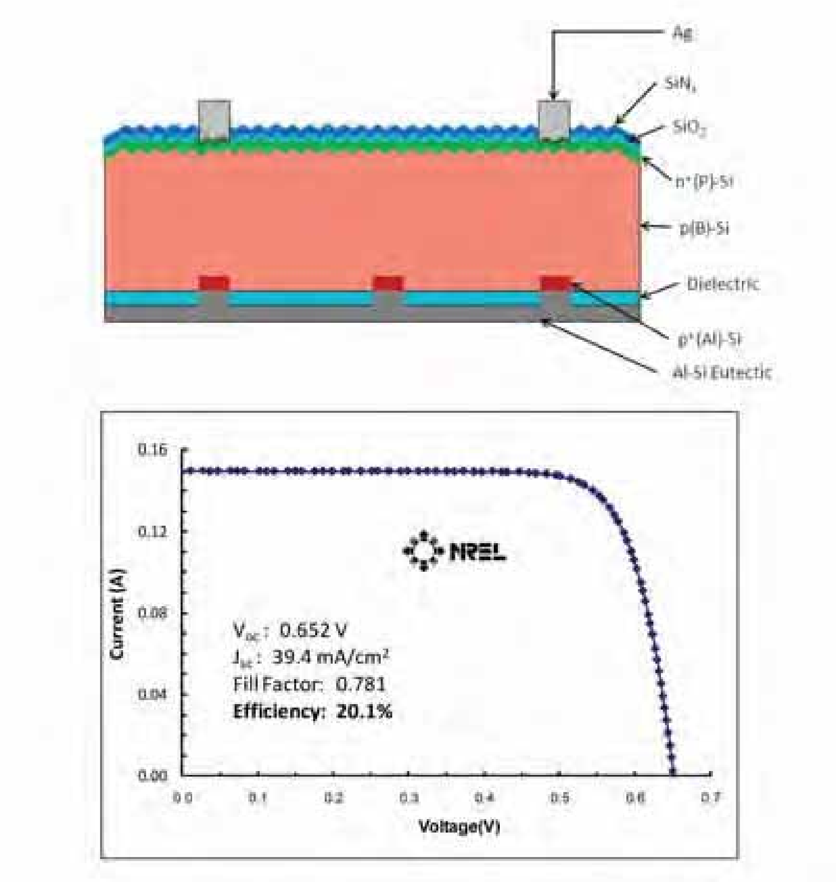


Figure 12. Structure of Delta-STAR cell (top) and corresponding current-voltage performance (4cm^2 FZ) (bottom).

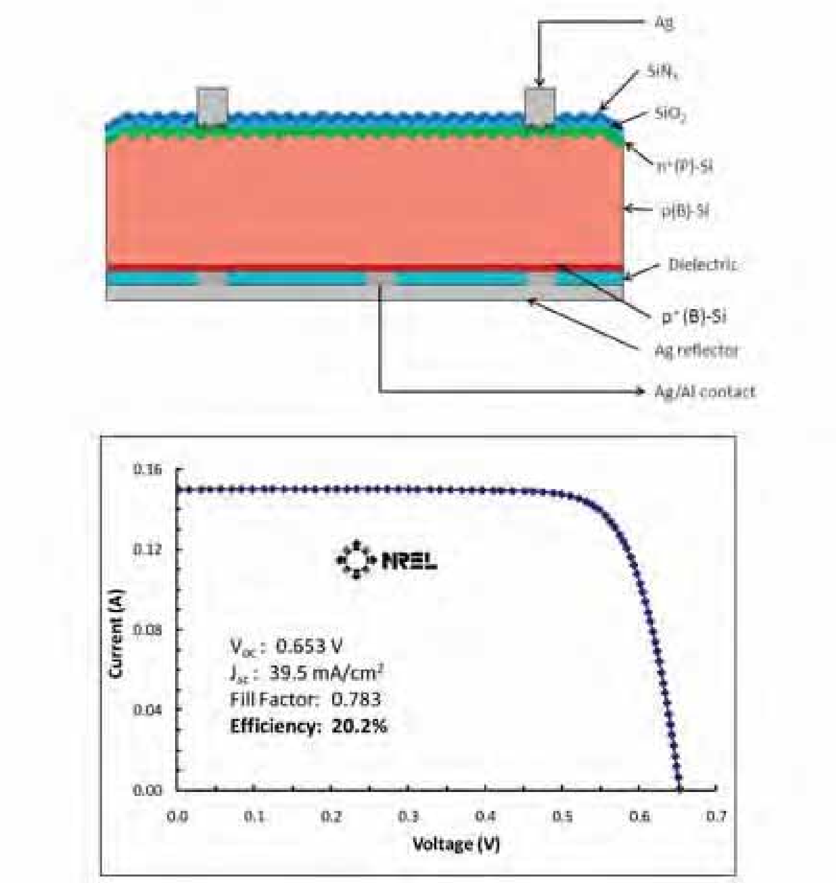


Figure 13. Structure of Beta-STAR cell (top) and corresponding current-voltage performance (4cm^2 FZ)(bottom).

throughput and simplicity, the production of implanted cells with a homogeneous emitter has begun. In the future, a pattern-recognition approach to grid-line alignment may be adopted to capture the added benefit of the selective emitter.

High-efficiency laboratory scale cells

The third development step in the technology roadmap calls for the development of 20%-efficient solar cells with simplified processing and low-cost screen-printed contacts. Detailed characterization and modelling of the 19% full Al-BSF cell shows a back-surface recombination velocity (BSRV, a measure of surface passivation) of 400cm/sec and a back-surface reflectance (BSR, a measure of light trapping) of 65%. In addition, a full Al-BSF results in 0.5% efficiency loss and wafer warpage when the wafers are thinned down to ~120µm. To address these issues, two screen-printed cell structures have been developed (Delta-STAR and Beta-STAR), which include rear dielectric passivation to increase BSR and lower BSRV, while eliminating wafer warpage.

Fig. 12 shows the structure and the corresponding efficiency of the NREL-validated 20% Delta-STAR cell. In this structure, an oxide/SiN_x stack provides the rear passivation and local Al BSF points are formed by opening vias either using a screen-printed etching paste or a laser. An Al paste was screen-printed on the rear side and cofired with the front Ag grid to form the local BSF through the vias without affecting the quality of the oxide/SiN_x stack passivation. The Delta-STAR structure raised the BSR from 65% to 93% and lowered the BSRV from 400cm/sec to 150cm/sec, resulting in 20.1% efficient cells.

Fig. 13 shows a second approach to 20% efficient cells, a feat that involves dielectric passivation of the boron back-surface field (B-BSF), referred to as the Beta-STAR structure. Unlike the Delta-STAR structure where the dielectric has the burden of improving both the BSR and the BSRV, in the second structure a passivated semitransparent B-BSF lowers the BSRV while the metal-capped dielectric provides the enhancement in BSR. Local ohmic contacts are made to the B-BSF by cofiring Ag/Al dots through the rear dielectric and Ag gridlines on the front. In this structure, the dielectric passivation quality does not need to be very high because of the presence of the B-BSF. In fact, detailed analysis showed that the dielectric/BSF interface has a recombination velocity of 45,000cm/sec, which translates into a BSRV of ~140cm/sec at the p/p^+ interface. This structure also has a BSR of 93% and a cell efficiency of 20.2%, both of which were independently validated by NREL.

Both the Delta- and the Beta-STAR structures have been demonstrated on 4cm^2

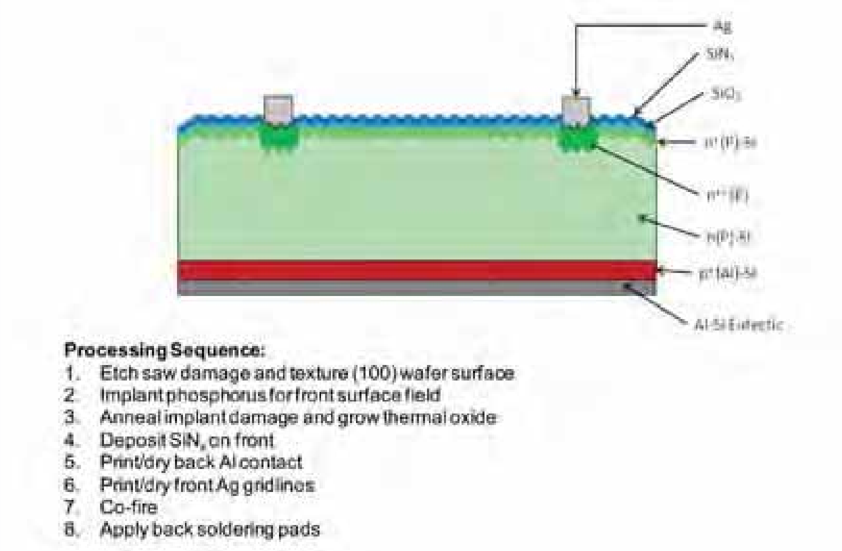


Figure 14. Cell with phosphorus-doped selective FSF, oxide passivated front surface, and aluminium alloy rear p-n junction.

R&D cells thus far as proof of concept, and work continues to scale up these structures for mass production. In addition, high-efficiency n-type cells are in development as well as a low-cost IBC process.

Initial n-base cells

Fig. 14 shows the structure and processing sequence for a simple n-base cell fabricated from 156mm pseudosquare n-type Cz wafers. This cell is known as 'PhosTop' because the top surface is doped with phosphorus rather than boron, as is usually the case for an n-base cell. The quality, uniformity, and reproducibility of the aluminium alloy p-n junction was shown to be satisfactory for silicon solar cells in 2001, with the first PhosTop cells having an efficiency of 14.2% on Sb-doped dendritic web silicon ribbon [10]. The patent for the structure and fabrication process [11] belongs to Suniva. Since then, other groups have explored this simple structure and process using monocrystalline n-type wafers [12-14].

The PhosTop structure is similar to that of the p-base ARTisun cell shown in Fig. 3. The differences between the two structures is that in the former, the Al-alloyed p-n junction lies at the rear of the cell, the front surface field (FSF) is selectively doped, and the front surface is passivated with a thermal oxide layer. High resistivity n-type wafers are used to ensure sufficiently high lifetime to support a rear-junction cell. Apart from removing the saw damage from the starting wafer, the processing sequence is strictly additive and is accomplished in just eight steps, as illustrated in Fig. 14. The selective phosphorus FSF is formed by a masked implant [9] along with a thermal anneal of implant damage. The front SiO_2 passivation layer is obtained as a by-product of the anneal at no cost. All PhosTop process steps in Fig. 14 are well in hand, except for the last step, which is in development.

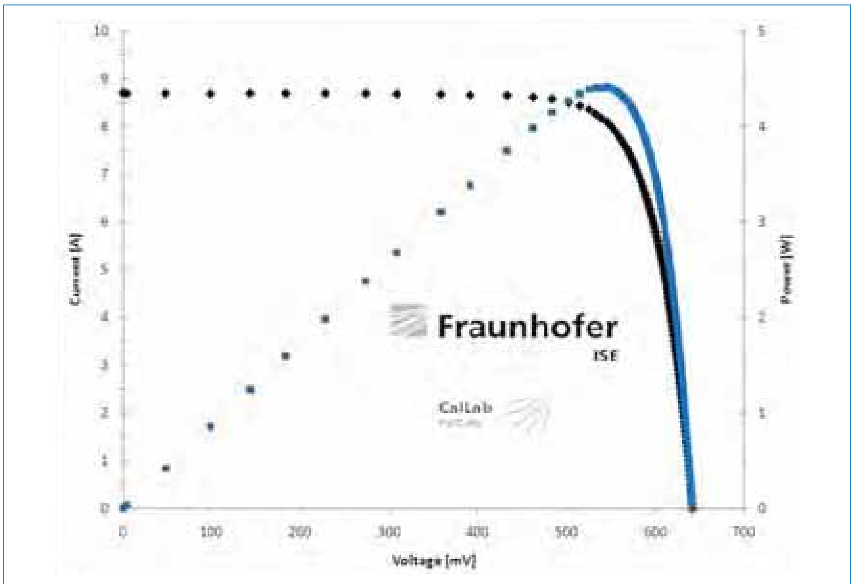


Figure 15. Certified full-area 18.5% cell fabricated from an n-type Cz wafer.

A certified I-V curve from the Fraunhofer Calibration Lab for a 156mm pseudosquare PhosTop cell (239cm^2 area) is shown in Fig. 15. A J_{sc} of 36.4mA/cm^2, V_{oc} of 0.641V, FF of 0.791, and efficiency of 18.5% show the promise of an n-base rear junction cell fabricated by ion implantation. This cell had no solderable back pads. Although small-area (4cm^2) R&D cells with alloyed Al rear emitters have reached 20.0% with amorphous Si passivation of the p$^+$ emitter surface [15] and 20.1% with Al_2O_3 passivation [16], it is believed that these cells represent the highest efficiency achieved for simple, full-area, production-worthy devices of this type where the alloyed aluminium remains in contact with the p$^+$ emitter.

Conclusion

Starting initial production with 17% efficient screen-printed p-base cells having $POCl_3$ emitters, Suniva then raised its production efficiency from 17 to 18% on enhanced cells. This improvement was accomplished through optimization of each layer of the traditional cell at zero additional cost. Recently, the company pioneered the use of ion implantation for volume manufacturing of high-efficiency Si cells, starting production of 19%-efficient cells with ion-implanted, high sheet resistance, and homogeneous phosphorus emitters. This technology innovation raised the cell efficiency by another 1% (absolute) while eliminating one complete process step, with improved efficiency attributed to a higher sheet resistance emitter with thermal oxide passivation and the recovery of active front cell area by eliminating laser edge isolation.

A family of ~19% efficient ion implanted selective emitter cells has also been developed, but they offer only a modest improvement in efficiency over the high-performance homogeneous emitter with high sheet resistance. Efforts are under way to scale to volume 20% p-base laboratory scale screen-printed cells, which have been demonstrated at UCEP by improved back surface passivation and reflection. Work on 156mm n-base cells has also begun, with 18.5% top-surface, phosphorus-doped aluminium-alloyed back-junction cells fabricated using a simple process.

Acknowledgments

The authors gratefully acknowledge valuable contributions from the R&D and manufacturing staffs at Suniva, the UCEP staff, and our partners at VSEA.

References

[1] Krygowski, T. & Rohatgi, A. 1998, "A simultaneously diffused, textured, in situ oxide AR coated solar cell process (STAR process) for high efficiency silicon solar cells", *IEEE Transactions on Electron Devices*, Vol. 45, pp.

194–199.
[2] Krygowski, T., Rohatgi, A. & Selzer, T. 1999, "A novel processing technology for high efficiency silicon solar cells", *Journal of The Electrochemical Society*, Vol. 146, pp. 1141–1146.
[3] U.S. patent number 5,972,784, October 26, 1999.
[4] Douglas, E.C. & D'Aiello, R.V. 1980, "A study of the factors which control the efficiency of ion implanted silicon solar cells", *IEEE Transactions on Electron Devices*, ED 27, pp. 792–802.
[5] Spitzer, M.B., Tobin, S.P. & Keavney, C.J. 1984, "High efficiency ion implanted silicon solar cells", *IEEE Transactions on Electron Devices*, ED 31, pp. 546–550.
[6] Westbrook, R.D., Wood, R.F. & Jellison, Jr., G.E. 1987, "Glow discharge implanted, thermally annealed, oxide passivated silicon solar cells of 19% efficiency", *Applied Physics Letters*, Vol. 50, pp. 469–471.
[7] Wood, R.F., Westbrook, R.D. & Jellison, Jr., G.E. 1987, "Excimer laser processed oxide passivated silicon solar cells of 19.5 percent efficiency", *IEEE Electron Device Letters*, EDL 8, pp. 249–25.
[8] Janssens, T. et al. 2010, "Implantation for an excellent definition of doping profiles in Si solar cells", *Proc. 25th EU PVSEC*, Valencia, Spain.
[9] Gupta, A. et al. 2010, "High efficiency selective emitter cells using in-situ patterned ion implantation", *Proc. 25th EU PVSEC*, Valencia, Spain.
[10] Meier, D.L. et al. 2001, "Aluminum alloy back p-n junction dendritic web silicon solar cell", *Solar Energy Materials & Solar Cells*, Vol. 65, pp. 621–627.
[11] U.S. patent number 6,262,359, July 17, 2001.
[12] Cuevas, A. et al. 2003, "Back junction solar cells on n Type multicrystalline and Cz silicon wafers", *Third World Photovoltaic Energy Conference*, Osaka, Japan.
[13] Schmiga, C., Nagel, H. & Schmidt, J. 2006, "19% efficient n type Czochralski silicon solar cells with screen printed aluminium alloyed rear emitter", *Progress in Photovoltaics: Research and Applications*, Vol. 14, pp. 533–539.
[14] Weeber, A.W. et al. 2008, "High efficiency solar cells with printed Al alloyed rear contacts", *Solid State Technology*, March edition.
[15] Bock, R. et al. 2010, "The ALU+ concept: N type silicon solar cells with surface passivated screen printed aluminium alloyed rear emitter", *IEEE Transactions on Electron Devices*, Vol. 57, pp. 1966–1971.
[16] Schmiga, C., Hermle, M. & Glunz, S.W. 2008, "Towards 20% efficient n type silicon solar cells with screen printed aluminium alloyed rear emitter", *Proc. 23rd European PVSEC*, Valencia, Spain, pp. 982–987.

About the Authors

Ajeet Rohatgi, founder and CTO of Suniva, is a Regents' Professor and a Georgia Power Distinguished Professor in the School of Electrical Engineering at the Georgia Institute of Technology, where he joined the ECE faculty in 1985 and was founding director of the University's Center of Excellence for Photovoltaic Research and Education. Rohatgi continues his research interests in the development of cost and efficiency roadmaps for attaining grid parity with silicon PV, and innovations in cell design and technology. He received a B.S. in electrical engineering from the Indian Institute of Technology, Kanpur; an M.S. in materials engineering from the Virginia Polytechnic Institute and State University; and a Ph.D. in metallurgy and material science from Lehigh University. Prior to joining the electrical engineering faculty at Georgia Tech, Rohatgi was at the Westinghouse Research and Development Center, and became a Westinghouse Fellow while working on the science and technology of photovoltaic and microelectronic devices. He is an IEEE Fellow and recipient of the William R. Cherry Award, has published more than 370 technical papers in the PV field, and has been awarded 11 patents.

Daniel Meier is chief scientist of Suniva, where he leads the development of new technology and advises on a variety of technical areas. He works closely with the R&D team on new device architectures and processes, and also supports the module side of Suniva's business, providing both technical and application direction. Meier joined the company as one of its first employees in 2007. He holds a B.S. from St. Vincent College and M.S. and Ph.D. from Carnegie-Mellon University, all in physics. He has published more than 75 technical papers in conference proceedings and archival journals, and holds 11 U.S. patents. Meier has also received three Westinghouse Signature Awards for excellence in engineering.

Enquiries

Email: arohatgi@suniva.com
Email: dmeier@suniva.com

Thin Film

TSMC to sell own-branded CIGS thin-film modules as first 200MW fab starts construction

TSMC chairman and CEO Dr. Morris Chang.

Moving away from its 'pure-play' foundry business model to which it has vehemently adhered in the semiconductor industry, Taiwan Semiconductor Manufacturing Company (TSMC) will directly sell copper-indium-gallium (di)selenide thin-film modules to the global market from its first 200MW plant, which broke ground recently. An initial US$258 million is being invested to build a Thin Film Solar R&D Center and production plant, using technology from Stion. The thin-film start-up is partnering with TSMC, which will be its manufacturing and technology development partner.

TSMC also announced plans to add a second phase to the facility and expand CIGS production to more than 700MW, employing around 2,000 staff at the facility in Taichung's Central Taiwan Science Park, home to its leading-edge semiconductor and newly-announced foray into the LED market.

First-phase equipment move-in was said to be planned for the second quarter of 2011, with plans to achieve initial volume production of 200MW per year in 2012. No timelines were given for the larger, second-phase capacity expansion. The first CIGS facility was said to be 110,000m^2 in size with a production area of 78,000m^2.

TSMC chairman and CEO Dr. Morris Chang (pictured) said, "Construction of this solar R&D center and fab, along with our Fab 15 Gigafab next to it, means Taichung's Central Taiwan Science Park will become home to much of TSMC's most advanced and innovative production."

R&D News Focus

GaAs solar cell from Spire sets 42.3% conversion efficiency record

Verified by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL), Spire Semiconductor, a wholly-owned subsidiary of Spire Corp., has fabricated the most efficient triple-junction, gallium arsenide (GaAs) cell, with an efficiency of 42.3% at 406 suns AM1.5D, 25C (42.2% at 500 suns). The 0.97cm^2 cell was developed as part of an NREL incubator subcontract.

Spire said that it had only taken 18 months to validate and incorporate the new concept into a production-ready cell design with world-record efficiency. This higher efficiency, next-generation GaAs CPV cell platform is now available commercially to the concentrator systems providers. The NREL incubator subcontract reached 39% efficiencies in the first phase.

Moser Baer gets Indian government grant to develop CIGS thin-film PV

Another solar PV company has joined the growing ranks of players attempting to bring CIGS thin film to market. India's Ministry of New and Renewable Energy has awarded a grant to Moser Baer India (MBI) to engage in the developmental activity of copper-indium-gallium-(di) selenide cells. MBI will conduct the development work from its corporate R&D facility in Greater Noida, Pradesh, with the efforts focused on developing a differentiated, indigenous, commercially viable CIGS technology. The monetary value of the grant or other details about the program has not been disclosed.

Moser Baer India's production facility.

Sulfurcell to debut new TÜV Rheinland approved product line

Sulfurcell Solartechnik will debut its newest prototypes for its 1.25m × 0.65m module line that has a TÜV Rheinland-confirmed efficiency rating of 10.7% and a peak output of 86.8W. Sulfurcell has been producing thin-film modules using selenide, not sulphur, in its new CIGSe modules with the intention of translating part of its production next year to CIGSe.

Sulfurcell has been working on CIGS modules to replace copper indium sulphide, or CIS technology. This past July, the company produced its first large-format CIGSe solar module prototype, which reached an efficiency of greater than 10%.

Mass production of Sulfurcell's CIS modules.

DelSolar and IBM to develop compound thin-film solar cells

DelSolar is making a move outside of its comfort zone and starting the process to develop compound thin-film solar cells with the help of IBM. The two companies are working towards improving the next-generation thin-film technology and bringing it into commercial production with hopes of making it potentially available for use in vaulted roof tops, curved glass curtain walls, other non-flat BIPV applications or extended applications such as curtains or shutters.

Solar Frontier, IBM to collaborate on development of CZTS thin-film PV technology

Solar Frontier and IBM have agreed to collaborate on the joint development of copper-zinc-tin-sulphur thin-film photovoltaics technology. IBM had said in February that it achieved 9.6% conversion efficiencies on champion cells made with the earth-abundant materials, and also recently announced that it has partnered with DelSolar to work on CZTS. CZTS-based technology uses materials that avoid heavy metals and are readily available at a lower cost.

Production News Focus

Lack of new capacity impacts First Solar's market share position, says IMS Research

The rapid capacity expansions by First Solar saw the CdTe thin-film leader scale the PV module rankings to become the number-one shipper in 2009. Although another aggressive phase of expansions has been announced, the lack of new capacity in 2010 compared to rivals, particularly Suntech and JA Solar, means First Solar has fallen to third place among module manufacturers in the third quarter, according to IMS Research.

However, the market research firm expects that weaker demand and increased pricing pressure in 2011 will enable First Solar to regain some of its market share losses from 2010 as it brings new capacity online.

First Solar to build thin-film plant in Vietnam; plans to double capacity by 2012

As part of new plans to double its manufacturing capacity to over 2.7GW by 2012, CdTe thin-film leader First Solar will build new facilities in Vietnam and the U.S. Two new four-line manufacturing plants are expected to add 500MW of capacity and be completed in 2012. Currently, First Solar is capacity constrained but is building further new lines in Malaysia and France. The Vietnam plant is the company's first in that country and follows semiconductor leader Intel in locating production in the country.

Oerlikon Solar launches upgraded Si thin-film production line, hits 11.9% cell efficiency

Oerlikon Solar has reached two milestones in its efforts to advance silicon thin-film photovoltaic technology and manufacturing. The company has launched a production line offering called 'ThinFab,' capable of hitting manufacturing costs of €0.50/Wp (US$0.64) and, in cooperation with glass partner Corning, has achieved NREL-confirmed record stabilized conversion efficiencies of 11.9% on its champion micromorph tandem-junction thin-film solar cells.

Specific enhancements include throughputs up to 100% higher than previous generation tools, 40% lower cost of ownership metrics, extended maintenance cycles, 30% lower facility energy costs, decreased scribe separation and better laser process stability, and best-in-class transmittance and light-trapping capabilities in the TCO layer.

German CIGS developer Solarion receives major investment; makes plans to build first factory

Contracts were officially signed between Walsin Lihwa and Solarion that will see Walsin invest €40 million and hold a 49% stake in Solarion. The Development Bank of Saxony contributed a grant of more than €20 million towards the Walsin investment. The first stage for the factory will consist of building an integrated cell and module factory that has a 20MW annual production capacity. Once the first stage is completed, an 180MW manufacturing plant will also be built on the site near the BMW Leipzig assembly plant.

CIS PV firm Odersun gets €10M in state loans; funds to be used to push production ramp, market entry

German thin-film PV manufacturer Odersun has received state loan guarantees totalling €10 million from the Federal State of Brandenburg. The company said that the credit line will allow it to move forward on its production ramp and facilitate the market entry of its customized solar products.

Odersun is commissioning its 20MW capacity CIS cell and module manufacturing facilities in Fürstenwalde/

Spree and expects the four already-installed production lines to be fully operational by the end of the year.

Odersun's "reel-to-reel" production process.

Masdar PV achieves 7.4% a-Si module efficiency

Masdar PV has reportedly improved the efficiency of its amorphous silicon (a-Si) solar modules to 7.4%, achieving an increase of over 1% in the past six months. "We have achieved this substantial increase in the efficiency of our modules because we have consistently focused on optimizing the production line in line with market requirements from the very outset."

Umicore invests €30 million to expand thin-film materials production

Newly-developed rotary target bonding technology will be employed as part of a €30 million investment by Umicore to expand production of rotary sputtering targets needed for thin-film PV deposition processes. The capacity expansions are to take place at all three of Umicore's existing target manufacturing facilities based in Providence, RI, Balzers, Europe and Hsinchu, Taiwan.

Umicore also highlighted that new test and development facilities would be established at its Balzers and Providence plants.

MiaSolé touts 14% efficiency solar modules

Following an announcement from ZSW for its 20.3% CIGS solar cell efficiency, MiaSolé also revealed that the NREL independently confirmed the 14.3% efficiency of the company's large-area production modules that measure one square metre in size. This marks the highest independently-confirmed efficiency for a commercial-scale CIGS module.

MiaSolé's announcement comes on the heels of its previous revelation that it had signed a 600MW contract with juwi solar to provide its CIGS modules.

ISET commences pilot manufacturing operations

International Solar Electric Technology (ISET) has initiated pilot manufacturing operations for its thin-film CIGS solar modules. The operation is set to certify the company's printing technology for the eventual expansion into volume production.

The pilot line, located in Chatsworth in the Los Angeles area, manufactures monolithically integrated CIGS modules on glass substrates with an area of one square foot. During the latest production runs, ISET stated that it accomplished 11% cell average conversion efficiency, with R&D teams producing laboratory devices with over 14% efficiency. Research efforts are said to be on track to reach 16% in the near term.

ISET's ink deposition of the CIGS absorber layer.

Apollo Solar Energy to expand tellurium production to meet expected demand

China-based material supplier Apollo Solar Energy is aggressively expanding and improving its production of 5N ultra-high-purity tellurium to meet expected growing demand from CdTe/CIGS thin-film manufacturers. Tellurium production capacity is set to increase 50%, which is expected to support sales worth US$27 million annually.

The company plans to acquire additional manufacturing equipment, including sophisticated analysis technology, and hire skilled technicians and support staff.

Thin-Film Order Focus

Anwell unit to supply at least 180MW in thin-film PV modules to distributor/developer

In what would be one of the largest orders for amorphous-silicon thin-film PV modules to date, Anwell Technologies' subsidiary Henan Sungen Solar Fab has received a deposit from an unnamed leading solar panel distributor/developer for a minimum of 180MW of amorphous-silicon thin-film PV modules to be delivered over the next three years. The deal will result in more than US$300M in projected revenue on completion of the contract, according to Anwell, with shipments scheduled to begin in October.

4JET reports high order intake for thin-film equipment

German machine supplier 4JET has reported a high order intake in its thin-film photovoltaics business. The company will supply laser equipment, edge deletion systems, glass drilling modules, and busbar stripping equipment to 10 different production lines for CIGS and CdTe manufacturing through mid-2011. In total, over 20 process modules will be supplied.

Air Liquide signs major long-term gas supply contract with 3Sun

Air Liquide has signed a major long-term contract with 3Sun – the newly formed manufacturing venture between Enel Green Power, Sharp and STMicroelectronics – to become the sole supplier of gases and services to the company. The Catania, Italy-based factory will start operations in 2011 and is expected to be the second largest Si thin-film solar factory in the world behind Sharp's facility in Japan. 3Sun's 160MWp per year output will be used by ENEL Green Power and Sharp to serve a large market that extends to Europe, Middle East and Africa. This agreement covers the supply of very large volumes of specialty gases, the pipeline supply of carrier gases and the provision of all related services.

Oerlikon Solar receives 40MW order for micromorph-Si production

August 2010 saw Oerlikon Solar and Hunan Gongchuang Photovoltaic Science & Technology sign a contract as part of the 60-year celebration for commercial ties between China and Switzerland. The companies have built on this contract with Gongchuang's recent order of a 40MW micromorph turnkey production line, which is also known as the FAB 1200. The production line is expected to start mass production by the end of 2011, with around 330,000 solar modules being manufactured per year.

Business News Focus

News

First Solar adds 380MW of new expanded European contracts for 2011

A key aim for First Solar in 2010 has been to focus on broadening its customer base in Europe to mitigate potential fluctuations in core markets such as Germany. In 2009, 71% of sales were to Germany but they declined to around 50% by the second quarter of this year as both utility-scale projects went ahead in the U.S. and important emerging markets in Europe, such as France and Italy continued to grow. Expanded contracts with seven key customers in Europe led to a 380MW increase in module supply agreements for 2011.

With over 2.2GW of captive projects in its pipeline, First Solar is continuing to attempt to retain full factory loading of its CdTe thin-film lines, crucial to its cost leadership position.

NanoMarkets releases report examining thin-film PV materials market

NanoMarkets recently published a new report entitled "Thin-Film Photovoltaics Materials Markets, 2011 and Beyond." The report studies and forecasts NanoMarkets' prognosis on materials sales for thin-film silicon, cadmium telluride and CIGS PV. Additionally, it examines the opportunities for materials in the TFPV space as well as giving an eight-year projection for core absorber materials, electrode, substrates and encapsulant markets.

NanoMarkets concedes that over the past year, changes have occurred in the industry, including First Solar's use of CdTe as a cost leader for solar panels and TFPV showing promise for its extensive use in BIPV projects. However, the research report notes that as the silicon shortage has declined, the case for using TFPV technology in the place of crystalline silicon PV has also diminished. Nevertheless, NanoMarkets' report anticipates that the TFPV will produce US$5.9 billion in 2016, compared to US$2.1 billion in 2011.

Launch of Cambridge's Eight19 to focus on OPV with a US$7 million backing from Carbon Trust, Rhodia

The OPV market received more competition with the announcement from Cambridge Enterprise, the University of Cambridge's commercialization office, and the Carbon Trust, who revealed their new endeavour: Eight19 Limited. The new solar energy company will be focusing on developing and manufacturing high-performance, low-cost plastic solar cells for high-growth volume markets. Professors Sir Richard Friend, Henning Sirringhaus and Neil Greenham of Cambridge, all part of the Cavendish Laboratory and the technology development company TTP, have also partnered for the creation of the new company.

Testing and Certification News Focus

PVflex obtains IEC 61646, 61730 certification for flexible CIGS module

PVflex Solar has completed comprehensive field tests on flat roofs, becoming the first European supplier to obtain IEC 61646 and 61730 certification for its flexible CIGS module.

Erik Theilig, CEO of PVflex Solar, said: "We have been developing and refining our technology since 2006, with a clear focus on meeting the requirements of our roofing industry partners. Now we are working on the market introduction in close cooperation with market-leading manufacturers of roofing materials."

PVflex Solar's thin-film laminate.

SoloPower is awarded UL certification for flexible CIGS modules

In a breakthrough achievement in flexible solar photovoltaics technology, SoloPower has received Underwriters Laboratory (UL) certification for its lightweight flexible CIGS modules, a first-ever accomplishment in the thin-film industry. This is the first UL-certified product in a range of high-power flexible modules being introduced initially to the European and North American markets.

The UL certification was granted following rigorous testing at an independent laboratory where the flexible thin-film modules were tested to UL 1703, the standard for safety for PV module manufacturing.

Dow Chemical's Powerhouse shingle receives UL safety certification

The Dow Powerhouse solar shingle, manufactured by Dow Chemical, has received Underwriters Laboratories (UL) safety certification after passing over 50 individual tests to measure its safety and building standards. UL testing included wind and fire resistance testing as well as validating proper wiring and PV connection. The Dow Powerhouse shingle achieved UL 746, 1703, 1897, 790, 486 and 514.

SoloPower earns pair of IEC certifications for flexible CIGS thin-film PV module

San Jose-based CIGS thin-film PV manufacturer SoloPower has achieved IEC 61646 and 61730 approvals to go along with the UL 1703 it announced earlier this year, allowing the company to sell its rooftop-focused products in the U.S. and Europe. SoloPower claims to be the first among its peers to obtain both IEC certifications for its flex panels.

The company's initial module format, the SFX1 (70/75Wp; 0.3m × 2.9m; 5kg) were IEC certified through TÜV SUD America, while the UL work was done by Intertek. Both standards test product durability, safety, reliability, and performance.

Solyndra is awarded ISO 9001:2008 certification by TÜV Rheinland

Solyndra has received ISO 9001:2008 certification, authorized by TÜV Rheinland. The internationally recognized standard provides a set of requirements that must be in place to have a quality management system, regardless of the organization's size, product or service line, or public or private status.

Certification to the ISO 9001:2008 standard is voluntary; however, organizations must complete a rigorous auditing process by a third-party registrar.

TÜV Rheinland Group's headquarters in Cologne.

Product Briefings

Atlumin Energy

Atlumin Energy's customized rotary sputtering targets deliver higher density and purity

Product Briefing Outline: Atlumin Energy has begun fabricating monolithic rotary 'barking' (dog bone) molybdenum and molybdenum sodium sputtering targets for solar thin-film module manufacturing. Monolithic molybdenum (moly) targets are claimed to offer superior performance due to higher density and higher purity than traditionally fabricated moly targets.

Problem: Rotary targets provide superior material utilization when compared to traditional planar targets for most applications. Barking targets also enable fewer target changes and longer run time between target changes.

Solution: Atlumin's barking configuration enables customers to make full use of their sputtering target materials by addressing accelerated wear at the ends of rotary targets. With added thickness at the ends of the target, these monolithic barking moly targets are designed to compensate for the magnetic characteristics of specific sputtering tools. Monolithic molybdenum targets are said to offer higher density and higher purity than traditionally fabricated moly targets.

Applications: Thin-film sputtering.

Platform: The physical dimensions can be customized to specific customer requirements by determining the geometry that strikes the optimal balance between sputtering performance, target life and tool utilization.

Availability: Currently available.

DuPont

DuPont's Kapton polyimide films offer improved thin-film performance

Product Briefing Outline: DuPont Circuit & Packaging Materials' 'Kapton' polyimide films have been engineered for thin-film and flexible photovoltaic substrates. The films are said to deliver ease of manufacturing and robust mechanical performance..

Problem: The mechanical properties and dimensional stability of thin-film a-Si modules and CIGS applications these substrates at elevated deposition temperatures are critical to producing cells with maximum efficiency and yields.

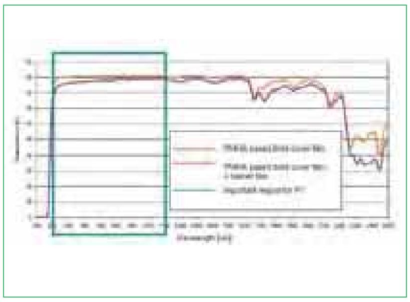
Solution: The low coefficient of thermal expansion, high glass transition temperature and low shrinkage of Kapton polyimide films help minimize stress at the interface with other materials of construction, both during processing and end use in temperature extremes. The thermal stability of the films also allows processing temperatures in excess of 400°C. The DuPont Kapton PV series of polyimide films also provide roll-to-roll processing capability, low moisture uptake and high moisture release characteristics, good electrical properties and increased voltage endurance, and ceramic-filled versions to increase corona resistance and thermal conductivity.

Applications: DuPont Kapton PV series polyimide films have been engineered specifically for thin-film and flexible photovoltaic substrates.

Platform: The DuPont Kapton PV9102 and PV9103 polyimide films are said to deliver ease of manufacturing, robust mechanical performance and maximum productivity.

Availability: Currently available. Additional Kapton technologies are said to be in development.

Evonik



Evonik's PMMA-based barrier film handles flexible thin-film roll-to-roll manufacturing

Product Briefing Outline: Evonik Industries has developed a highly transparent and weathering-resistant barrier film based on polymethylmethacrylate (PMMA) that can replace glass plates as a front cover. The film is said to allow continuous production of flexible solar modules.

Problem: If the barrier film protecting the solar cells from environmental effects is made of plastic rather than glass, lightweight, flexible and therefore cost efficient thin-film solar cells can be realized with a number of semiconductor materials. In a continuous roll-to-roll manufacturing process, the covering film should have properties as similar to glass as possible, including the capability to act as a barrier to water vapour and oxygen and adhere well to solar cells.

Solution: PMMA has many of the required properties such as high transparency, weathering resistance, and UV stability. To meet further requirements, Evonik has been developing a multilayer film consisting of several functional and bonding layers and an outer PMMA layer. The 'Rohaglas' protects the underlying layers of the film very efficiently against the effects of weathering, thus ensuring the necessary longevity. In the spectral range relevant to photovoltaics, Evonik's new film achieves transmission rates of 88 and 90% in the short-wave and long-wave regions.

Applications: Flexible thin-film solar modules.

Platform: Evonik's multilayer film was designed with damp heat testing and UV resistance in mind. Its water vapour barrier is 10^{-3}g/(m^2/d).

Availability: As the film is currently being put through tests for compliance with the IEC 61646 standard for thin-film solar cells, availability has yet to be determined.

Linde

Generation-F platform from Linde enables chamber cleaning without SF_6 or NF_3

Product Briefing Outline: On-site generation of high-purity F_2 gas has been developed by Linde to deliver the gas on demand and at low pressure, thus eliminating the need for large-volume and high-pressure storage and ensuring safe and reliable supply to CVD process tools.

Problem: The fluorinated gases typically used for PECVD chamber cleaning (SF_6 or NF_3) have high global warming potential and contribute a significant amount of carbon footprint to the finished product – a critical factor for PV products which are perceived to be intrinsically 'green.'

Solution: Fluorine has zero global warming potential and the low F-F bond energy means fluorine radicals are easily and efficiently produced, leading to shorter cleaning times, higher tool throughput, and a reduction in the amount of material and power used. For the latest, largest panel sizes, the use of F_2 enables existing processes to be scaled without the significant hardware modifications required with NF_3 or SF_6. By generating the gas on-site, on demand and at low pressure, safety concerns regarding transport, storage and safe delivery to the process tool can be more easily addressed.

Applications: Within large-scale TFT-LCD and thin-film PV production, F_2 is used to clean PECVD process chambers, displacing NF_3 or SF_6. Similar cleaning applications exist within semiconductor manufacturing where it can also displace high-pressure cylinder F_2 or ClF_3. A number of process applications are under development.

Platform: The Generation-F platform has a flexible modular design which allows for a wide range of flows and quantities to be delivered from pilot-line development through to high-volume production.

Availability: Currently available.

3M

3M's 'Ultra Barrier Solar Film' designed for flexible thin-film applications

Product Briefing Outline: 3M has introduced into volume manufacturing its Ultra Barrier Solar Film for flexible thin-film technologies. The product, which is the result of more than a decade of development in transparent barrier technology, is said to have the potential to drastically reduce the total system costs for rooftop solar installations while also being suitable for an array of niche applications.

Problem: Transparent barrier layers have previously suffered from degradation, reducing power output and in a flexible substrate have lacked long-term moisture barrier and overall weatherability. The need for a robust film enables the design of unique module form factors that could enable lower cost-per-watt for flexible thin-film applications.

Solution: 3M Ultra Barrier Solar Film acts as a replacement for glass with high light transmission, good moisture barrier performance and weatherability. Compared to glass-glass modules, large-area, lightweight flexible PV modules can achieve lower balance of systems (BOS) costs by requiring less installation time, removing the need for metal racking, and reducing logistics expenditures. The film is also claimed to lower module manufacturing costs by allowing manufacturers to commercialize large-area modules, effectively reducing fixed costs associated with module manufacturing, assembled in a continuous roll-to-roll process.

Applications: Flexible thin-film technologies such as CIGS, CdTe, and organic PV solar modules, and roll-to-roll manufacturing processes.

Platform: It is highly transparent, provides moisture vapour transmission rates (MVTR) below 5 * $10^{-4}g/m^2/day$, and demonstrates excellent durability.

Availability: Currently available.

Solar Metrology

Solar Metrology expands XRF metrology platform to integrated linear GIGS thin-film applications

Product Briefing Outline: Solar Metrology has expanded its SMX XRF tool portfolio for film composition and thickness measurement of CIGS photovoltaic depositions with the addition of the System SMX- LINEAR ISI. This platform is said to be fast, flexible and easily integrated into any vacuum deposition tool or vacuum process station.

Problem: The properties of TFPV films are difficult to measure due to their optical properties. This is compounded by the high-volume production requirements of thin-film substrates and the impact the wrong composition can have on decreasing efficiency and manufacturing yield.

Solution: The SMX-Linear ISI is an in-situ x-ray fluorescence (XRF) metrology tool platform that provides cross-web or cross-panel gradient measurement of CIGS composition and thickness measurements for thin-film solar PV metal film stacks on flexible roll-to-roll substrates such as stainless steel, aluminium and polyimide or rigid substrates such as float glass.

Applications: Typical measurement applications include Mo thickness and all CIGS combinations (including all CIG alloys and/or film combinations and final CIGS formulations).

Platform: The SMX LINEAR ISI platform does not affect the deposition process since all components reside outside of vacuum for optimum performance and serviceability. Linear ISI configurations feature three standard ports, with additional ports available upon request.

Availability: Currently available.

Flexible PV survivor: Uni-Solar banks on efficiency, cost, BOS improvements to weather the storm

By **Tom Cheyney**

News

Photos courtesy of Uni-Solar

One of the busiest of the couple-dozen solar manufacturing factory floors I've seen this year belonged to ECD Uni-Solar, at its Auburn Hills 2 (AH2) facility just up the road from the Palace where the NBA's Detroit Pistons play hoops. When I toured the plant in late July, the three production areas – cell deposition, cell finishing, and module stringing/lamination/final assembly – were humming, as the 1.5-mile-long rolls of flexible stainless-steel starting material were transformed into triple-junction amorphous-silicon thin-film PV laminates. The company's latest quarterly results confirm those observations at the factory, as production output grew some 58% over the previous period – from 21.2MW to 33.6MW – pushing capacity utilization to about 90%.

However, what I saw at AH2 stood in direct contrast to the ominous announcement that shook the industry the day before my visit: Applied Materials' shuttering of its SunFab division and de facto withdrawal from the a-Si thin-film sector. For Uni-Solar's Subhendu Guha, the news had a bit of déjà vu to it.

"The same thing happened to us when BP Solar pulled out of amorphous silicon [in late 2002], and people wrote amorphous silicon off, because if BP goes out, what does it mean?!" the Uni-Solar chairman and ECD CTO recounted. "We stood and we survived. So when Applied Materials pulls out, again there is this thing, 'oh my god, if Applied Materials can't do it, how can anyone else do it?'

"But what I tell people is that our business strategy is different. We're not trying to compete with First Solar [like Applied was] nor are we trying to compete with crystalline high-efficiency solar cells. We have a market, which is the rooftop market – that's where we want to be."

Uni-Solar is certainly a survivor in the PV market, and continues to be the only company capable of manufacturing high volumes of lightweight, flexible solar laminates in a roll-to-roll production scheme.

Although several companies (SoloPower, Global Solar, Ascent) have begun to make copper-indium-gallium-(di)selenide (CIGS) flexible modules with the building-integrated rooftop market in mind, they are just beginning to ramp up their lines and do not have the sun-soaked track record that the thin-film silicon pioneer does, even if their claims to higher efficiencies and lower costs raise concerns for Guha and his team.

"We are watching them very carefully," he said. "You cannot develop a business strategy assuming the other guys are going to fail. You have to develop a business strategy assuming those guys are going to succeed. CIGS has its challenges. The biggest one is moisture, but eventually they can solve that. CIGS being a lower bandgap material, we will typically produce 20% more electricity per kilowatt than CIGS, so we have that advantage. The third issue is bankability: Uni-Solar has bankability on its side."

"CIGS should come but they have some barriers, so we just have to stay ahead of them, ahead in terms of conversion efficiency, in terms of applying the product to the roof," he continued. "We have to make sure we can sell the kilowatt-hour per kilowatt advantage and, more importantly, we have to make sure we can reduce the installed cost even further by some of the innovations we are making. We're lucky we're the only large-scale manufacturer of flexible solar laminates, but you can't enjoy that position forever."

Uni-Solar is aggressively trying to stay ahead in the flexible-module game by finding ways to boost efficiencies and chip away at expenditures in the capital and operational areas, as well as the aforementioned balance-of-systems improvements for its differentiated products and a big-picture strategy to push its business model more downstream to garner more "projects" business.

The company says it has stayed on track with the efficiency and cost roadmap announced in June. The plan calls for 10% aperture-area conversion efficiencies at a cost of $1.15/W on its AH1 line, upgraded with a new very-high-frequency deposition process, before calendar 2011 ends.

Those numbers will improve to 12% and 95 cents, respectively, the following year, once the next-gen nanocrystalline technology is implemented. During the earnings call in early November, the company announced its extended roadmap, which aims for 14% efficiencies at 65 cents per watt by 2015.

(Guha told me they can hit $1.50/W at 150MW/year production levels, using the current 8–8.5% efficient technology. President/CEO Mark Morelli said costs were $1.61/W during the first quarter of FY2011. System-level ASPs are about $4/W installed now, and should go down to about $2.50 by 2012, once the efficiency and cost reduction metrics kick in, according to the chairman/CTO.)

Still in an earlier stage of Uni-Solar's gated-development path, the photon-harvesting "HybridNano" materials will replace the green and red light-absorbing layers in the triple-junction stack. One of the banes of thin-film silicon – light-induced degradation – is apparently not an issue with the nano films.

The R&D efforts on the morphologically complex materials need to demonstrate higher efficiencies (they're 11% now, need to reach 12%) as well as better large-area uniformities before any capital equipment is modified for the nano-secret sauce process, according to Guha. The team will make a decision in February/March 2011 about the design of the souped-up tool, knowing that they will have until October 2012 to start production with the technology.

Looking even farther out, Uni-Solar has reached 15.4% on small-area nanocrystalline silicon-hydride research devices. It believes there's headroom to get to 25% efficiencies through continuing

to push the light-trapping envelope even harder – maybe even breaking the "random scattering barrier" – and thereby increasing short-circuit current density as well as fleshing out the fill factor from 75% to 85%, through the use of novel deposition methods (hot-wire CVD, rapid thermal annealing, etc.), interlayer enhancements, and plasmonic and other exotic back-reflector variations.

As for the tool being readied at AH1, Guha explained that the high rate of deposition that the modified very-high-frequency PECVD technology enables can be accomplished without changing the existing equipment set. The upgrade is accomplished by the incorporation of a new cathode design, improved power supplies, a new back-reflector material in the cell stack, and other "tinkering with various parameters to design of experiments."

The aluminum zinc-oxide film currently sputtered as the back reflector will be replaced with a texturized silver zinc-oxide cocktail, which is said to be superior in capturing a greater spectrum of light and helping trap those elusive photons.

Having demonstrated uniform deposition over the requisite large-area substrates, the VHF process will double the throughput of the R2R triple-junction a-SiGe:H cell processing machines from 30MW to 60MW in addition to popping the aperture-area efficiency up to 10%.

Modifications to the Auburn Hills 1 tool, the twin of AH2, have been completed, and the system has been going through its optimization paces for a few months. Certain minor changes have been made to the cathode since R&D, Guha told me during Solar Power International, noting that with the VHF approach, for example, "grounding can be rather tricky; as the frequency increases, there can be losses at the contact, so one thing we want to do is, the stainless steel" – all 1.5 miles of the moving substrate – "has to be grounded."

Morelli said during the conference call for the quarter ended Sept. 30 that the big vacuum tool had been through 40 optimization runs already and would continue to be optimized (and tested/qualified) in order to be ready for commercial production of the new, improved laminates by summer 2011. He also noted an area of roadmap acceleration: the VHF retrofit of AH2 has already begun.

Speaking of those deposition machines, when you walk alongside one of them, it's hard not to be struck by the level of sheer ingenuity and innovation. Six of those massive spools of thin steel roll through the 70-meter-long system at a time, the foil flipped up vertically, entering and exiting the 34 N-, I-, and P-layer process chambers over the course of the 62-hour cycle time.

Interferometric sensors check film thickness throughout the process sequence; those and other performance measurements are monitored assiduously in the impressive control room, providing data for the curiously acronymed YETI (yield, efficiency, throughput, improvement) team.

It's readily apparent that if Uni-Solar had not devised a way to retrofit the expensive behemoths, the price tag for replacing them could have led to a potentially bank-breaking dilemma for the already cost- and profit-challenged company, well beyond the revised fiscal-year capex guidance of $40 million offered by CFO Kriss Andrews.

Another area of operational savings came when it was decided that back-end assembly operations would be

discontinued in AH2, and those activities then focused in the company's lower-cost Tijuana 150MW facility. This move was made just a few weeks after I had had to dodge workers as they interconnected the cells into series strings and polymer-encapsulated those strings into laminates on that hustly-bustly part of the shop floor.

In a surprise announcement, it has been revealed that Tijuana will soon have a sister assembly line in Ontario, just across the border from Auburn Hills. ECD has decided to take advantage of the province's lucrative rooftop market via its neighbor's FiT "domestic content" provision and set up a 30MW production facility in an as-yet-unannounced location. The first 15MW line will come up in the second or third quarter of next year. The company would not confirm if the back-end toolset sitting idle in AH2 will indeed be the capital gear redeployed to the Ontario factory.

Asset reorganization and process enhancements are not the only pathways that Uni-Solar has utilized to reduce costs and improve its products. Guha showed me an enhanced laminate design, which incorporated a scaled-down junction box and ongoing reductions in the "dead area" – those inactive zones around the sides of the module.

Historically, the total area of the laminate included about 18% dead area, contributing to the wide discrepancy between aperture- and total-area efficiencies. At that point, the team had reduced the inactive area to 12%, mainly by narrowing the edge areas, with a goal of whittling that down to 5% by 2012. If all goes well, by then the efficiency gap would be tightened to 12% (aperture) and 11.4% (total).

The junction box has been made smaller and thinner, freeing up even more potential photoactive area. The design has already been approved, and the new j-box is expected to go into production in December, build inventory for a few months, then launch to the market in February or March of next year, Guha told me during SPI. The goal is for the compact j-box to be a standard component on all products by mid-June.

The laminate and the j-box have both been submitted in parallel to IEC and UL for certifications, which should be signed off by late 2010 or early 2011, according to Guha.

While the PV laminates continue to be Uni-Solar's core offering, the growing suite of commercial and residential rooftop products has become a key part of the company's growth engine. Along with that expanded portfolio comes repetitive branding, with names such as PowerTilt, PowerBond, PowerMembrane, PowerTile, and PowerShingle hammering the messaging into customers' brains that these products can carry a charge, by golly.

One of the most aesthetically appealing of these offerings is UniSolar's version of the solar shingle, which it believes has strong upside for parts of the U.S. residential rooftop market. It's not a new idea, as an earlier incarnation of the concept fell flat when launched more than 10 years ago, largely because they were hard to install and had to be connected in a roof-penetrating manner.

The reborn shingles, set for market re-entry in mid-2011 after a prelaunch at SPI, use flat connectors and are nonpenetrating. During my visit, Marcelino "Mars" Susas, VP of corporate strategy and marketing, escorted me to the residential display area and showed me the first- and second-generation of the current shingle design.

Noting how they're trying to incorporate the "thought process of the roofing companies, in terms of how to install using standard roofing materials and tools," he said that they "wanted to get as much above the deck as we could" with the new shingle design, with all module-to-module connections on top.

Cut into 5- and 10ft lengths, the first-gen shingles are covered with channels or "raceways," with each kilowatt section separated into three channels, including two columns of 10ft modules, 20 rows high, according to lead engineer, Troy Glatfelter. By next year, the second-gen shingle system will do away with the raceways, be much more integrated, and feature further improvements to the connectors. In effect, the first product is BAPV, while the second one is BIPV.

The installation procedure consists of "putting the module down, snapping the connectors together, aligning the module, then nailing it in," he said. "It's that simple, almost as fast as [laying down] asphalt shingles."

The engineer detailed a clever aspect of the wiring approach. "They're connected in series, plus/minus, all the way up the deck. But how do you get the first negative up to here," as he gestured at the roof mock-up, "without carrying a wire up or putting something under the deck that might get pierced later?"

"What we do is run a neutral bar through all the modules and then on the first module, we put a shorting connector there," explained Glatfelter, channeling his inner contractor. "This shorts the negative to the neutral, and now the negative's on the top. So as the roofer installs, these panels are not live, there's no voltage across the leads, so it's very safe for them to work with. Even if they pierce it with a nail, there's no voltage there, there's no complete circuit."

Hence the "trades" are separated, with the roofer-installer doing his thing and the electrician coming in with the final components to finish the circuit, making for a very safe work environment, according to Uday Varde, director of product development.

Mother Nature almost used me to complete a circuit as I drove south on I-75 toward Detroit airport from Uni-Solar's Auburn Hills campus. Mind-boggling torrential squalls and instantaneous flash-boom lightning/thunder dowsed, illuminated, and shook my rental car, as a satellite radio garage-rock program boomed from the speakers inside the cab.

That brush with the elements triggered my mythic imagination: I wondered if the downpour was some kind of omen of the prospects of the first company in flexible PV, a sign of turbulent times ahead or perhaps what happens when the storm has passed.

The reality is anything but epic: ECD Uni-Solar must stay on or accelerate its technology and cost roadmap, expand its "demand creation activities," and find its way back to profitability if it expects to weather the storm.

This feature is a revised version of a blog that originally appeared on PV-Tech.org.

Transparent conducting oxide deposition techniques for thin-film photovoltaics

V. Sittinger, **W. Dewald**, **W. Werner** & **B. Szyszka**, Fraunhofer Institute for Surface Engineering and Thin Films (IST), Braunschweig, Germany, & **F. Ruske**, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany

ABSTRACT

Highly conductive transparent films are of significant interest in the field of thin-film photovoltaics. The solar cell type defines the necessary properties of the TCO used. Besides the obvious qualities of transparency and conductivity, stability and morphology are important. The most significant properties of these aspects for front contacts in amorphous/microcrystalline silicon tandem, CIGS and CdTe solar cells are presented in this paper. Commonly used deposition techniques like CVD and sputter technology are described herein, focusing on particular techniques for SnO_2:F and ZnO:B (CVD) and ZnO:Al (sputtering) fabrication. New developments of deposition methods are also discussed.

Introduction

Transparent conductive oxides (TCOs) are a special class of materials, combining the two contradicting physical properties of transparency and electrical conductivity. Electrical conductivity is limited in this application because a high electron density leads to absorption in the near infrared, a result of the interaction between electrons and incoming light. To avoid pronounced absorption, there has to be a trade-off between conductivity and optical transmittance.

Conductivity is often optimized for high transmittance in the spectral range corresponding to the sensitivity of the human eye. In this case, conductivities below $10^{-4}\mu\Omega$cm can be reached, which are close to the theoretical limit of conductivity in current research materials [1,2].

Nevertheless, there are many applications for which the characteristics of high transparency and low resistivity alone do not suffice. Therefore, optimization of the deposition processes has to be adapted to the final application of the TCO films. For photovoltaic applications, the desired properties of the TCO are as follows:

- Minimal optical absorption
- High electrical conductivity
- Durability against environmental impact
- Suitable light trapping due to structured rough surfaces
- High transparency in the near infrared (absorption range of the absorber).

The necessary material properties as set out above are only one aspect of the necessary TCO optimization. The film also has to survive several processing steps that can damage the material, such as the high temperatures used during the production of electronic devices like solar cells, or reactive plasmas (e.g. hydrogen) used for depositing silicon absorbers.

Finally, the whole process of TCO deposition has to be chosen and approached carefully in order to ensure a good integration into the production line and the desired material properties. Temperature-limited processes include the deposition of TCOs on photovoltaic absorbers or the usage of sensitive substrates as foils – it is of utmost importance that the substrate is not affected in any way.

Therefore, the selection of a suitable TCO material for a certain application should involve the consideration of further material properties as well as optical and electrical properties and cost. Some material characteristics can be adjusted with the proper deposition parameters, ensuring that the deposition process is cost effective, below the maximum substrate temperature and capable of being industrially integrated.

The most widely used TCOs are tin-doped indium oxide (ITO), fluorine-doped tin oxide (FTO) and aluminium-doped zinc oxide (AZO). Photovoltaics comprise one of the main application fields of large-area coating with TCOs, while silver-based multilayers that display similar properties to TCOs are employed by default as low emitting films in architectural glass applications. A silver film has to be as thin as 10nm in order to achieve the required transparency. As a result of this and the low chemical stability of silver, these films were applied only on the protected interior glass sides. Recent developments show the thin silver multilayers being implemented more and more often as front electrodes in organic photovoltaics, mainly because of better encapsulation methods being available nowadays.

The development of TCOs needs to heed the advances in thin-film solar technology. In particular, the optical properties and the deposition parameters

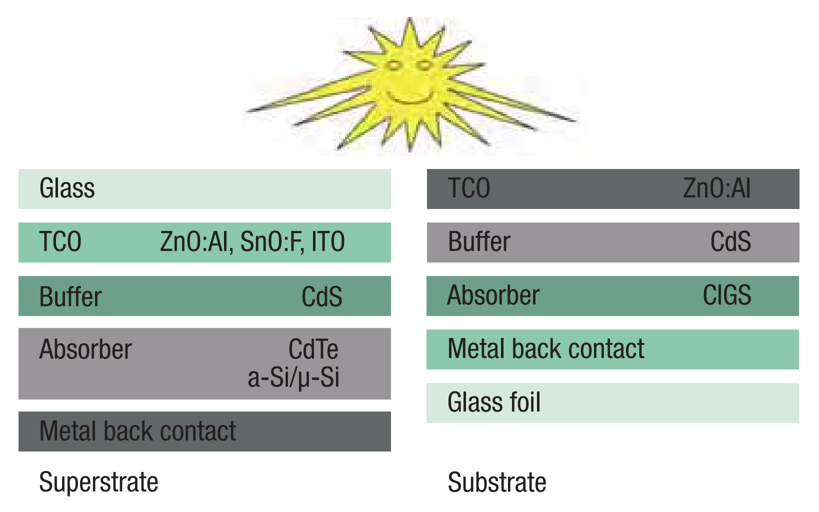
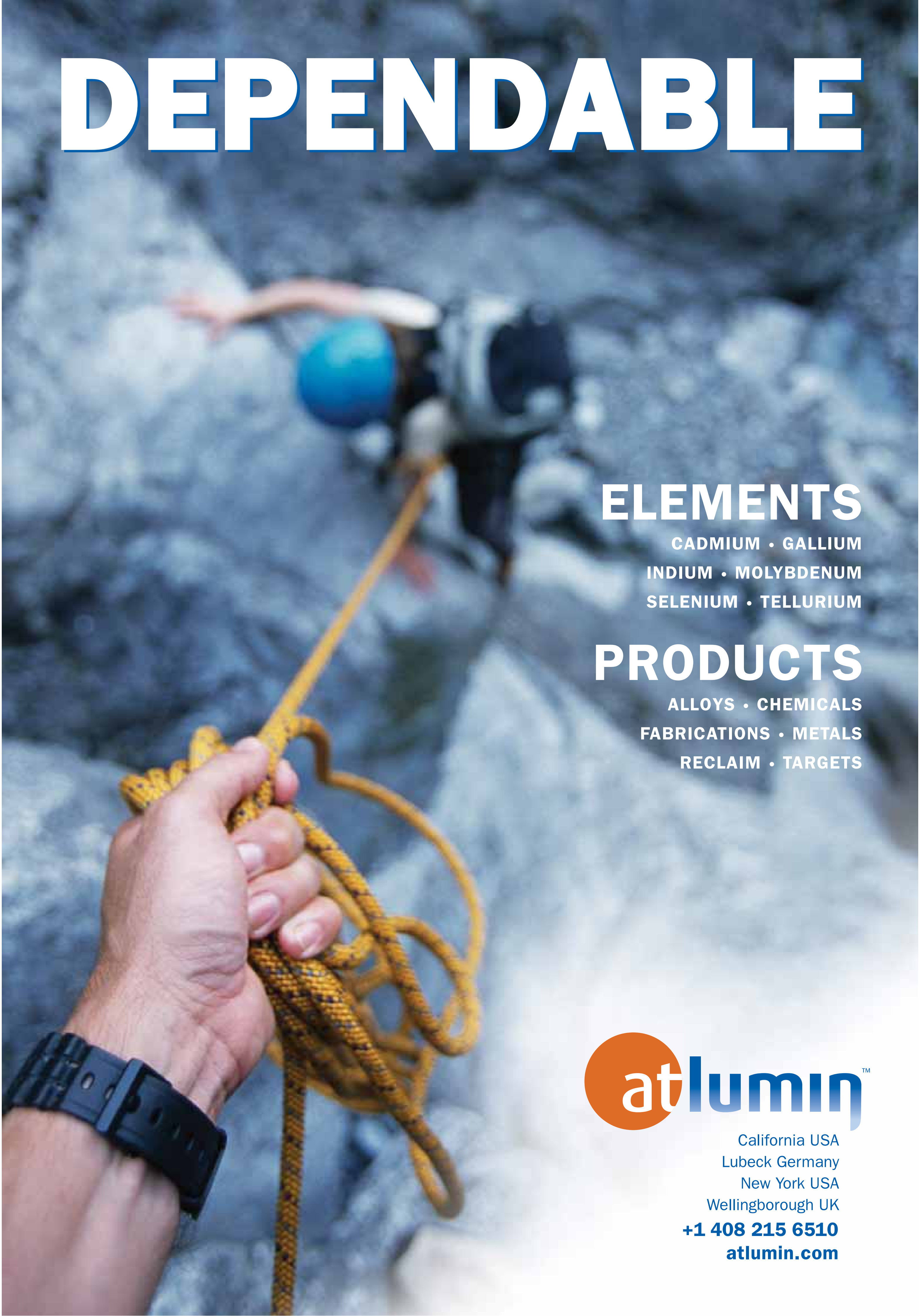


Figure 1. Superstrate and substrate configurations of a solar cell.


DEPENDABLE
ELEMENTS
CADMIUM • GALLIUM
INDIUM • MOLYBDENUM
SELENIUM • TELLURIUM
PRODUCTS
ALLOYS • CHEMICALS
FABRICATIONS • METALS
RECLAIM • TARGETS
atlumin™
California USA
Lubeck Germany
New York USA
Wellingborough UK
+1 408 215 6510
atlumin.com

have to be adapted to the specific cell type and production process, such as whether the cells are fabricated in the so-called superstrate or substrate (Fig. 1).

Optical transmittance of the TCO film

In both cell configurations (superstrate and substrate), the conversion of incoming light to electron-hole-pair and therefore electrical current takes place in the absorber film. In order to achieve a high conversion efficiency, any loss due to reflectance at and absorption in the TCO has to be minimized. The optical properties have to be adjusted with reference to the absorber properties and not, contrary to some reference literature, to the sensitivity of the human eye. The all-important absorption rate of the absorber is illustrated via the example of amorphous (a-Si:H) and microcrystalline silicon (μc-Si:H), as shown in Fig. 2. As μc-Si:H absorbs up to a wavelength of 1100nm, the TCO should be expected to have a high transmittance in that range.

> "In order to achieve a high conversion efficiency, any loss due to reflectance at and absorption in the TCO has to be minimized."

The free charge carriers in TCO films show a metallic optical behaviour in the infrared and have a high reflectance [3]. The transition frequency, where high transmittance changes to high reflectance, is known here as plasma frequency ω_p and is connected to the carrier concentration n_e in the film as shown in Equation 1.

$$\omega_p^2 = \frac{n_e \cdot e^2}{m^* \cdot \varepsilon} \qquad (1)$$

where e is the electrical charge of an electron, m* is its effective mass and ε is the dielectrical constant. The higher the free carrier concentration, the higher the frequency at which TCO films become transparent.

The TCO film can be optimized only with a low carrier concentration, brought about by a low doping or by applying specific deposition techniques. In addition, the conductivity of the TCO, which is proportional to n_e, must be maintained at a high enough level if the sheet resistance of the films is to be kept constant. Alternatively, thicker films are required.

Light trapping

A low absorber thickness in thin-film silicon solar cells leads to an incomplete light absorption. In order to overcome this

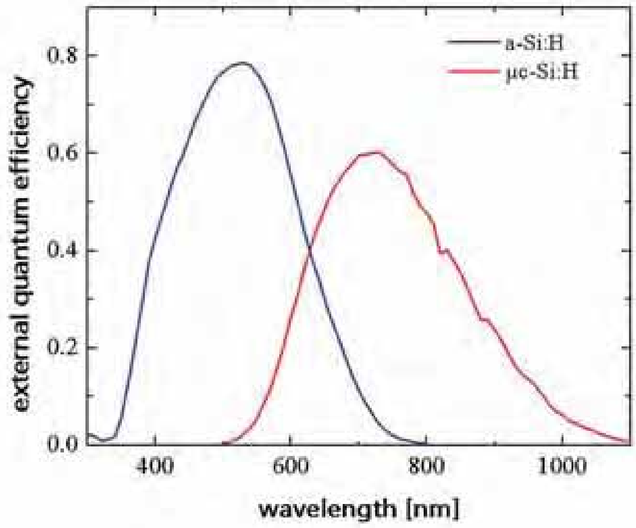


Figure 2. Quantum efficiency of a-Si:H (red)/μc-Si:H (blue) solar cells. Cell deposition and EQE measurements were performed at IEF5 Forschungszentrum Jülich.

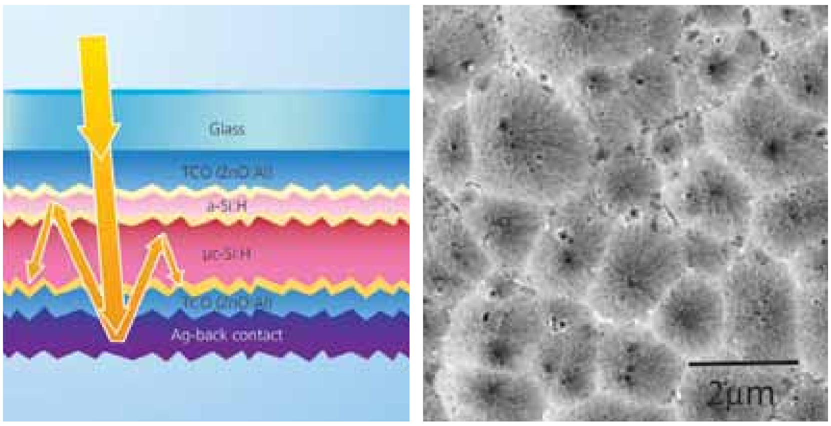


Figure 3. Sketch of light trapping in a thin-film silicon solar cell (left); optimized and etched AZO film from Fraunhofer IST (right).

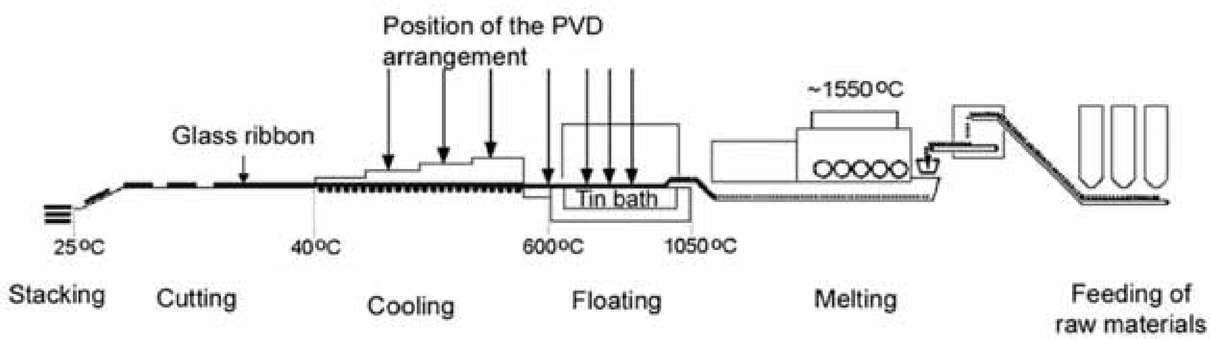


Figure 4. Sketch of a float line with an inline CVD coating and its position in relation to the required temperature [8].

drawback, either the absorber films can be thicker, which means longer deposition times, or the internal light pass of the incoming light has to be increased. In a-Si:H-based solar cells, it is necessary to avoid thick absorbers, as this will increase cell degradation as a result of the Staebler-Wronski effect. Therefore, efficient light-trapping schemes should be used in these cells. As light falls onto a cell's surface, the light rays are scattered and pass through the cell at different angles. The light then undergoes reflection at the back reflector. If this angle of reflection is bigger than a critical angle, total reflection occurs at the TCO/glass interface. Multiple internal reflections occur in this way until the major part of the light has been absorbed. This process is similar in principle to an optical fibre.

Literature on the subject has informed us of approaches such as the roughening of TCO films like AZO in a post-deposition etch step in diluted HCl in order to effect a strong light scattering behaviour at the TCO surface [4]. This scattering is strongly dependent on the deposition parameters of the film. Using this method effectively scatters the light into the cell, increasing the short-circuit current and the conversion efficiency of the solar cell.

Stability of TCO

The stability of the TCO is crucial. Depending on the chosen configuration (substrate or superstrate) and the deposition process, the quality of TCOs can suffer under certain conditions. In the superstrate configuration for thin-film silicon, the silicon process takes place in hydrogenated plasma. Hydrogen can reduce the TCO, which leads to a loss in transmittance. Zinc oxide (ZnO) shows the highest stability against activated hydrogen [5].

Whereas the deposition takes place at temperatures of 200°C for thin-film silicon, the CdTe and CIGS process needs a considerably higher temperature of over 500°C, which poses a high risk for degradation of the TCO. In response to this, TCOs with a higher temperature stability are used, such as SnO_2:F and ITO for CdTe, and ZnO:Al for CIGS solar cells' substrate configuration. These encapsulated solar modules show good stability, withstanding the typical damp heat test conditions of 85% relative humidity at 85°C for 1000 hours to gain EN/IEC 61646 certification. Nevertheless, non-encapsulated modules tend to exhibit a severe degradation in this test [6], caused by an increase in resistivity of the ZnO:Al [7]. This topic is subject of ongoing research, as discussed in the following sections.

Manufacturing technology for TCOs

There are various different technologies available for the production of TCO coatings. The more commonly used approaches are outlined in the following.

Chemical vapour deposition technologies

Using the online APCVD (atmospheric pressure CVD) technique, electrically conductive layers based on SnO_2:F can be produced on a large area at a float glass drawing velocity of 9m/min. In this process, precursors are dissolved in an organic or inorganic solvent and dispersed in a carrier gas like nitrogen, and then supplied to the float glass at temperatures between 500 to 700°C [8]. A schematic sketch

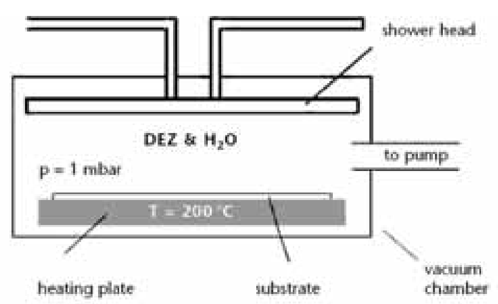


Figure 5. Typical assembly of an LPCVD reactor [10].

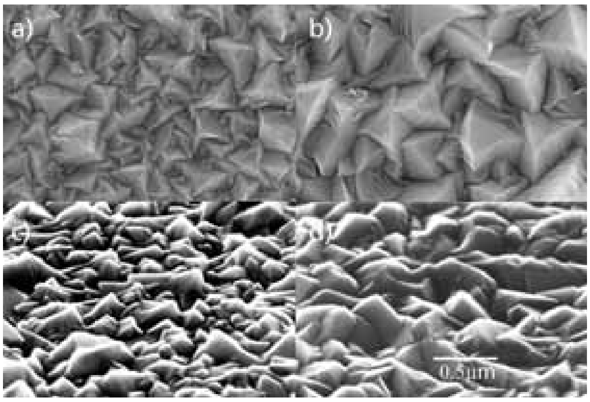


Figure 6. Examples of difference in morphology of CVD-deposited TCOs: a) and b) ZnO:B from LPCVD deposited under different conditions (topview); c) SnO_2:F from NSG; d) SnO_2:F from Asahi (60° tilted).

	Horizontal	Vertical
Carrier	No	Yes
Carrier return	No	Necessary
Large substrate size	Yes	Complex
Problem with back-side deposition	Yes	No
Deposition to edge	Yes	Problematic
Particle contamination	Problematic	Low

Table 1. Comparison of horizontal and vertical sputter coater geometry.

of such a line is shown in Fig. 4. The main advantage of this process is that it is carried out at atmospheric pressure and therefore offers lower production costs than vacuum-based deposition technologies. This kind of concept is widely used by companies such as Nippon Sheet Glass, Pilkington, AFG Industries or Saint Gobain.

SnO_2:F coatings produced in this way are commonly used in CdTe and amorphous silicon solar cells. For application in amorphous microcrystalline silicon tandem solar cells, attaining higher efficiency requires a more sophisticated film morphology regarding the light-trapping issue. Offline CVD is used by the Asahi Company to reach larger and more homogenous feature sizes, such as the Ashai U type.

Another possibility for producing optimized light scattering for so-called 'micromorph' cells was introduced by Oerlikon by applying the LPCVD (low pressure CVD) technique. Typically, boron-doped ZnO is deposited at low pressure with diethylzinc and water vapour and diboran as doping gas [9]. The deposition takes place at ~ 50Pa at substrate temperatures of approximately 200°C. A sketch of the process can be seen in Fig. 5 [10].

A similar process entitled MOCVD (metal organic CVD) is used at Solar Frontier for the deposition of ZnO:B on CIGS solar cells. Research is also being carried out for plasma-enhanced MOCVD [11]. Variable morphologies can be reached using the different CVD techniques, as shown in the SEM picture in Fig. 6.

State-of-the-art sputter technology

Magnetron sputtering is the standard deposition technique for transparent front contacts in industrial production of chalcopyrite solar modules. It is easy to scale up, and substrates up to $18m^2$ can be coated in coaters designed for deposition of architectural glazings. For aluminium-doped zinc oxide (AZO), sputtering of ceramic ZnO:Al_2O_3-targets or reactive sputtering of metallic Zn:Al-targets can be carried out. Because of the sophisticated control that is needed for reactive sputtering, ceramic targets are normally used. Intensive work has been carried out on the optimization of target materials [12]. Nowadays, more and more production lines use rotatable targets for their higher material utilization and therefore higher throughput than planar targets. Benefits and drawbacks of horizontal and vertical coaters, two different concepts for magnetron sputtering coaters, are shown in Table 1.

Both types of coaters are available from a variety of companies; a good overview of TCO equipment for sputter and CVD coaters can be found in [13].

Because the absorber buffer interface is not stable above substrate temperatures of 200°C, the AZO deposition for CIGS solar cells takes place at this temperature. For the amorphous/microcrystalline tandem solar cell, higher deposition temperatures are possible because of the superstrate technology used in these cell types. As mentioned, an effective light trapping is crucial for a good performance of these cell types.

In order to prevent shunts, the particle density on the substrates also has to be lowered significantly. Magnetron cathodes are themselves a potential particle source, as oxide material is re-deposited at the edges of the racetracks and forms dust. Moving magnets [14] or rotatable targets offer a possible solution as the target surface is kept clean during the process.

Recently, Applied Materials deposited highly-conductive ZnO:Al films by magnetron sputtering from a rotatable ceramic target and post-etched the films in diluted hydrochloric acid. The crater-like etching morphology is responsible for a good light-trapping behaviour and an stable efficiency of 10.5% was reached for a micromorph silicon module (a-Si:H/μc-Si:H) on the $1.43m^2$ size [15]. Applied Materials used a horizontal ATON coater for TCO deposition for $5.7m^2$ substrates. Rotatable targets offer a very good

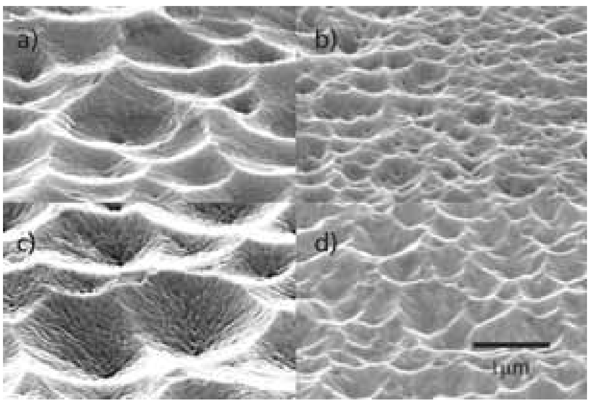


Figure 7. Examples of difference in morphology between sputtered ZnO:Al samples at Fraunhofer IST: a) RF; b) DC; c) DC with seed layer; d) reactive MF.

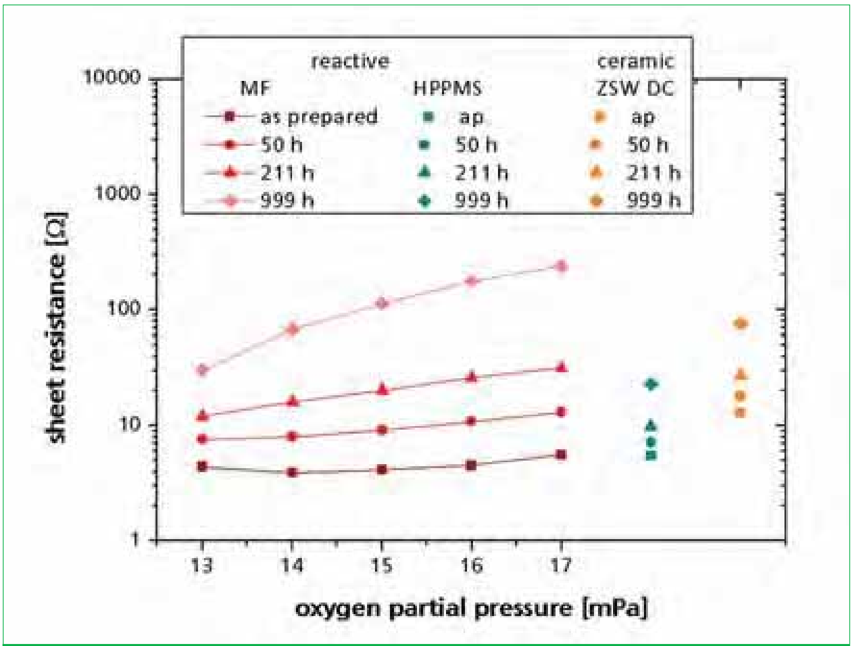


Figure 8. Damp heat stability of ZnO:Al films on CIGS substrates deposited by reactive sputtering MF at 180°C and reactive HPPMS sputtering at 190°C versus a DC process from ZSW Stuttgart.

utilization of target material and stable deposition conditions over the target lifetime and during deposition.

Sontor built up a vertical in-line facility, the 'New Aristo 1200L', as supplied by Applied Films, now Applied Materials. In production, the company uses SnO_2:F as TCO, but research is now focusing on ZnO:Al planar ceramic ZnO:Al_2O_3 targets, which are DC sputtered. A planar Movemag is used to improve the target utilization. The glass substrate has a dimension of 1.78m² and the substrate temperature during deposition is selected at below 300°C. As the process is currently being upscaled, efficiencies reached were higher than for conventional SnO_2:F [16].

For further cost reduction, the reactive sputtering from metallic targets will likely be established over the next few years. Many efforts are ongoing to come to a stable process control [17,18].

Different morphologies are reached using different sputtering conditions. Typical structure size is shown in the SEM examples in Fig. 7. An optimized morphology is typically deposited with RF sputtering [19]. With pure DC from ceramic targets, slightly smaller feature sizes can be reached [20]. The morphology of etched reactively sputtered ZnO:Al is dependent on the operating point during sputtering [21]. Reactive mid-frequency magnetron sputtering (RMFMS) from metallic zinc targets is also an interesting option for CIGS solar cells. This approach with reactive MF sputtering is described in [22,23].

Sputter technology development

A further option in the quest for higher damp heat stability in CIGS solar cells is the use of high power pulse magnetron sputtering (HPPMS), also known as high power impulse magnetron sputtering (HiPIMS) technology [24].

The sheet resistance of an AZO film on a CIGS substrate was measured before and several times during damp heat testing at ZSW Stuttgart, the results of which

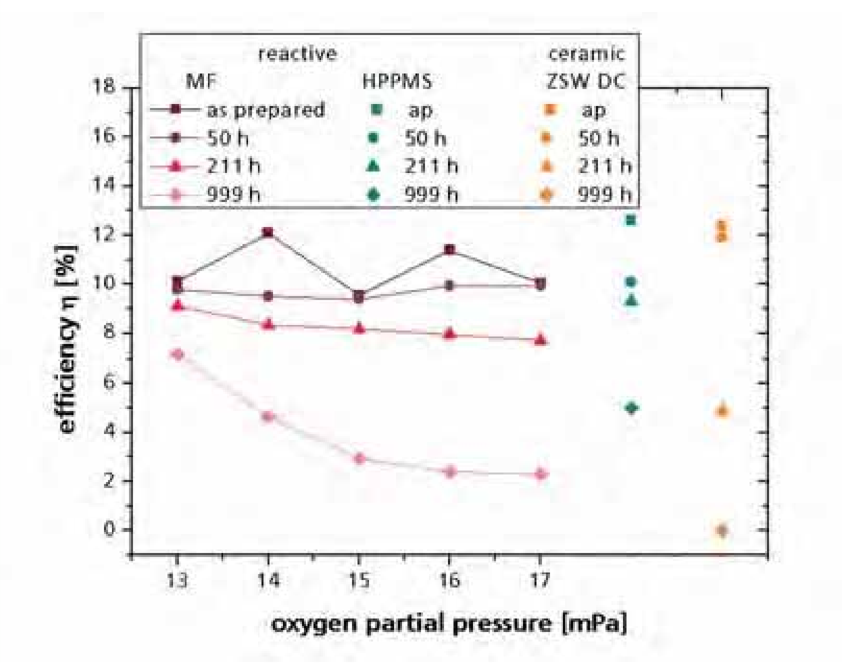


Figure 9. Damp heat stability of mini-module efficiency deposited by reactive sputtering MF at 180°C and reactive HPPMS sputtering at 190°C in comparison with a DC process from ZSW Stuttgart. All module characterization and manufacturing were performed at ZSW Stuttgart.

are visible in Fig. 8. A film deposited by DC sputtering from a ceramic target and from the reactive MF process is included for the purposes of comparison. The reactively sputtered HPPMS films on CIGS substrates show the lowest degradation compared to the conventional reactively sputtered MF films and the reference film coated with DC process, as performed at ZSW Stuttgart.

Fig. 9 shows the efficiency of the mini modules made at ZSW Stuttgart. Aside from the good damp heat stability, the efficiency for the HPPMS-sputtered ZnO:Al shows the best performance compared to the other deposition techniques.

Fig. 10 shows SEM pictures of cross-sections of the mini-modules. A more dense columnar structure of the AZO layer is observed for HPPMS compared to an MF-deposited film at 180°C as well as a DC-sputtered film at 150°C substrate temperature.

This is attributed to higher ad-atom mobility on the growing film. The increased mobility can also explain a better coverage of the CIGS grain boundaries that form macro grain boundaries in the AZO layers, which are known to limit damp heat stability severely [25].

It should be taken into account that this investigation's remit was restricted to one set of process parameters for AZO on CIGS. Therefore, research on partial pressure variation as well as charge voltage variation is an optional field for further improvements.

Further research

Another possible deposition technique for ZnO:Al is the so-called expanding thermal plasma CVD process. The method was tested in a-Si solar cells with a comparable efficiency to Asahi's U type [26]. Many other options exist for developments in producing TCOs with vacuumless techniques. For example, sol gel technology shows the feasibility for TCO deposition of n-type materials (such as ZnO:Al and ITO) and p-type materials (such as $CuCrO_2$), more details of which can be found in [27]. The electrodeposition technique has the ability to deposit a ZnO film on electrical conducting substrates [28]. Both of these processes would be attractive for a reel-to-reel process, which has a high cost reduction potential.

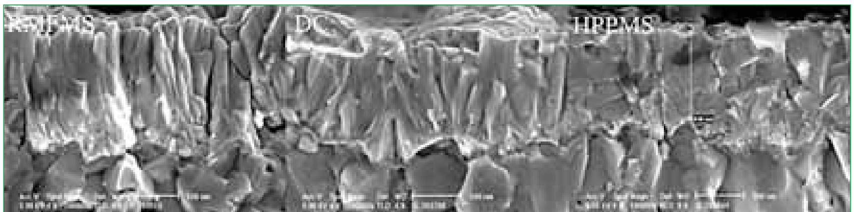


Figure 10. SEM pictures of cross-sections of CIGS mini modules measured at ZSW Stuttgart. The pictures show the top part of the module structure with the ZnO:Al layer. The samples show (left to right): reactive MF sputtering at 180°C; DC sputtering of ceramic target at 150°C; and reactive HPPMS sputtering at 190°C.

References

[1] Agura, H. et al. 2003, "Low resistivity transparent conducting Al-doped ZnO films prepared by pulsed laser deposition", *Thin Solid Films*, Vol. 445, pp. 263–267.

[2] Suzuki, A. et al. 2001, "Pulsed laser deposition of transparent conducting indium tin oxide films in magnetic field perpendicular to plume", *Jpn. J. Appl. Phys.*, Vol. 40, pp. L401–L403.

[3] Exarhos, G.J. & Zhou, X.-D. 2007, "Discovery-based design of transparent conducting oxide films", *Thin Solid Films*, Vol. 515, pp. 7025–7052.

[4] Müller, J. et al. 2001, "Upscaling of texture-etched zinc oxide substrates for silicon thin film solar cells", *Thin Solid Films*, Vol. 392, pp. 327–33.

[5] Minami, T. et al. 1989, "Heat treatment in hydrogen gas and plasma for transparent conducting oxide films such as ZnO, SnO_2 and ITO", *Thin Solid Films*, Vol. 176, pp. 277–282.

[6] Klenk, R. 2008, "Chacopyrite solar cells and modules", *Transparent conductive zinc oxide*, Klaus Ellmer, Andreas Klein, Bernd Rech (Eds.), Springer.

[7] Klaer, J. et al. 2004, *Proc. 19th PVSC*, Paris, France, p. 1847.

[8] Gläser, H.J. 2005, *Large area glass coating*, Von Ardenne Anlagentechnik GmbH (Ed.), Dresden, Germany.

[9] Faÿ, S. et al. 2005, *Solar Energy Materials and Solar Cells*, Vol. 86, p. 385.

[10] Kroll, U. et al. 2005, "TCO für Dünnschichtsolarzellen", *FVEE Workshop*.

[11] Volintiru, I. et al. 2007, "Evolution of the electrical and structural properties during the growth of Al doped ZnO films by remote plasma-enhanced metalorganic chemical vapor deposition", *Journal of Applied Physics*, Vol. 102/4, p. 043709.

[12] Sittinger, V. et al. 2009, "Comparison of different ceramic Al-doped ZnO target materials", *Photovoltaics International*, Vol. 6, pp. 101–108.

[13] Richard, D. 2010, "Deposition equipment for conductive layers – survey", *Photon International* (March), pp. 142–153.

[14] Braatz, C. et al. 2003, *Proc. Glass Processing Days*, Vol. 15, p. 391.

[15] Wieder, S. et al. 2010, "Large area thin film modules with 10% efficiency", *Proc. 25th EU PVSEC*, Valencia, Spain.

[16] Stannowski, B. et al. 2010, "Novel high rate DC magnetron sputtered zinc oxide and its excellent potential in a-Si/µc-Si tandem thin film module production", *Proc. 25th EU PVSEC*, Valencia, Spain.

[17] Ruske, F. et al. 2006, "Process stabilization for large area reactive MF-sputtering of Al-doped ZnO", *Thin Solid Films*, Vol. 502, pp. 44–49.

[18] Sittinger, V. et al. 2010, "Optical on-line monitoring for the long-term stabilization of a reactive mid-frequency sputtering process of Al-doped zinc oxide films", *Thin Solid Films*, Vol. 518, pp. 3115–8.

[19] Berginski, M. et al. 2008, "Recent development on surface-textured ZnO:Al films prepared by sputtering for thin-film solar cell application", *Thin Solid Films*, Vol. 516, p. 5836.

[20] Dewald, W. et al. 2009, "Optimization of process parameters for sputtering of ceramic ZnO:Al_2O_3 targets for a-Si:H/µc-Si:H solar cells", *Thin Solid Films*, Vol. 518, pp. 1085–90.

[21] Sittinger, V. et al. 2006, "ZnO:Al films deposited by in-line reactive AC magnetron sputtering for a-Si:H thin film solar cells", *Thin Solid Films*, Vol. 496, pp. 16–25.

[22] Sittinger, V. et al. 2006, Proc. EU PVSEC, Dresden, Germany.

[23] Koble, C. et al. 2009, "DC reactive sputtering of aluminium doped zinc oxide films for solar modules controlled by target voltage", *Thin Solid Films*, Vol. 518/4, p. 1204.

[24] Sittinger, V. et al. 2008, "Research on promising applications for high power pulse magnetron sputtering", *SVC Annual Technical Conference Proceedings*, Vol. 51, pp. 293–301.

[25] Greiner, D. et al. 2009, "Influence of damp heat on the optical and electrical properties of Al-doped zinc oxide", *Thin Solid Films*, Vol. 517/7, p. 2291.

[26] Groenena, R. et al. 2005, "Property control of expanding thermal plasma deposited textured zinc oxide with focus on thin film solar cell applications", *Thin Solid Films*, Vol. 492, p. 298–306.

[27] Szyszka, B. et al. 2010, "Development of new transparent conductors and device applications utilizing a multi disciplinary approach", *Thin Solid Films*, Vol. 518, pp. 3109–14.

[28] Wellings, J.S. et al. 2008, "Growth and characterisation of electrodeposited ZnO thin films", *Thin Solid Films*, Vol. 516, pp. 3893–3898.

About the Authors

Volker Sittinger is a senior scientist at the Fraunhofer Institute for Surface Engineering and Thin Films (IST) in the Large Area Coating department. Currently working on magnetron sputtering for photovoltaic applications, in the past he held the role of scientific assistant at the Institute of Solar Energy Research GmbH (ISFH). Volker received his doctoral degree in optical and electrical characterization of electrodeposited $CuInSe_2$ solar cells from the University of Oldenburg in 2003 and studied physics at the University of Karlsruhe.

Wilma Dewald has been a junior scientist in the Magnetron Sputtering group at the Fraunhofer IST in Braunschweig since 2008. She is currently working on her doctoral thesis on the subject of electrical, optical properties of TCOs and light management in thin-film solar cells. She studied physics at the University of Göttingen and received a diploma degree in 2007.

Wolfgang Werner has been working as an engineer in the Magnetron Sputtering group at the Fraunhofer IST in Braunschweig since 2001. He has 23 years' experience in material engineering in the field of machinery and plant manufacturing, and studied material engineering at the University of Applied Sciences Aalen.

Bernd Szyszka is head of the department of Large Area Coatings at the Fraunhofer IST, which he founded in 2003. After studying physics at the TU Brunswick, he started his scientific work at Fraunhofer IST in 1995, and received his doctorate degree Dr. rer. nat. in 1999 on the topic of "Reactive Magnetron Sputtering of Transparent Conductive Oxides".

Florian Ruske is a senior scientist at the Institute for Silicon Photovoltaics of the Helmholtz-Zentrum Berlin (HZB). He works on transparent conducting oxides and functional layers for silicon-based photovoltaic devices. He studied physics at the University of Bonn and afterwards worked at the Fraunhofer IST in the Large Area Coating department as a Ph.D. student. He received his doctoral degree from the University of Gießen in 2008 for a thesis on reactive sputtering of Al-doped ZnO for photovoltaic applications.

Enquiries

Fraunhofer Institute for Surface Engineering and Thin Films (IST)
Bienroder Weg 54 E
38108 Braunschweig
Germany

Helmholtz-Zentrum Berlin fur Materialien und Energie GmbH
12489 Berlin
Germany

Controlling surface texture of sputtered ZnO:Al using different acidic single- or multi-step etches for applications in thin-film silicon solar cells

Jorj I. Owen, Jürgen Hüpkes, Hongbing Zhu, Eerke Bunte,
IEK5-Photovoltaik, Forschungszentrum Jülich GmbH, Jülich, Germany

ABSTRACT
Magnetron-sputtered ZnO:Al is often used as a front contact in thin-film silicon solar cells due to its transparent conductive oxide (TCO) properties and its ability to be texturized by chemical etch processes to introduce light trapping. The transparency, conductivity, and surface texture after etching depend strongly on the sputtering conditions. Consequently, the typical preparation method is to find the right balance in TCO properties and light scattering, leading to a very narrow sputtering parameter window. It is preferable to separate the electro-optical optimization from that of texturization to allow for a larger process window and improve ZnO:Al film properties further. This paper presents some methods of controlling the surface features using various mixtures of HF and HCl, and two-step etching processes in aqueous solutions of both. Results include methods for controlling the density of craters, texturizing compact ZnO:Al films, and fabricating novel modulated surfaces with more than one characteristic feature size. The two-step etch process enables the creation of good surface textures even on high-rate material that, via state-of-the-art HCl etching, tend to lead to poor solar cell performance.

Introduction
Aluminium-doped zinc oxide (ZnO:Al) films, prepared by magnetron sputtering and surface textured by chemical etching, form a promising TCO for use as a front contact in amorphous and microcrystalline silicon thin-film solar cells [1,2]. Cost-effective processes are required for industrial application, including high-rate deposition using a high discharge power from ceramic targets [3], reactive sputtering from metallic targets [4], or more effective target usage from tube rather than planar targets [5]. Sputtering and subsequently etching ZnO:Al thin-films allows for the separate optimization of TCO properties and etch features.

However, the density and shape of resultant craters depend strongly on the ZnO:Al sputtering conditions used [1-3,5-7], and the two process steps (sputtering and etching) are not independent of each other. Thus, the current state-of-the-art is to tailor the deposition conditions of ZnO:Al to optimize electrical, optical, and the resultant etch features simultaneously. The best solar cell performance is achieved using ZnO:Al front contacts sputtered at low rates with radio frequency excitation from relatively expensive planar ceramic targets [8]. The transfer of this approach to other especially industrially-relevant processes has proved difficult in the past, even though the transparency and conductivity of these ZnO:Al films are well suited for solar cell application. If, however, the electro-optical optimization could really be separated from the texturization optimization, ZnO:Al thin-films that are better suited for solar cell applications could be prepared and industrially-relevant processes could be applied easily.

"The best solar cell performance is achieved using ZnO:Al front contacts sputtered at low rates with radio frequency excitation from relatively expensive planar ceramic targets."

It was recently shown that optimization of the etch process can lead to slightly different surface textures [9] and our group revealed that hydrofluoric acid (HF) texturizes sputtered ZnO:Al differently from hydrochloric acid (HCl), exhibiting small jagged and large smooth craters, respectively [10]. In this paper, the different etching properties of HF and HCl are used to:

1. vary the crater density on a given ZnO:Al film;
2. effectively texturize a compact ZnO:Al film that texturizes poorly under state-of-the-art HCl etching; and
3. fabricate a modulated (more than one feature size) surface texture for additional light trapping [11].

Experimental
The polycrystalline ZnO:Al thin-films used in this work were sputtered under two different conditions and will be referred to as low- or high-rate ZnO:Al. In both cases, the ZnO:Al was deposited using an in-line sputtering system (VISS 300, Von Ardenne Anlagentechnik) onto a cleaned glass substrate (CG, Corning, Eagle XG). Low-rate ZnO:Al substrates, which exhibit uniform crater coverage after HCl etching, were deposited on CG by radio frequency (RF) magnetron sputtering from a planar ceramic target at 13.56MHz. The ceramic target consisted of ZnO with a dopant concentration of 1 w/w% Al_2O_3; deposition was performed at a temperature, pressure, and discharge power of 300°C, 0.1Pa, and 1.5kW, respectively. The deposition rate for these sputtering conditions is 6nm m/min [6]. Details on film properties are available elsewhere [6].

High-rate ZnO:Al substrates, which exhibit relatively flat surfaces with a few large craters after HCl etching, were deposited on CG by mid-frequency dual magnetron sputtering from rotating ceramic targets at 40kHz. The rotatable ceramic targets consisted of ZnO with a dopant concentration of 0.5 w/w% Al_2O_3; deposition was performed at a temperature, pressure, and discharge power of 350°C, 1.5Pa, and 14kW, respectively. The deposition rate for these sputtering conditions is 100nm m/min [12]. Details on the ZnO:Al film properties are available elsewhere [12].

Varying crater density

Low-rate deposited ZnO:Al thin-films were etched in mixtures of HF and HCl, where the HF concentration was held constant at 1 w/w%, while the HCl concentration was varied from 0 to 1 w/w% in 0.125 w/w% steps. Etching times were adjusted so that approximately 150nm of the originally 800nm-thick film was removed, as determined by a surface profiler (Dektak 3030, Veeco). Surfaces were subsequently characterized by scanning electron microscopy (SEM, Supra 55VP SmartSEMTM, Carl Zeiss).

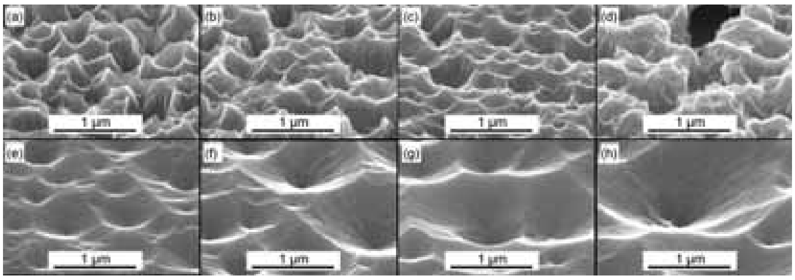


Figure 1. Low-rate ZnO:Al films etched in various mixtures of HF w/w%:HCl w/w%. Specifically, (a), (b), (c), (d), (e), (f), (g), and (h) were etched in 1:0, 1:0.25, 1:0.375, 1:0.5, 1:0.625, 1:0.75, 1:1, and 0:0.5, respectively.

Texturizing compact ZnO:Al films

High-rate deposited ZnO:Al thin-films were etched in 1 w/w% HF for 120 seconds. Following the HF etch, samples were etched in 0.5 w/w% HCl for 2, 4, 8, and 16 seconds. For reference, low- and high-rate ZnO:Al films were etched in 0.5 w/w% HCl for 40 and 50 seconds, respectively. The surface morphology was measured by atomic force microscopy (AFM, Nanostation 300, SIS), and the height and angular distributions were characterized using techniques described elsewhere [13]. Microcrystalline solar cells with a thickness of approximately 1.2μm were deposited by plasma-enhanced chemical vapour deposition (PECVD). Back contacts consisting of approximately 80nm of ZnO and 700nm of silver were deposited by RF sputtering and thermal evaporation, respectively. Test cells had an area of 1cm^2. The current density-voltage (I-V) characteristics of the solar cells were measured at 25°C under AM 1.5 illumination.

Fabricating modulated surfaces

Low-rate deposited ZnO:Al thin-films were etched in 0.5 w/w% HCl for 50 seconds. Following the HCl etch, samples etched in 1 w/w% HF for 5, 10, 20, or 40 seconds. Reference HCl- and HF-only surfaces were also made by etching in the respective solutions for 50 and 40 seconds. Thickness and morphology were determined by surface profiler and SEM, respectively. Reflection, total transmission, and diffuse transmission measurements were performed using an optical spectrometer with an integrating sphere (Lambda 950, Perkin Elmer). Diiodomethane was used for refractive index matching during total transmission and reflection measurements.

Results and discussion

Varying crater density

Fig. 1 shows SEM images of the low-rate ZnO:Al films etched in various mixtures of HF and HCl. Notice that the feature sizes and shapes can be varied from large smooth craters of about 1-2μm in diameter as etched in HCl alone to small jagged craters of about 300nm in diameter as etched in HF alone. The transition, however, is not smooth and it appears that one etching process dominates the other. Specifically, Fig. 1 (b), (c), and (d) with HCl concentrations equal to or below 0.5 w/w% have features more similar to that of the HF etch alone as seen in Fig. 1 (a), while Fig. 1 (e), (f) and (g) with

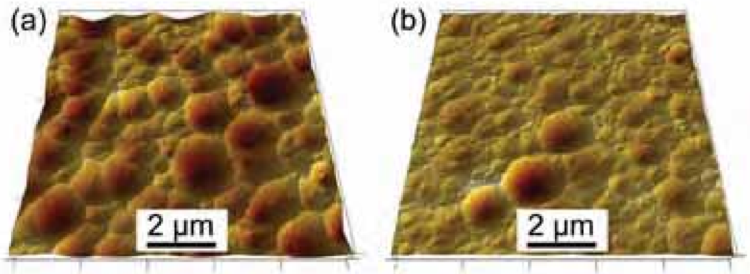


Figure 2. AFM images of (a) low-rate ZnO:Al etched in 0.5 w/w% HCl for 40 seconds; and (b) high-rate ZnO:Al etched in 0.5 w/w% HCl for 50 seconds.

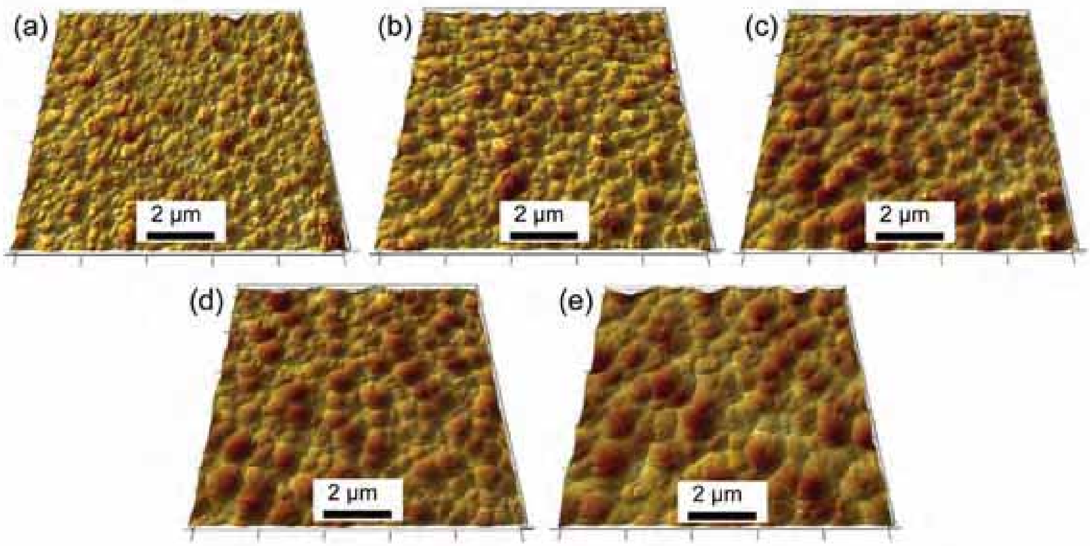
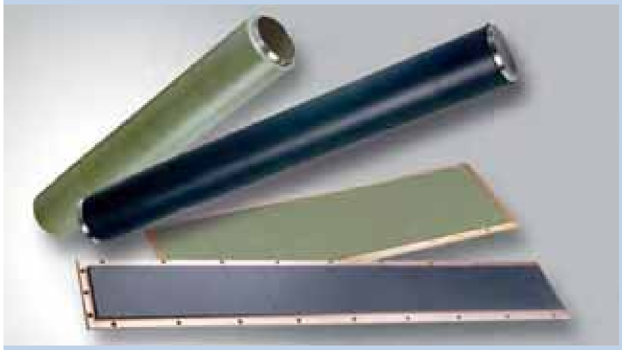


Figure 3. AFM images of high-rate ZnO:Al etched in 1 w/w% HF for 120 seconds then 0.5 w/w% HCl for (a) 0, (b) 2, (c) 4, (d) 8, and (e) 16 seconds.



HCl concentrations equal to or above 0.625 w/w% have features more similar to that of the HCl etch alone as seen in Fig. 1 (h).

The different etching behaviours of HF and HCl have been attributed to the different size and dissociation constants of the two acids [10]. HF with a smaller molecular size and much weaker dissociation constant is able to penetrate more grain boundaries before dissociating and etching [10]. By etching in mixtures of the two acids the density of craters can be somewhat controlled.

Texturizing compact ZnO:Al films

AFM images for the low-rate and high-rate reference etches in 0.5 w/w% HCl are shown in Fig. 2 (a) and (b), respectively. The low-rate deposited ZnO:Al exhibits homogeneous surface coverage with relatively large craters. This type of surface morphology has been shown to exhibit good light-trapping capabilities for microcrystalline solar cells [6]. The high-rate deposited ZnO:Al exhibits inhomogeneous texturization being mostly flat with a few large craters. Surfaces such as these exhibit low roughness [5,12], and poor light trapping due to their relatively flat nature.

AFM images of the high-rate ZnO:Al etched first in 1 w/w% HF for 120 seconds then 0.5 w/w% HCl for times between 0 and 16 seconds are shown in Fig. 3. The high-rate ZnO:Al etched only in HF is shown in Fig. 3 (a). Like the low-rate deposited ZnO:Al (Fig. 1 (a)), etching high-rate deposited ZnO:Al in HF leads to a higher density of craters [10]. AFM images of high-rate ZnO:Al etched in HF for 120 seconds followed by HCl for 2, 4, 8, and 16 seconds are shown in Fig. 3 (b), (c), (d), and (e), respectively. As the HCl etching time is increased, the diameter of the craters increases and the crater density decreases. After the longest HCl etching step (16 seconds, Fig. 3 (e)), relatively flat plateaus, like those observed on the high-rate deposited sample etched in only HCl (Fig. 2 (b)), begin to appear.

Height and angle distributions as calculated from the AFM images presented in Figs. 2 and 3 are given in Fig. 4. Median-centred height histograms, quantized into 10nm increments, are shown in Fig. 4 (a). Etching in only HCl yields broad and narrow distributions of feature heights for the low-rate (dashed black line) and high-rate (solid black line) deposited ZnO:Al substrates, respectively. The widths correspond to the different RMS roughness. Etching the high-rate ZnO:Al in only HF (red line) gives a slightly wider distribution of height values as compared to the HCl-only process (solid black line). The height distribution is widened further with the application of a second HCl-based etching step (orange, green, blue, and violet lines). Note, however, that the widest height distributions resulting from two-step etching are not as wide as the low-rate ZnO:Al reference. Thus, the RMS roughness and optical haze (diffuse transmission/total transmission) would remain smaller on these two-step textured surfaces than the low-rate HCl etch [14].

> "As the HCl etching time is increased, the diameter of the craters increases and the crater density decreases."

Angular distributions of the surface segments quantized into one degree increments are shown in Fig. 4 (b). Etching in only HCl yields a broad distribution with a peak at 23° and a narrow distribution with a peak at 12° for the low- and high-rate deposited ZnO:Al substrates, respectively. Etching only in HF or the shortest additional HCl etching time (two seconds) yields sharp surface features as seen by the higher peak in angular distribution at 27° and 29°, respectively. Notice also that for these etches, a significant fraction of the surfaces is covered with very step angles (above 50°). For samples with a second etching step in HCl between 4 and 16 seconds, the angular distributions shift to a spectrum very similar to that of the low-rate ZnO:Al, with peak angular distributions between 20° and 24°. Like the low-rate ZnO:Al surface, there are close to zero very steep angles.

Microcrystalline silicon solar cells were deposited onto high-rate ZnO:Al etched in HCl, HF, and HF then HCl, as well as low-rate ZnO:Al etched in HCl. The average short-circuit current density (J_{sc}) of the five best cells on HCl texturized high- and low-rate ZnO:Al films were, respectively, 20.9 and 23.4mA/cm^2. Etching the high-rate ZnO:Al film in only HF increased average J_{sc} by 5% to 22.0mA/cm^2. Using a two-step etching process in HF then HCl increased the J_{sc} on the high-rate ZnO:Al by 11 % (as compared to the HCl etch) to 23.1mA/cm^2. Notice that the two-step etched high-rate ZnO:Al exhibits J_{sc} values almost as high as those observed on the low-rate ZnO:Al. The increase in J_{sc} directly increased the cell efficiency, and the cells on the two-step etched high-rate ZnO:Al rivalled those of the HCl etched low-rate substrate. Although the example given in this paper was made using ceramic targets, this process has also been successfully applied to reactively sputtered films [15] and industrial-type ZnO:Al on commercial float glass. From these results, we conclude that the two-step etching process is able to reliably produce surface texture with good light trapping on production-type sputter-deposited ZnO:Al films.

Fabricating modulated surfaces

SEM images of low-rate ZnO:Al textured with a single etching step in 0.5 w/w% HCl

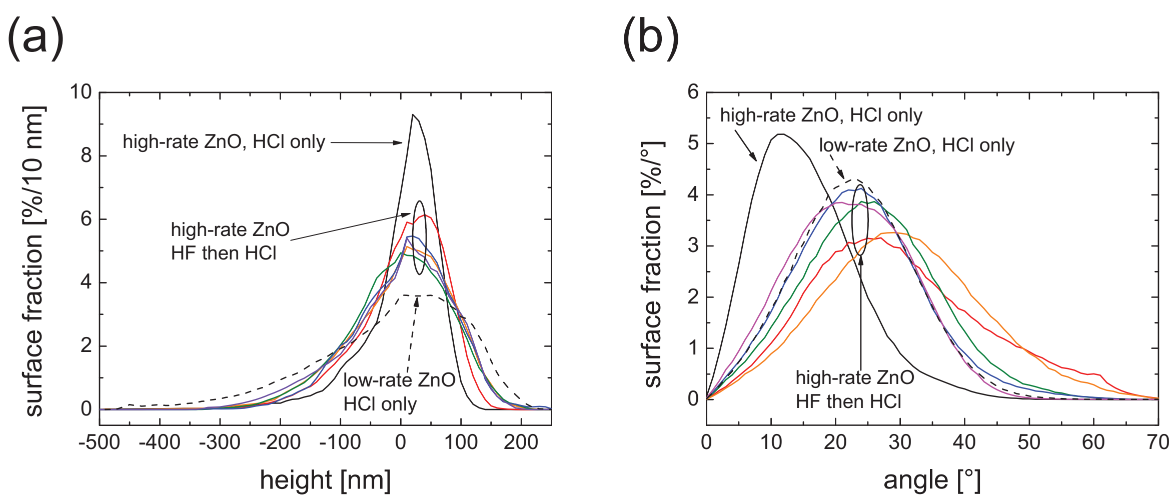


Figure 4. (a) Histograms of feature height in 10nm increments, and (b) surface angular distribution in one degree increments. The low-rate and high-rate reference surfaces are indicated by dashed and solid black lines, respectively. The 120 seconds HF etched followed by 0, 2, 4, 8, and 16 seconds of HCl etching are solid red, orange, green, blue, and violet lines, respectively.

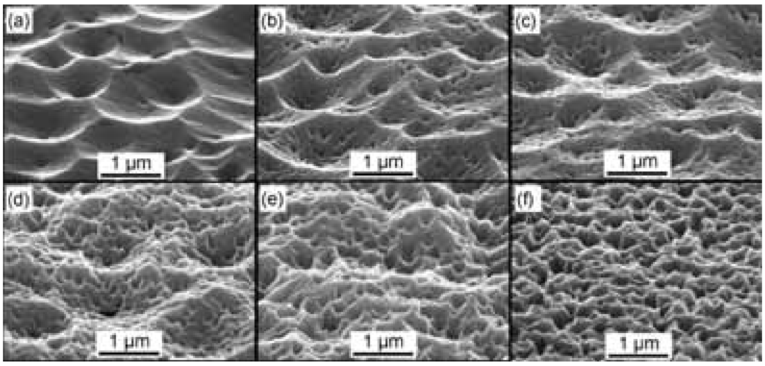


Figure 5. Low-rate ZnO:Al substrates etched in (a) 0.5 w/w% HCl for 50 seconds, 0.5 w/w% HCl for 50 seconds followed by 1 w/w% HF for (b) 5, (c) 10, (d) 20, and (e) 40 seconds, and (f) 1 w/w% HF for 40 seconds.

or 1 w/w% HF are shown in Fig. 5 (a) and (f), respectively. Fig. 5 (b-e) contain SEM images of modulated features etched into low-rate deposited ZnO:Al. The etching time for the first HCl-based etch was held constant at 50 seconds, while the second HF-based etch was varied; the 5, 10, 20, and 40 second etching times are shown in Fig. 5 (b), (c), (d), and (e), respectively. The first HCl-based etch yields large smooth craters, while the second HF-based etch introduces smaller jagged craters superimposed on the larger craters. As the duration of the second HF-based etch is increased, the small features deepen and the overall surface becomes more jagged.

The optical properties of the modulated and reference ZnO:Al samples are shown in Fig. 6. The total transmission, absorption, and reflection as a function of wavelength are shown in Fig. 6 (a). Transmission in the shorter wavelength region (400-600nm) is almost identical for the HCl-only and the modulated surfaces, while it is slightly reduced for the HF-only surface. In the longer wavelength region (700-1300nm), transmission generally increases with an increase in the duration of the second HF etching step. The only exception to this trend is the sample with a second HF etching time of 20 seconds, which exhibited higher total transmission than the sample with second HF etching step of 40 seconds. The HF-only etched surface also showed the lowest transmission values over this longer wavelength region. Since the reflection remained relatively constant, the absorption trends appeared inverse to those in total transmission.

> "The first HCl-based etch yields large smooth craters, while the second HF-based etch introduces smaller jagged craters superimposed on the larger craters."

The haze measurements as a function of wavelength and etching method are shown in Fig. 6 (b). Like the total transmission, the haze generally increases with an increasing duration of the second HF-based etching step. Once again, the only exception was a second etching step of 20 seconds in HF, which had higher haze then that of 40 seconds. Like total transmission, the HF-only etch also showed the lowest haze values across the whole measured spectrum (400-1300nm), exhibiting an average value of 8%. The average haze value over the same range was 29 and 37% for the HCl-only and maximum modulated surface structures, respectively.

The increased absorption in the long and short wavelength regions by the ZnO:Al

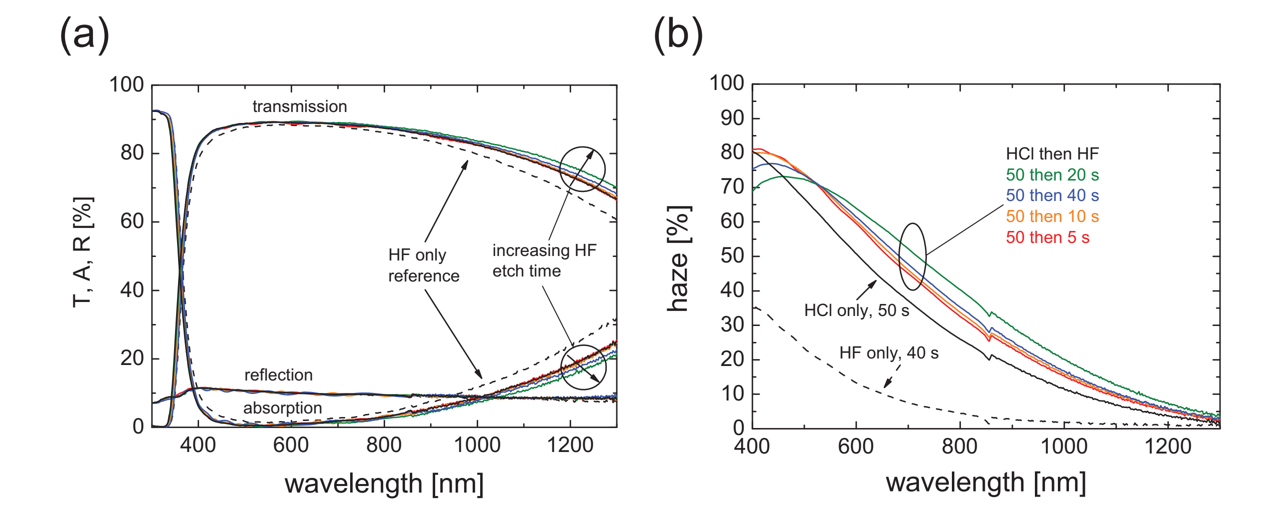


Figure 6. (a) Total transmission (T), absorption (A), reflection (R), and (b) haze as a function of wavelength for the various single and modulated etched surfaces.

sample etched only in HF is likely due to largest film thickness and thus largest free carrier absorption and steep angles causing strong internal light trapping, respectively. The decrease in absorption in the longer wavelength region with an increasing duration of the second HF-based etching step can be attributed to a decrease in film thickness, which was verified by surface profiler (with the 20-second HF modulated surface being thinnest).

The increase in haze observed from HF-only to HCl-only, and further with the modulated surfaces, is likely related to an increase in the ZnO:Al surface roughness [14]. The reduction in haze observed between the second HF-based etching step of 20 and 40 seconds is probably related to the loss of some of the underlying HCl-induced features. If allowed to progress too long (more than 20 seconds) the HF-induced features dominate and erase the HCl-induced features (see Fig. 5 (e)).

Conclusions and outlook

Using only different mixtures of and multiple etching steps in HF and HCl, we have demonstrated the ability to control the surface structures on sputtered ZnO:Al. Specifically, using various mixtures of HF:HCl, or two-step etching to create regular craters in HF and shaping them by HCl, the density of craters can be controlled. This may be especially applicable for surfaces that texturize poorly in HCl alone or amorphous silicon solar cells, where smaller feature sizes are desired. The two-step etching process was applied to high-rate ZnO:Al, which texturizes irregularly in HCl, and developed regular distribution of large craters. It closely mimics the surface texture of low-rate ZnO:Al. Solar cell prepared on a two-step texturized high-rate ZnO:Al showed similar light trapping and efficiencies as compared to a low-rate HCl textured surface.

Thus, this process is especially pertinent to industrial applications, where the deposition rates are high and common texturization methods are not ideal. This method provides a way to optimize the electro-optical properties and texture separately. Modulated surfaces were fabricated by etching low-rate ZnO:Al first in HCl then in HF. These surfaces have high haze and may be especially applicable in tandem solar cells, as they have both large and small surface features. Using a combination of these different approaches, it may be possible create modulated surfaces on the compact high-rate ZnO:Al films.

Acknowledgments

The authors would like to thank Janine Worbs, Hilde Siekmann, Joachim Kirchhoff, and Hans Peter Bochem for their technical assistance, as well as Sascha E. Pust and Aad Gordijn for enlightening discussion. Financial support by the German BMU (contracts 0327693A) is gratefully acknowledged.

References

[1] Kluth, O. et al. 2003, *Thin Solid Films*, Vol. 442, pp. 80–85.
[2] Müller, J. Et al. 2003, *Thin Solid Films*, Vol. 442, pp. 158–162.
[3] Tohsophon, T. et al. 2008, *Thin Solid Films*, Vol. 516, pp. 4628–4632.
[4] Hüpkes, J. et al. 2006, *Thin Solid Films*, Vol. 502, pp. 286–291.
[5] Zhu, H. et al. 2009, *Thin Solid Films*, Vol. 517, pp. 3161–3166.
[6] Berginski, M. et al. 2007, *J. Appl. Phys.*, Vol. 101, p. 074903.
[7] Kluth, O. et al. 1999, *Thin Solid Films*, Vol. 351, pp. 247–253.
[8] Rech, B. et al. 2006, *Thin Solid Films*, Vol. 511–512, pp. 548–555.
[9] Kumer, N. et al. 2010, *Photovoltaics International*, Vol. 9, pp. 137–141.
[10] Owen, J. I. et al. 2010, *Phys. Status Solidi A.*, DOI: 10.1002/pssa.201026164.
[11] Isabella, O. et al. 2010, *Phys. Status Solidi A.*, Vol. 207, pp. 642–646.
[12] Bunte, E., Zhu, H.B. & Hüpkes, J. 2008, *Proc. 23rd EU PVSEC*, Valencia, Spain, pp. 2105–2108.
[13] Schulte, M., Zahren, C. & Stiebig, H. 2006, *Proc. 21st EU PVSEC*, Dresden, Germany.
[14] Bennett, H.E. & Porteus, J.O. 1961, *J. Opt. Soc. Am.*, Vol. 51, pp. 123–129.
[15] Zhu, H. et al. 2010, *Solar Energy Materials and Solar Cells* [accepted].

About the Author

Jorj Owen received his B.S. in applied physics from Brigham Young University (Provo, Utah) and his M.S. in nanoscience and nanotechnology from Yonsei University (Seoul, Korea). He has been pursuing his Ph.D. for the last three years in the light scattering contacts group of the photovoltaics department (IEK5) in Forschungszentrum Jülich GmbH (Jülich, Germany). Since its inception, the light scattering contacts group, headed by Dr. Jürgen Hüpkes, has included such members as Dr. Eerke Bunte and Hongbing Zhu.

Enquiries

IEK5-Photovoltaik
Forschungszentrum Jülich GmbH
52425 Jülich
Germany
Tel: + 49 24616 12956
Fax: + 49 24616 13735
Email: j.huepkes@fz-juelich.de

Despite multiple challenges, the maturing thin-film PV sector looks set to increase market share

Shyam Mehta, GTM Research, San Francisco, California, USA

ABSTRACT

The three most viable thin-film photovoltaic technologies – cadmium telluride (CdTe), copper-indium gallium (di) selenide (CIGS), and amorphous silicon (a-Si) – continue to mature and grow technologically and in market stature. But apart from the dominance shown by CdTe leader First Solar, the rest of the TFPV manufacturers have had a fairly difficult time making significant commercial inroads as the price of mainstream crystalline-silicon modules plummeted over the past couple of years. Other factors delaying the long-predicted age of thin film include bankability challenges and difficulties in reducing production and system costs. Yet entrants in all three thin-film categories have reason for optimism, as they push toward a competitive market position. This paper provides an overview of the current status of the thin-film PV sector and its players, offering insights into why certain companies might emerge successfully in the years ahead.

Introduction

With a few notable exceptions, there is little doubt that after the growth and promise shown in 2008, the past year or so has been difficult for thin-film PV companies. There are three main reasons for this: polysilicon/crystalline-silicon module price drops, bankability challenges, and cost reduction difficulties.

Crystalline silicon price drops

Much of the value proposition of thin-film technologies rests on the price and availability of polysilicon for PV, and it was in this context that thin-film technologies emerged as an attractive proposition. Near-term feedstock availability for thin films is not an issue, meaning they could be deployed to fill the supply-demand gap resulting from the lack of polysilicon. Moreover, the high cost of polysilicon has made thin-film economics all the more favourable. The relative abundance and cheapness of polysilicon through 2009 therefore reduced the value proposition of thin-film technologies by eroding their cost advantage significantly, making life especially difficult for many thin-film manufacturers that had not ramped up manufacturing sufficiently to achieve cost gains from economies of scale.

Figs. 1 and 2 illustrate the pace at which c-Si pricing changed and the pricing and cost pressure that thin-film PV faced in 2009 as a consequence. Asian c-Si module prices in the fourth quarter of 2008 were in the US$3.50/Wp range; based on efficiency and performance differences, this meant that fair prices for representative CIGS and CdTe efficiencies were over US$3.00/Wp, while single-junction a-Si could sell at US$2.05/Wp. In nine months, Asian c-Si compression to US$2.25/Wp necessitated a 35% drop in thin-film prices, a required reduction for

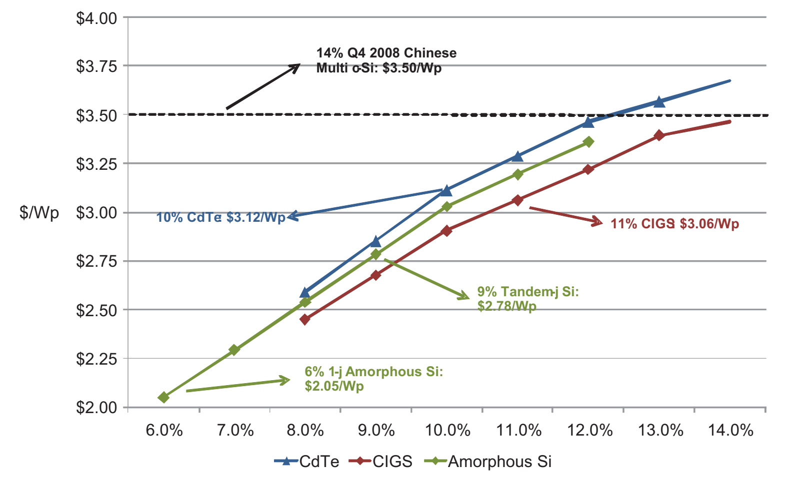


Figure 1. Effect of efficiency, BOS and performance on required module price (Q4 2008).

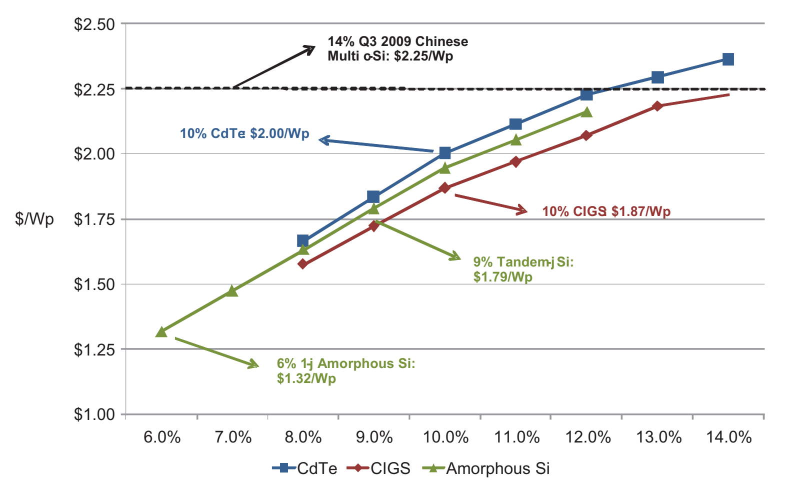


Figure 2. Effect of efficiency, BOS and performance on required module price (Q3 2009).

which most thin-film firms were completely unprepared. Single-junction amorphous silicon, for example, would have had to sell for US$1.32/Wp, at or below cost for most producers at that time. Even First Solar was not immune to crystalline-silicon price drops, as it was forced to introduce a rebate program in Germany for installed panels in order to preserve market share and maintain demand for its modules. To make matters worse, many less-established manufacturers were forced to offer further discounts to reflect the greater perceived risk associated with thin-film projects due to the bankability/risk factor.

Bankability challenges

The term 'bankability' refers to a project's ability to obtain financing. The credit crisis of 2007 and 2008 means that capital today is both scarce and expensive, which has forced lenders to be much more risk-averse than previously with respect to which projects they choose to finance. In other words, the projects that receive capital are those with the lowest risk profiles. Technology components comprise roughly 85% of a PV project's cost – of which the module comprises roughly 50%, which means that the module represents the largest cost component of a PV project. This has placed the module manufacturers under special scrutiny from banks, in two important respects:

- **Financial/balance sheet risk**. Since module warranties last for 20–25 years, it is essential that the module manufacturer be available during that time in order to honour its warranty. The long-term financial health of the company and the strength of its balance sheet come under the microscope here.
- **Technology/process risk.** Combining questions of risk with scarce, expensive capital means that banks have begun to exert their desire to control the technology. The long-term durability and performance (i.e., energy output) of the module in the field and the robustness of process flow of the manufacturer (to ensure consistent module quality) are of greatest concern in this respect.

The confluence of both these factors has resulted in many banks (particularly in Europe) passing on thin-film projects in favour of relatively less risky c-Si projects. On one hand, many thin-film manufacturers were formed relatively recently and have precious little to show in the way of sales and operating experience, meaning that their long-term financial viability is under question. Secondly, CdTe, CIGS and tandem-junction a-Si modules have not been deployed in the field for the full 20–25-year operating lifetime; in the case of CIGS, widespread operating data do not even exist for 5- or 10-year periods.

Consequently, banks have a perception of risk regarding the degradation (and thus the performance) characteristics of these modules, especially given the higher degradation rate of thin film as established by accelerated lifetime tests. Even single-junction amorphous Si, for which reliable system operating data exist, is not exempt, as lenders closely scrutinize the manufacturing process flow and control to ensure product consistency and durability. By contrast, c-Si generally offers a lower risk profile, since many companies in this space have been in business for more than a decade: the technology has a well-established manufacturing process, and field data are widely available. In fact, some c-Si projects built in the mid-1980s are still operating within their expected performance range.

The concern that thin-film companies may not be around to honour their warranties can be addressed using a simple solution: insurance can be offered for the warranty beyond the statutory warranty period (24 months in most of Europe and the U.S.), also known as a product guarantee cover. While this may add to module costs, the economic security obtained makes a huge difference when it comes to finding project financing, undercutting incumbents' advantage in this department. So far, Signet Solar, QS Solar, and NexPower (all a-Si companies) have been early adopters of this approach, and more are expected to follow. For all of these companies, insurance was provided through a combination of a regional industrial insurer (Marsh, in this instance), which is in turn reinsured by a globally established reinsurer (Munich Re). It must be stressed that by no means is the availability of a guarantee cover a given; the module vendor in question has to pass rigorous due diligence to qualify for the product.

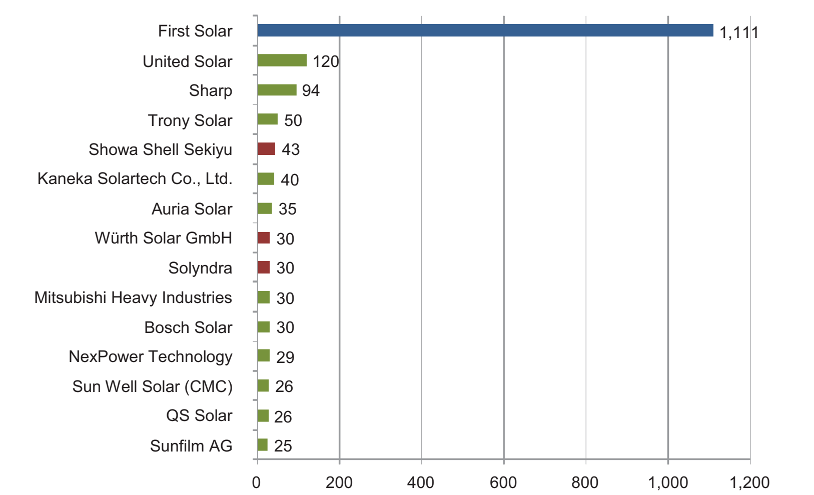


Figure 3. Top 20 thin-film firms by 2009 cell production (MW DC).

Cost reduction issues

The challenges faced by thin-film players were also compounded by their limited ability to reduce costs during this time, largely for two reasons. One, the lack of bankability for most producers meant they were restricted to producing a few megawatts of product a month, which did not allow them to reach economies of scale and thus reduce their unit costs. It was not until late 2009, when bankable supply had been exhausted, that sufficient demand existed to help those players who had reached 30MW-plus scale to improve costs (and margins) meaningfully. Second, many new firms (especially CIGS and a-Si turnkey producers) continued to encounter technical snags in process control and optimization, particularly with yields and throughputs, which also restricted a meaningful commercial ramp.

> "Overall, most thin-film players are still some distance away from being competitive with low-cost c-Si production on an efficiency-adjusted basis."

Overall, most thin-film players are still some distance away from being competitive with low-cost c-Si production on an efficiency-adjusted basis. With demand strength keeping utilizations high and continuous progress being made in terms of process optimization, 2010 and 2011 will be proving grounds for thin film, as it will become clear exactly which producers will have been able to execute on the more aggressive cost targets that a low-cost c-Si world dictates.

Top producers

Fig. 3 displays the top 15 thin-film producers in 2009. It should be noted that, with the exception of First Solar, less

Firm	Location	2009 Production (MW)	YE 2010 Capacity (MW)	Module Efficiency	Recent Developments
First Solar	Germany, US, Malaysia	1011	1341	11.2%	Reduced module cost to $0.76/Wp; expanding module capacity to 2.5 GW by YE2013; purchased U.S. developer NextLight in Apr 2010; U.S. project pipeline at 2.2 GW now
Abound Solar	US	4	100	10.0%	Obtained loan guarantee worth $400M from U.S. Dept. of Energy; will use to expand capacity
Calyxo GmbH	Germany	1	25	9.0%	Book value on Q-Cells balance sheet written down from EUR 77M to EUR 46M; looking to expand to 135 MW in 2011, but financing remains a question
Solexant	US	0	0	n/a	Competed 2 MW pilot line; raised $41.5M in Series C funding in June 2010; will receive further $44M from Oregon state; planning on constructing 100 MW facility in 2011
Primestar Solar	US	0	13	n/a	Plant to launch modules in 2011; GE is majority shareholder and public supporter of CdTe

Table 1. Key CdTe manufacturers and current status.

than 50% of thin-film production in 2009 was actually shipped and deployed in the field; this was indeed the case with the second-largest producer on the list, U.S.-based United Solar, with 120MW (actual shipments were around 71MW). United Solar is followed by Sharp (94MW), China-based Trony Solar (50MW), and CIGS-based Solar Frontier, formerly known as Show Shell Sekiyu K.K.

Eleven of the top 15 firms are amorphous silicon-based; most of them are small or midsized players that produced between 20-40MW in 2009. Three are CIGS firms (Solar Frontier, Würth, and Solyndra), and First Solar is the only CdTe name on the list. Notably, only five companies are Chinese or Taiwanese in origin, indicating that the region has yet to establish the kind of dominance it enjoys in c-Si manufacturing.

Cadmium telluride

Cadmium telluride is at once the most and least successful thin-film technology. It is the most successful because it is still the only technology to have been successfully commercialized at multi-hundred-megawatt scale, a feat accomplished by U.S.-based First Solar, which produced a world-record 1.111GW of modules in 2009. On the other hand, CdTe has by far the least representation in terms of the number of firms pursuing it as a preferred technology. As an indication of this skewed state of affairs, non First-Solar CdTe production in 2009 was only 5MW.

At this point, CdTe remains largely synonymous with First Solar. In terms of the company's recent progress, significant developments have been achieved on multiple fronts. These are summarized below:

- **Production and capacity.** With 1.1GW of modules sold in 2009 (compared to 504MW in 2008), First Solar emerged as the biggest selling module vendor

Firm	Location	Substrate	Manufacturing Process	2009 Production (MW)	YE 2010 Capacity (MW)	Module Efficiency	Target Market					Recent Developments
							Residential	Commercial	Utility	BIPV	Off-grid	
Avancis	Germany	Glass	sputtering and selenization	6	80	11.0%	v	v				Announced construction of second plant by BOY 2012, 100 MW capacity; achieved efficiency of 15.1% fully encapsulated module
Global Solar	US, Germany	Metal foil	coevaporation, roll-to-roll	10	76	10.0%	v	v		v	v	Dow to use Global's cells in development of CIGS solar shingles; product release in 2011. Already produces flexible modules for portable applications
Miasole	US	Metal foil	sputtering, PVD & roll-to-roll	4	60	10.5%		v	v			Supply agreements worth 12 MW signed with juwi, Phoenix Solar for 2010; expects to ship 22 MW in 2010
Nanosolar	US	Metal foil	printing, rapid thermal processing	5	80	9.0%			v			12 MW annual run-rate in 2009; shipping product to multiple customers in 2010; still in initial stages of commercial production
Odersun	Germany	Copper tape	roll-to-roll on copper tape	3	25	10.0%	v	v		v		Shifting focus to flexible modules for BIPV market and customized products
Solar Frontier	Japan	Glass	sputter & selenization	43	80	12.2%	v	v	v			Constructing 900 MW fab in Japan; expects to have 600 MW capacity online by EOY 2011
Solibro GmbH	Germany	Glass	coevaporation	14	135	12.6%	v	v	v			Expects to reach costs of EUR 0.80/Wp by EOY 2010; produced 25.5 MWp in H1 2010
Solyndra	US	Glass	coevaporation	30	110	9.7%		v				Canceled announced IPO but raised $175M in convertible debt; secured 16.2 MW in PPA sales to Southern California Edison in July 2010 Closed first factory in Q4 2010 citing lack of cost competitiveness, reduced 2013 capacity target from 610MW to 285–300MW
Stion	US	Glass	Two-stage sputtering process; pursuing double-junction CIGS/chalcopyrite module in 2011	0	10	11.8%	v	v	v		v	Received $70 MW in Series D round, $50M from Taiwan Semiconductor, who will also assemble modules; expanding to 100 MW
Würth Solar GmbH	Germany	Glass	multi-source evaporation	30	45	12.6%	v	v	v	v	v	Begins to license production technology; downstream-integrated into systems sales, integration, development, EPC, and operation; divisions brought 10.9 MW system to completion

Table 2. Leading CIGS manufacturers and current status.

across all technologies. Production in 2010 is expected to be around 1.4GW and more than 2.1GW in 2011. The company's capacity has been sold out for 2010 since the beginning of the year, as it sells most of its modules through long-term contracts. At this point, First Solar's modules have been established in the market as reliable and bankable.

- **Efficiency.** Consistent progress was also made on the efficiency front: module conversion efficiency has increased from 10.9% in Q2 2009 to 11.2% in Q2 2010, reaching 11.3% in Q3 2010.
- **Costs.** Manufacturing costs also decreased by 13% over the last four quarters, from US$0.87/Wp in Q2 2009 to US$0.76/Wp in Q2 2010 (with a rise of one cent to US$0.77 in Q3 2010).
- **U.S. utility-scale development.** First Solar continued to expand its EPC/project development business in the U.S. utility-scale market in 2009 and 2010. First, it acquired a-Si producer Optisolar's 1.9GW pipeline, which included a 550MW power purchase agreement (PPA) with California utility PG&E. It also secured development rights to two projects totalling 550MW for SCE (another utility in California), as well as a contract for the construction of a 22MW plant in New Mexico. In April 2010, it acquired U.S. developer Nextlight, bringing its total utility-scale pipeline of projects in the U.S. to 2.2GW. At this point, First Solar and SunPower are the only PV companies to have integrated downstream with clear success.

Table 1 lists the most important manufacturers of CdTe. There are four other firms besides First Solar that merit attention: U.S.-based Abound, Solexant, and Primestar, and Q-Cells subsidiary Calyxo. At the moment, only Abound is producing modules in commercial quantities, and a US$400 million U.S. federal loan guarantee is expected to be used to fund the company's expansion beyond the 100MW capacity mark. Module efficiencies range from 9% (Calyxo) to 11% (First Solar). 2011 could be a very significant year for CdTe, with Abound expected to ramp into 50MW-plus production, and commercial shipments promised by a number of other firms on the list. Given the constant delays experienced by many thin-film firms, however, this cannot be taken for granted.

> "Most firms are still in the process of bringing their first major (non-pilot) facility online, or have recently done so and are ramping up production."

One advantage that CdTe companies have over other thin-film firms is that they are considered safer and thus more bankable than other technologies, thanks to First Solar's success, the availability of four to five years' worth of operational data for First Solar projects, and producers that can employ a blend of First Solar and other CdTe modules in projects to de-risk output. This is an important benefit for producers such as Abound, and it remains a key factor in developing market traction.

Copper indium gallium (di)selenide

Claims of low-cost, high-throughput manufacturing at crystalline silicon-like efficiencies have created much hype around CIGS over the last three years, making it the beneficiary of billions in venture capital investment. While CIGS was supposed to break into large volume manufacturing in 2007 and then again in 2008, producers have not had an easy time of it, being plagued by yield, efficiency, and throughput issues. Progress so far has been steady rather than spectacular.

Table 2 lists the 10 most important CIGS producers in the market today, with key information and recent developments; the U.S. and Germany are home to all but one of these firms. Although sputtering and coevaporation are the two most commonly-used absorber-layer deposition processes in the CIGS space, the specifics vary greatly across producers and form the basis of intellectual property and competitive advantage in the sector. Glass is the most popular substrate and is associated with higher-efficiency modules; however,

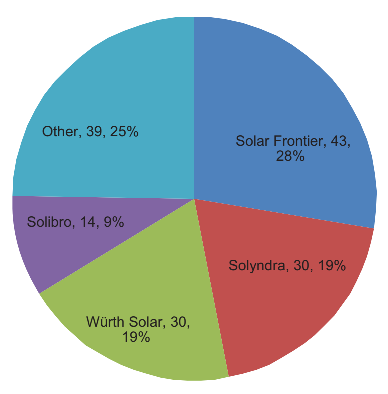


Figure 4. CIGS cell production for 2009 (MW DC).

a few companies (e.g., MiaSolé, Nanosolar, Global Solar, Odersun, SoloPower) are pursuing deposition on flexible metal substrates, which allows for a high-speed roll-to-roll process, though in most products made by these firms, the cells are still finally encapsulated in glass-glass packaging. Overall, most firms are still in the process of bringing their first major (non-pilot) facility online, or have recently done so and are ramping up production, which signifies that major hurdles in process control have been crossed.

It is interesting to note the wide variation in the types of markets these companies are targeting. Some, such as Solyndra and Nanosolar, are single-mindedly focused on a specific market (large commercial rooftop and utility-scale ground mount, respectively). Others, like Global Solar and Odersun, produce products for a variety of applications but have shifted focus to off-grid and BIPV modules given their high cost structure. Finally, there are a few that maintain the traditional grid-connected focus (residential/commercial/utility-scale), such as Solibro, Solar Frontier, and Stion. It will be interesting to see which product designs are better suited for different applications, especially in the commercial segment, where almost every company wants to participate. Although dedicated products (such as Nanosolar's Utility Panel) may have the edge in specialized markets, First Solar's success with a standard module design for all grid-connected applications proves that this is not necessary.

Fig. 4 breaks down 2009 CIGS production by manufacturer. The top four firms make up almost three-quarters of the 156MW of modules made in 2009, and most CIGS firms produced to sub-10MW levels. Still, the production numbers are notably higher than 2008, and three of these four (Solar Frontier, Solibro, Solyndra) will produce more than 50MW in 2010.

Fig. 5 indicates CIGS module efficiencies for the 15 CIGS manufacturers in commercial production. In 2008, the top CIGS module efficiency stood at 11.5% (Würth Solar) and 11 firms had module efficiencies of 9% and above; today these metrics stand at 12.6% and 14, respectively, indicating that manufacturers have made definite progress in boosting efficiencies. Of the deposition processes, thermal evaporation has yielded the best commercialized results so far (12.6% for both Würth and Solibro), although sputter-based Solar Frontier says it will be selling 12.2% modules in January 2011, indicating that the firm is not too far behind. At this rate, it is not inconceivable that CIGS efficiencies could soon catch up with those of traditional multicrystalline silicon, which has module efficiencies of around 14.3%.

Amorphous silicon

The business case for investment in amorphous silicon acquired significant momentum in 2007 and 2008, during the era of scarce and exorbitantly-priced polysilicon. Unlike its crystalline cousin, feedstock (silane) utilization was relatively insignificant, meaning that raw material availability was not much of a problem. In addition, unlike CIGS and CdTe, a-Si was already a relatively mature technology; companies like Sharp, Mitsubishi Heavy Industries, and flexible laminate producer United Solar had been shipping product for a few years. With ready-made manufacturing lines available, barrier to entry was low, meaning a producer could cash in on the then-current boom immediately. While manufacturing costs were still higher than US$2.00/Wp for most (aided by equipment costs of US$2.50/Wp to US$3.00/Wp), cost pressure was low in a supply-constrained market with high c-Si prices. If product could be made, it could be sold. The result was dozens of new entrants to the market, many of them purchasing turnkey equipment from numerous vendors.

The situation changed dramatically in 2009, as sharp c-Si price drops put most producers under heavy margin pressure; in the blink of an eye, a single-junction module that could easily fetch more than US$2.00/Wp had to sell for US$1.40/Wp to be competitive. Few a-Si manufacturers were then in a position to compete with the incumbent heavyweights, i.e., First Solar and Asian multicrystalline silicon. Combined with lower bankability relative to crystalline Si, this hit production and shipments hard; as of February 2010, for example, a mere 30MW of modules from Applied Materials had been installed. Compared to 2007 and 2008, when more than 40 firms entered the a-Si market, new orders for equipment almost completely dried up in 2009 and 2010, with only four firms purchasing equipment (all from Swiss vendor Oerlikon).

> "Low module margins for a-Si may necessitate movement downstream as a means of capturing the system/power purchase agreement margin."

Given these difficult circumstances and the sheer number of relatively undifferentiated and uncompetitive manufacturers in the space, some of whom had little previous experience or knowledge of PV, it was inevitable that casualties would occur. Table 3 lists recent market exits in the a-Si space; the highest-profile of these was equipment giant Applied Materials' decision to cease selling its SunFab turnkey line to new customers in July 2010. Along with Applied, three of the tool firm's customers also faced a struggle for survival, with German companies Sunfilm and Signet Solar declaring insolvency and Suntech Power ceasing production from its 50MW line.

The constant flow of bad news associated with a-Si companies has given the technology a negative image in general, and many observers do not consider

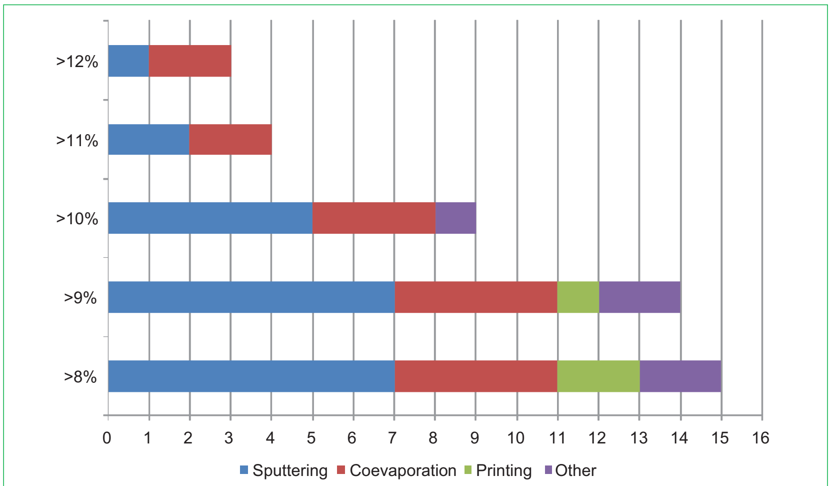


Figure 5. Number of CIGS firms by manufacturing process and efficiency.

Date	Firm	Equipment Vendor	Description
Apr 2010	Sunfilm	Applied Materials	Merged entity of Sunfilm and Sontor (Q-Cells subsidiary) w/total tandem-junction capacity of 145 MW; aiming to restructure and find new investors
Mar 2010	EPV Solar	Self	Equipment vendor and module producer filed for bankruptcy, reports of poor capital management
Jun 2010	Sanyo ENEOS	Self	Proposed JV b/w Sanyo and Nippon Oil to produce tandem-junction Si modules; canceled before commercial production began; cited c-Si price drops; employees returned to parent companies
Jun 2010	Signet Solar	Applied Materials	Single-junction producer w/20 MW capacity; aimed to obtain loan guarantee from U.S. Dept. of Energy for construction of U.S. fab; claims delinquent payments from customers; looking for new investors
Jul 2010	Applied Materials Sunfab	Self	Forced to discontinue sales of Sunfab to new customers; focused on selling individual tools to customers, continue selling to existing customers and research into thin-film
Aug 2010	Suntech Power	Applied Materials	Ceased production from 50 MW Sunfab line; costs likely not competitive; lack of commited resources also likely

Table 3. Recent market exits in a-Si PV.

its prospects bright. With more than 50 a-Si producers in the space, it would be unwise to write off the technology altogether; indeed, many firms have made significant progress on a number of fronts in recent months. Table 4, which profiles the most important a-Si producers in the world today, brings some of these accomplishments to light.

A clear trend is the shift from single- to tandem-junction as the representative technology. Most firms on the list are focused on the development and production of 9%+ modules; one firm (Sharp) has already breached that barrier. Interestingly, only two firms (ENN Solar and Tianwei SolaFilms) have opted for a complete turnkey solution from equipment vendors (Applied and Oerlikon, respectively), while the others have purchased individual tools from vendors, or have developed equipment internally. In a way, this is not surprising; one expects a high correlation between customers that bought turnkey lines and their competence (or lack thereof) in thin-film manufacturing.

An increasing number of a-Si companies, in contrast to their c-Si competitors, have integrated downstream into system sales, integration, and development. Partly, this has to do with the fact that after Germany, the biggest market for Chinese a-Si companies is China itself, where the lack of sophisticated developers makes it necessary for many module companies to enter into development. This may also be a good technology fit for downstream services when one considers that balance-of-systems (BOS) costs for a-Si are the highest of all technologies, meaning that a great deal of value can be added by owning installation and BOS segments. Moreover, low module margins for a-Si may necessitate movement downstream as a means of capturing the system/power purchase agreement margin; a-Si's real benefit is its kilowatt-hour per kilowatt performance advantage,

Firm	Ownership	Technology	Location	Equipment Vendor	2009 Production (MW)	YE 2010 Capacity (MW)	Module Efficiency	Recent Developments
Astronergy	Subsidiary of Chint Group (player in low-voltage electrical, power T&D industries in China)	a-Si/μcSi	China	Oerlikon/Self	8	75	9.0%	Claims will be at $0.71/Wp manufacturing cost by BOY 2011; providing system sales/installation/development services
ENN Solar	Spun out of natural gas company XinAo Group in November 2007; co-founded with ENN Group, a diversified clean energy company with $3 billion in revenue in 2008	a-Si/μcSi	China	Applied Materials	4	70	9.2%	Entered into systems integration/development; won bid to supply modules for 5-MW plant in Inner Mongolia
GS Solar	Private	a-Si (2)	China	Self	11	108	8.0%	Plans to construct 130 MW plant by 2011; offers production plant operating services; proprietary equipment design company, Apollo Solar, is publicly traded on HK Exchange
Inventux Technologies AG	Private	a-Si/μcSi	Germany	Oerlikon/Self	22	33	9.2%	Increased commercial efficiency from 8.9% to 9.2% in 2010; launched value-added services segment; running at full utilization in H1 2010
NexPower Technology	Subsidiary of IC Foundry, UMC Group	a-Si/μcSi	Taiwan	ULVAC	29	100	9.0%	Introduced product guarantee cover (i.e. module warranty insurance) in 2009, through Marsh and Munich Re
QS Solar	Subsidiary of Qiangsheng (QS) family of companies, which was founded in 1993 as an industrial manufacturer	a-Si (2)	China	Undisclosed	26	200	6.0%	Introduced product guarantee cover through Munich Re; entered EPC/project financing/development; expects to be at 500 MW capacity by EOY 2010
Sharp	Subsidiary of Sharp Co.	a-Si/μcSi	Japan	TEL/Self	94	320	10.0%	Began volume production out of 160 MW Sakai fab in Mar 2010; 10% module in production. Looks to sell 1 MW+ utility-scale systems in 2011
Tianwei SolarFilms Co.	Affiliate of the Tianwei Group, a state-owned international high-tech company with more than 50 years experience in the energy industry and the world`s biggest transformer supplier.	a-Si	China	Oerlikon	13	47	6.4%	Placed upgrade order with Oerlikon to switch over to 75 MW tandem-junction in 2011
Trony Solar	Private; investors include Intel Capital	a-Si (1)	China	Self	50	205	6.0%	Manufacturing cost of $1.09/Wp in July 2009; attempting to launch IPO on hong Kong Stock Exchange in 2010

Table 4. Key a-Si manufacturers and current status.

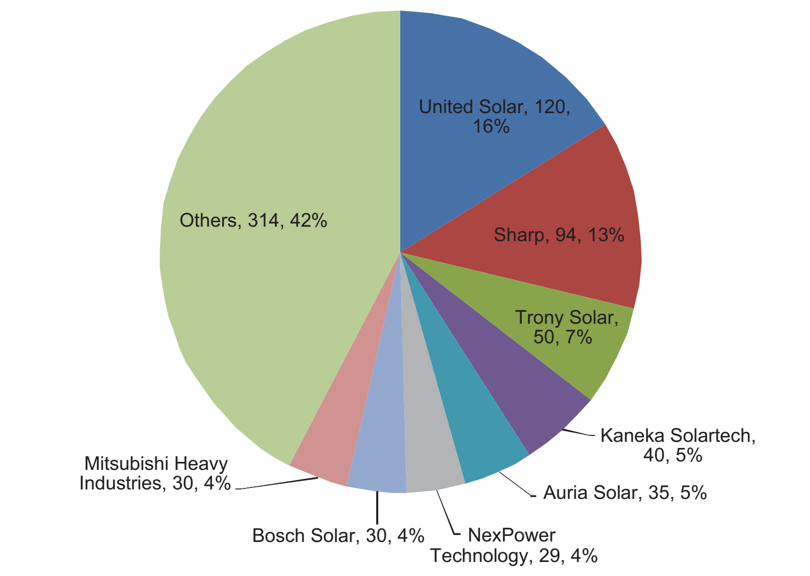


Figure 6. Amorphous-silicon cell production in 2009 (MW DC).

which is difficult to incorporate into a module price for an undiscerning buyer.

In the cases of Astronergy, ENN, QS Solar, and Sharp, this performance benefit is recognized and made possible by the existence of a large corporate parent with the balance sheet and reputation to leverage in the downstream business, particularly when it comes to the cost of financing. The protection afforded by a corporate parent is a definite source of differentiation and competitive advantage in this space.

Fig. 6 displays the largest a-Si producers in 2009. United Solar, Sharp, and Trony hold the top three positions, followed by Kaneka Solartech (Japan) and Auria Solar (Taiwan). Again, only one single-junction producer (Trony) makes the top eight. The fact that these eight players make up only 58% of production is an indication of just how crowded and fragmented the space is, which, along with the fact that many producers share the same equipment vendor, makes this space ripe for further consolidation.

Outlook

The thin-film sector should continue to increase its share of the overall photovoltaic market share over the next several years, going from 20% in 2010 to more than 26% in 2013. Thin-film module production will more than double, rising from an estimated 3.2GW in 2010 to more than 6.7GW in 2013. Revenues from companies in the sector are forecast to grow from US$4.8 billion to US$6.3 billion during the same period. Conversion efficiencies for the three main thin films will continue to improve, with CdTe expected to reach at least 12.4%, coevaporated CIGS 14%, sputtered CIGS 12.8%, and tandem-junction a-Si 11.3% by 2014. In a forward-looking analysis of the top 15 firms ranked in terms of projected efficiency/bankability-adjusted module cost in 2012, five of the companies come from the thin-film ranks, led by First Solar in the number-one slot, and Solar Frontier, Solibro, and Sharp occupying the eighth, ninth, and tenth positions, respectively.

Fig. 7 shows best-in-class module manufacturing costs by technology and region for 2012. As can be seen from the graph, First Solar will remain the cost leader for CdTe, and will continue to lead other manufacturers by a fair distance, but the best CIGS and amorphous silicon firms (Solar Frontier and Sharp, respectively) are expected to have costs under US$0.85/Wp.

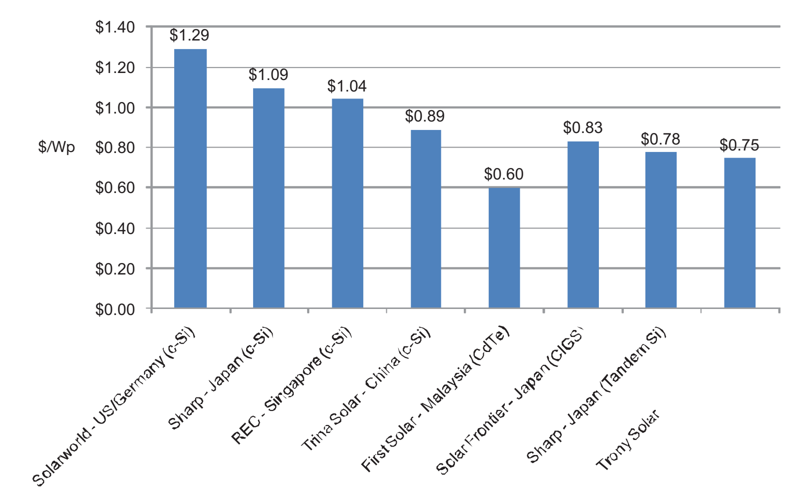


Figure 7. Best-in-class module manufacturing costs by technology/region, 2012E.

Conclusion

One clear market leader has emerged from the thin-film sector so far: CdTe purveyor, First Solar. The company's success can be attributed to its ability to scale to gigawatt-plus manufacturing capacity, achieve acceptable conversion efficiencies, maintain an industry-leading cost structure, and extend its business model downstream into utility-scale project development. Although other thin-film companies have been pressured by issues such as cheap crystalline-silicon modules, bankability, and relatively high production costs, several CdTe, CIGS, and a-Si contenders have emerged recently as commercially viable candidates, with growth potential across a wide variety of mainstream and differentiated market segments.

Acknowledgments

This paper is based on an excerpt from the GTM Research report, *PV Production, Technology, and Cost Output: 2010-2015*, originally published in October 2010. This report spans the entire breadth of the PV supply chain, from polysilicon to module production, and analyzes technical parameters, facility-specific capacities and production, manufacturing costs, and competitive analysis of module producers. The report is available from www.gtmresearch.com. Editing and additional information provided by the *Photovoltaics International* staff; used with permission.

About the Author

Shyam Mehta is a senior analyst at GTM Research, focusing on global solar markets. Before joining the Greentech Media unit, he was a financial analyst at Goldman Sachs Global Investment Research, where he covered equities in the alternative energy sector, primarily solar companies. Before that, Mehta was a research analyst at The Brattle Group, an economic consulting firm, where his work focused on problems within the electricity industry. He received his B.S. in mathematics summa cum laude from the University of California, Berkeley. Mehta has been widely published and has spoken at numerous industry conferences over the world on the subject of solar PV.

Enquiries

Email: mehta@greentechmedia.com

PV Modules

DuPont™ Tedlar® PVF Film

For more than twenty-five years, Tedlar® film has enabled long-term, reliable power output and module performance.

Proven Performance

A reliable backsheet is a module's foundation for maintaining power output over time. This is why industry leaders are choosing Tedlar® and its unmatched record of durability to meet solar needs today and 25+ years into the future.

Under normal, as well as extreme UV and damp heat exposure, Tedlar® resists delamination, yellowing and degradation that compromise other backsheet materials.*

* To learn more about the performance of Tedlar® in various backsheet constructions, go to tedlar.dupont.com/pv

energy for a thriving world™

DuPont™ Tedlar® is part of DuPont Photovoltaic Solutions which offers a broad and growing portfolio of PV innovations helping transform the sun's potential into clean, efficient energy the world needs to thrive.

DUPONT®

The miracles of science™

the koncordia group

job #
TFP10_16438 Tedlar® PVF Film Advertising

client
Alyssa Koontz
DuPont™ Tedlar®

publication
Photovoltaics International
210mm x 297mm

first insertion
August 2010

creative
"25+ Performance"

initial date

account executive
MR

creative director
MB

copywriter
JG

art director
MB

production
KJ

proofreader
MR

approved for PDF
MR

approved to disc
MR

approved output from disc
MR

News

SunPower sold out for 2011: project pipeline stands at 5GW

Tom Werner, CEO of SunPower

Despite an ongoing ramp of its Malaysia-based Fab 3 cell production plant that will increase its megawatt production by 65% in 2011, Tom Werner (pictured), CEO of SunPower, noted in its third-quarter financial conference call that demand for its products has exceeded supply in the second half of this year and will do the same in 2011.

The leading high-efficiency solar module manufacturer and project developer posted revenue of US$554 million, up 41% over the second quarter of 2010, and an increase of 19% compared to the third quarter of 2009. SunPower expects revenue to reach between US$2.15 billion and US$2.25 billion in 2010. Its PV project pipeline now stands at 5GW – a 4GW increase from last year.

In the residential and commercial segment, SunPower reported revenue of US$293 million in the third quarter, compared to US$264 million in the second quarter. The company has been capacity constrained for most of the year. However, Werner noted that production had actually increased in the quarter due to Fabs 1 and 2 in the Philippines delivering record performance in cell production, as overall equipment effectiveness and improved average solar cell conversion efficiencies and yields were achieved.

Capital expenditures in the third quarter were US$4.3 million and should be in the range of US$125 million to US$150 million for the full year. During the third quarter, US$2 million in capital was contributed to the Fab 3 joint venture. SunPower produced 152MW of modules in the quarter and plans to exceed its previous plan of 550MW by year-end as module production ramps in Malaysia. Module production in the second quarter was 137.9MW.

Smart Module News Focus

Suntech places bet on smart modules

With an eye on increasing the capacity, Suntech's main factory at Prenzlau will be modernizing its oldest production line, 'aleo I.' Capacity will also be increased by improving production efficiency and by utilizing solar cells with a higher output rating. The avim solar production joint venture, based in Gaomi, China, will also lift production capacity to 90MW from the current 50MW, while the Spanish plant at Santa Maria de Palautordera will maintain its current capacity of 20MW.

Integrating energy harvesting technologies into crystalline solar modules is fast becoming the latest trend, which promises lower BOS costs compared to bolt-on applications. With the number of companies entering this market mushrooming in 2010, Suntech has decided to collaborate with at least four such firms, Tigo Energy, National Semiconductor, Azuray Technologies, and Enphase Energy.

Suntech, the largest c-Si module producer, is working on developing the right technologies that integrate both technology solutions into its modules. In May 2009, Suntech said that it was evaluating National Semiconductor's 'SolarMagic' power optimizer chipset.

According to National Semiconductor, real-world tests as part of the original agreement with Suntech revealed its technology could recoup an average of 50% of energy lost due to shading and module mismatch, and in some cases captured as much as 75% of otherwise lost energy compared to standard panel performance.

Tigo noted that its Energy Maximizer solution is designed to quickly integrate into the junction box and provides statistical conversion efficiency of 99.5%, mitigating the need for heat dissipation to be designed into the system. Tigo also claimed that some microinverters created 10W of power radiated as heat that went into the PV module.

Key developments taking place with the technology offerings include the integration of the chipsets into the back of the conventional junction box. Although timelines were not given as to when smart modules would be made commercially available, a growing number of module manufacturers are working to launch integrated solutions in the next 12 months.

Suntech has also signed smart panel-related collaboration deals with two other companies: Azuray Technologies and Enphase Energy. The Chinese solar manufacturer will investigate Azuray's maximum power point tracking (MPPT) DC-to-DC technology, which claims to yield as much as 25% greater solar energy harvest from panels affected by shading, mismatch, or other real-world conditions.

Along with Enphase, Suntech will explore the integration of microinverters into Suntech PV panels to simplify and accelerate solar system installation and maximize energy output.

Source: Tigo Energy

Tigo Energy Maximizer solution.

First smart modules to go into production

Green Energy Solar (GESolar) is sampling its first smart modules with customers, using National Semiconductor's SolarMagic power optimizer chipset within Huber+Suhner NS3 junction boxes. Pre-testing was claimed to show that the GESolar smart module could recoup an average of 50% of energy loss and could capture as much as 75% compared to standard panel performance.

TÜV Rheinland is currently performing the safety and emissions compliance testing to assure that the modules meet ANSI 1703 and IEC 61730 and IEC 61215 safety standards as well as FCC Part 15 (Class A&B) and EN 61000 emissions and immunity standards. GESolar started operations in 2007 with a module manufacturing capacity expected to reach 300MW by the end of 2010, up from 150MW.

Tigo and Schott Solar join forces to produce a more "intelligent" solar module

Tigo Energy and Schott Solar have come together to work on what they perceive to be a more intelligent solar module, which also has an increased power output. Schott has tested and established system compatibility, compromising of the frame mounting procedure, with Tigo's Energy Maximizer Solution and Schott's solar PV modules. Their partnership will also see Tigo encourage the Schott Solar Initiative

to embrace intelligent electronics in next-generation module design.

Upsolar, Enphase Energy partner to produce AC-enabled solar module product

Upsolar has formed a partnership with Enphase Energy for the incorporation of Upsolar's current and future-generation photovoltaic modules into Enphase junction boxes compatible with Enphase microinverters, resulting in the AC-enabled solar module product, ACE.

Source : Enphase Energy

Enphase microinverter.

Module Production News Focus

aleo solar increases production capacity to 390MW

aleo solar is to increase the combined annual production capacity of its three factories from 250MW to 390MW by the end of 2011. Around €20 million is being invested in the expansion, which will create a total of 100 new jobs.

Solarwatt doubles module capacity to 400MW

Dresden-based Solarwatt has officially opened its new production line. The development has doubled the capacity of the facility to 400MW and now allows Solarwatt to produce a solar module every 28 seconds. A new 13,000 square-metre logistics centre has also been built, which includes a 260kWp solar power plant, thus bringing total investment for the entire project to €35 million.

Source: Solarwatt

While visiting the new production plant Stanislav Tillich, Premier of Saxony gains insight into the new production line.

Photo: REC

Module production at REC Tuas, Singapore.

As is the norm for many Western-based manufacturers, the key to module manufacturing competitiveness is to have highly-automated plants. According to Solarwatt, the new line employs 29 industrial robots from Kuka Systems, which include its Robo Frame, Robo Trimm, and Robo Load solutions. However, despite the increasingly automated nature of the plant, the new production lines have still created 140 new jobs.

CTDC announces expansion plan of 150MW by 2011

China Technology Development Group (CTDC) has outlined the plans for its crystalline PV module production capacity expansion. The company aims to achieve 150MW production capacity by the end of 2011 and 300MW by the end of 2012. CTDC cites an increase in market demand and its desire to maximize value for their shareholders as reasons for their planned expansion. Additionally, the company stated that in order to further facilitate company growth, it will be actively seeking out mergers and acquisitions to complete an overall expansion.

REC set to close 150MW solar module plant in Sweden

Despite recent efforts to improve the cost-competitiveness of a fully-automated 150MW c-Si module assembly plant in Glava, Sweden, REC will wind-down and close its operations at REC ScanModule by the end of 2010. Åsmund Fodstad, senior vice president sales and marketing at REC Solar, told PV-Tech that the plant had been running at close to full capacity but due to its isolated position from other facilities within the group, it had struggled to be profitable. The Glava plant employed approximately 300 employees and REC expects to incur restructuring costs of approximately SEK104 million in the third quarter of 2010.

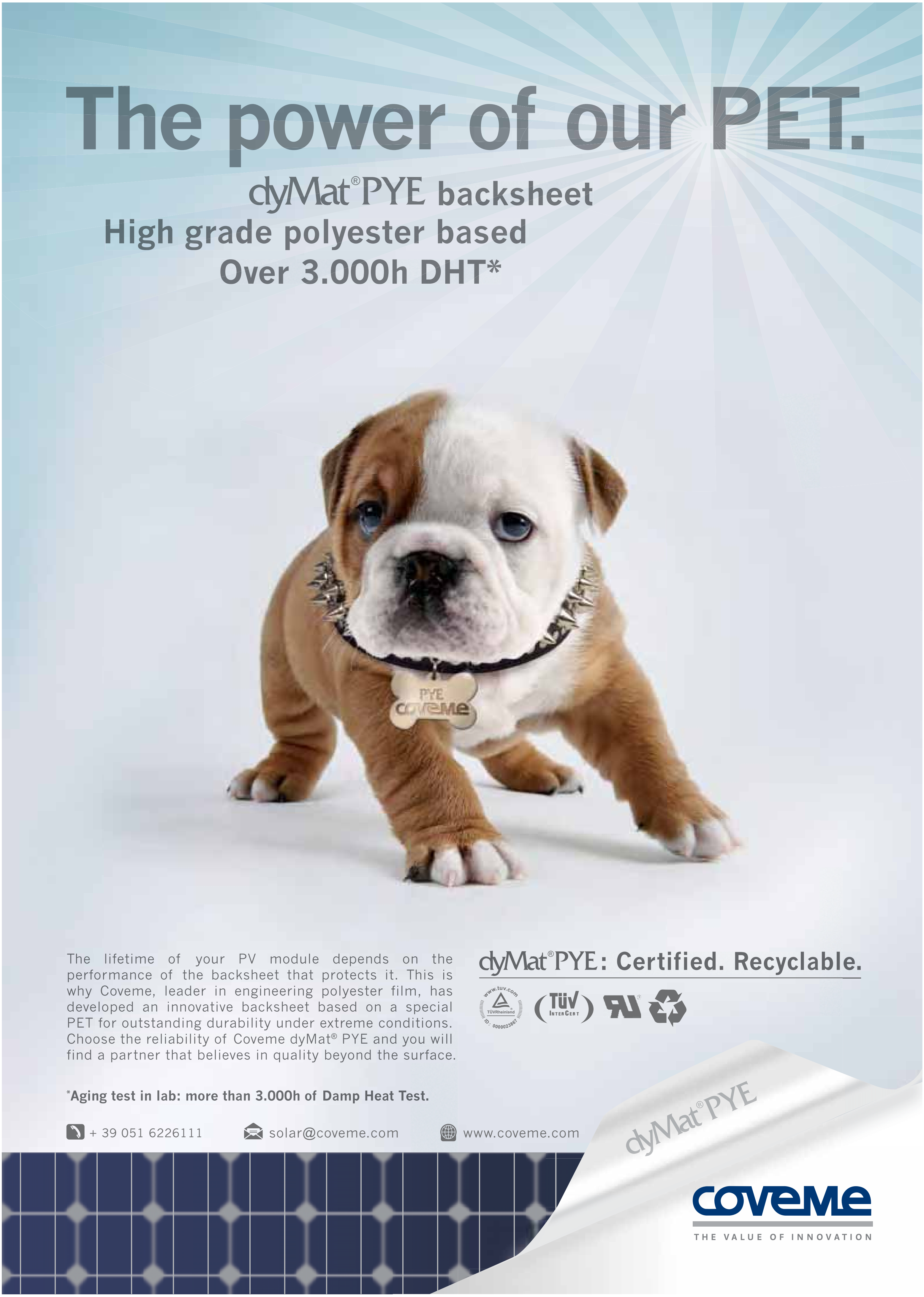
With the ramp of its new integrated module assembly plant in Singapore underway, REC noted that module supply would be unaffected by the closure of the plant in Sweden. The company will be using outsourced, contract manufacturing for some of its module production requirements as well. The operations of REC's 180MW solar cell plant in Narvik, Norway, will also be unaffected by the announced closure of REC ScanModule, according to the company.

Schott, Solland Solar ink tech licensing, R&D, production deal for back-contacted PV modules

Schott Solar and Solland Solar have signed a partnership agreement that includes technology licensing, R&D and production of Solland's proprietary metal wrap through-based, back-contact cell PV modules. The companies said that serial manufacturing of the 16%-efficient modules will begin by 2011, with a pilot line to be built at Solland's facility in the Netherlands. Financial terms of the deal and planned initial production volumes were not disclosed.

Source: Solland Solar

Solland Solar's Sunweb module.


The power of our PET.
dyMat® PYE backsheet
High grade polyester based
Over 3.000h DHT*
PYE
COVEME
The lifetime of your PV module depends on the performance of the backsheet that protects it. This is why Coveme, leader in engineering polyester film, has developed an innovative backsheet based on a special PET for outstanding durability under extreme conditions. Choose the reliability of Coveme dyMat® PYE and you will find a partner that believes in quality beyond the surface.
dyMat® PYE: Certified. Recyclable.
*Aging test in lab: more than 3.000h of Damp Heat Test.
+ 39 051 6226111
solar@coveme.com
www.coveme.com
dyMat® PYE
COVEME
THE VALUE OF INNOVATION

Fidelis delivers first shipment of solar modules to TinSol Energy

Fidelis Energy has manufactured and shipped more than 23MW of solar modules to its first customer, TinSol Energy, located in South Africa. The company began module production at its manufacturing facility in China earlier this year, accelerating the manufacturing process and reaching the anticipated shipping date ahead of schedule.

This shipment, which was due to be delivered in the first quarter of 2011, is the first of several expected to be sent out by TSEL in order to reach the companies long-term solar 207MW module supply agreement worth US$475 million. The modules and US$52.5m are expected to be received by December 15th, 2010.

Day4 Energy inks module supply deal with Italian distributor Enerpoint

Day4 Energy has signed a deal with Enerpoint to supply the Italian solar PV distributor with the Canadian company's 60MCI crystalline-silicon modules. Day4 joins Trina, Schott, Sharp, REC, Kaneka, and other PV manufacturers whose panels are offered in the Enerpoint portfolio.

Financial and other terms of the agreement were not disclosed.

ET Solar nabs 50MW module supply deal with PM Service

ET Solar has been providing PM Service with modules for the past three years, but a new module supply agreement marks the largest annual supply volume to be delivered between the two companies. The contract will see ET Solar deliver 50MW of mono- and multicrystalline PV modules to PM Service throughout 2011

CNPV enter into agreements with AE Photonics and Standby Europe

CNPV Solar Power and AE Photonics have entered into a long-term strategic partnership for the supply of 300MWp photovoltaic modules from 2011 to 2013. The agreement will see CNPV will supply AE Photonics with 60MWp during 2011 and then deliver 96MWp and 144MWp in 2012 and 2013, respectively. This is the largest contract in the history of both companies.

CNPV have also secured a long-term strategic partnership agreement with Standby Europe to supply 150MWp high performance photovoltaic modules from 2011 to 2013. Under the terms of this agreement, CNPV will supply Standby Europe with 40MWp of modules in 2011 and 50MWp and 60MWp in 2012 and 2013, respectively.

JA Solar supply agreements top 1.2GW in 2011

New supply agreements with multiple customers have pushed JA Solar's 2011 delivery commitments past 1.2GW. The cell and module manufacturer said it had secured an additional 600MW of new product orders, all with delivery dates in 2011, and had received prepayments associated with these customer orders.

Solon to supply France Photovoltaique with standard modules

Solon has finalised an agreement to supply France Photovoltaique with standard modules for distribution within the private sector in France. The company aims to grow within this area, which is currently expanding due to the attractive feed-in tariff rate currently set for the private sector.

JinkoSolar to deliver a further 100MW of modules to Enfinity Asia Pacific

JinkoSolar has signed a follow-up supply agreement with Enfinity Asia Pacific for the supply of 100MW of photovoltaic modules throughout 2011. The companies had already signed an agreement earlier in 2010 for the delivery of 24MW.

LDK signs 84MW PV module supply deal with Czech project developer H Power

LDK Solar has signed a module supply deal with Czech-based PV project developer H Power. The agreement calls for LDK Solar to provide 84MW of solar modules to H Power during 2011. Financial terms of the deal were not disclosed.

Yingli sees sales contracts hitting 1GW by year end; secures 7.9MW Cegelec deal

Yingli Green Energy held an investor day on November 3rd, 2010 with key executive team members discussing the outlook for the company over the next year. Zongwei Li, Yingli's director and CFO, began the day and highlighted that Yingli had obtained 575MW of purchases under legally binding sales contracts and anticipated the number to rise to 1,000MW by the end of this year. Most of the sales contracts have a required prepayment from the customers, although Li stated that Yingli is forecasting a somewhat flat trend in the average selling price during its fourth quarter, which will develop into a stable level in the first half of 2011, followed by a modest decline in the second half of next year.

Sunways partners with LDK Solar for module supply

In a quasi-OEM module agreement, LDK Solar will be supplying 30MW of c-Si modules using Sunways own solar cells in an effort to offer greater choice of competitive products to its distribution partners. Sunways said that the supply agreement was for one year but expected to extend the contract in the future. The first solar modules from the new partnership will be available in the market within a few weeks.

BlueChip Energy prepares for 75MW expansion of solar modules in 2011

BlueChip Energy revealed that installation and trial runs have been completed for its first production line of PV solar modules. This will allow the company to expand its annual module production capacity to 75MW for 2011. The panels will be manufactured under the ASP brand, which already has designated 20MW of production to orders received for delivery at the beginning of next year.

DuPont and Fujipream claim to build the thinnest crystalline silicon solar panel in the industry

DuPont Kabushiki Kaisha and Fujipream announced their newest development – a thin crystalline silicon glass-glass PV module. The companies assert, with the exception of the frame, that this new module is 25% lighter in weight than traditional c-Si modules using standard solar grade front glass.

The module is constructed using two sheets of DuPont's PV5300 series ionomer-based encapsulant, which surround and protect the module's silicon cells and circuitry that has been placed between two 1.1mm sheets of thin glass. The PV5300 technology is said to replace EVA-based encapsulants, lending to a stronger, but thinner module that is able to withstand load and hail tests.

Roth & Rau enters EVA backsheet production market with plant in Italy

In a move that will see them moving into a new business area, Roth & Rau are to begin production of EVA (ethyl-vinyl-acetate) backsheet material for customers at a new plant in Monza, Italy. The German firm already possess a high market share for EVA foil in the Italian market, but believe the €2.5-million plant investment will enable a faster response to customer requirements and help boost Southern European sales. The new EVA production plant is one of the most modern in Europe and has an annual production capacity of five million square metres.

Testing and Certification News Focus

Beyond IEC 61215: TÜV Rheinland develops new accelerated, long-term PV module testing method

TÜV Rheinland has developed a new accelerated environmental testing methodology to simulate long-term operational conditions that solar photovoltaic modules could experience throughout their lifetime. This will enable TÜV to approximate more accurately real outdoor module behaviour and power output degradation characteristics in a laboratory environment.


TÜV Rheinland's headquarters in Cologne.

The company's long-term sequential testing exceeds the requirements of the IEC 61215 standard with an approximately nine-month-long test sequence that evaluates the degradation of solar modules affected by multiple external variables. The sequence consists of four major subcomponent tests: damp heat, thermal cycling, humidity freezing, and bypass diode.

An even more challenging protocol, known as 'PLUS', includes optional plug-in tests for hotspots, hail, and mechanical load tests. Due to the harshness of the sequence, only a limited number of products will be able to pass these tests, as a single test module is put through this sequence, and the degradation in power generated is measured after each stage.

The first customer for the new service, Kyocera, said it has already completed major milestones in the tests. The PV manufacturer said that its standard 210W module has passed two of the four major subcomponent tests (damp heat, thermal cycling) of the new TÜV protocols, and expects to complete the other two (humidity freeze, bypass diode) by December 2010.

Ametek completes purchase of Atlas Material Testing Technology

Ametek has successfully acquired Atlas Material Testing Technology from Industrial Growth Partners for US$159 million. Atlas, a weather test instruments and consulting company, has an estimated US$85 million in sales for 2011 with its headquarters in Chicago and manufacturing facilities in Germany. Atlas will function as part of Ametek's Measurement & Calibration Technologies division – a subdivision of Ametek's Electronic Instruments Group.

PVEL closes funding for development of PV performance, reliability testing lab in San Francisco

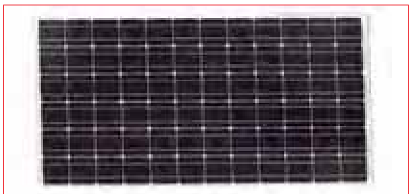
PV Evolution Labs (PVEL) has come one step closer towards completing a testing laboratory in San Francisco by closing funding for the solar panel reliability and performance laboratory. PVEL claims the laboratory is an independent, high-throughput testing facility using the company's environmental, mechanical and electrical stress and characterization systems.

CNPV receives UL certification; awaits CEC listing

CNPV Solar Power's crystalline silicon solar PV modules have successfully achieved UL and C-UL certifications, which are required for the modules' use in the U.S. and Canadian markets. CNPV now anticipates listing with the California Energy Commission (CEC) to follow its UL certification and is looking into opening a sales office in California and Canada to meet anticipated demands from the North American sector.

Schott Solar's in-house test lab granted VDE certification

Schott Solar's in-house test lab for new products, processes and materials under IEC 61215, IEC 61646 and IEC 61730, has completed the requirements necessary and received certification by the VDE Association for Electrical, Electronic and Information Technologies. Schott's laboratory meets all required IEC standards and will now have all test reports prepared by the Alzenau test centre forwarded to VDE. VDE will then confirm and issue approval for the use of the VDE mark.



Source: CNPV Solar Power

CNPV's standard mono crystalline solar module.

JinkoSolar secures CEC approval for trio of PV modules

Chinese PV manufacturer JinkoSolar said that three of its modules have met the requirements of the California Energy Commission (CEC). As a result, one of the company's 175–185W models and two of its 220–240W models will also be added to the list of Senate Bill 1 guidelines-compliant photovoltaic modules eligible for finance and project incentives in the state of California, Hawaii, and some other U.S. states.

Evergreen Solar gets UK certification for modules

Evergreen Solar was awarded Microgeneration Certification Scheme (MCS) accreditation from the United Kingdom's British Board of Agreement, demonstrating that the company's ES-A series panels meet the requirements for solar projects under the feed-in tariff scheme, which started in the UK this April. Solar projects must use MSC certified panels that are installed by MCS accredited installers in order to qualify for the funding.

Business News Focus

CDB to provide LDK Solar with US$8.9 billion for company growth initiatives, corporate development plans

LDK Solar has entered into a strategic financing agreement with China Development Bank (CDB) for the provision of up to RMB60 billion (approximately US$8.9 billion) of credit facilities for LDK over a five-year period. Terms of the individual credit facilities and lending agreements will be subject to CDB's internal risk management requirements and operational regulations.

China Sunergy finalizes purchase of CEEG module manufacturers

China Sunergy recently concluded its 100% acquirement of equity interest in CEEG (Shanghai) Solar Science & Technology and CEEG (Nan Jing) New Energy. Both companies were associated with China Sunergy before the purchase and have added to the company's total annual module capacity, now standing at 480MW.

China Sunergy notes that CEEG held a strong sales presence in the U.S., Germany, Spain, Italy, the Czech Republic, and Southeast Asia and referred to its balance sheet, which they consider to be strong enough to allow them to be more than capable of funding the acquisition, which now has a total consideration of around US$46 million.

CBD Energy signs MOU with Tianwei Group for PV module manufacturing in Australia

CBD Energy, along with its wholly-owned subsidiary ecoKinetics, has signed a memorandum of understanding (MOU) with the Tianwei Group for a solar equipment manufacturing business in Australia. According to the terms of the MOU, Tianwei will own 5% of the joint venture company, increasing its ownership stake to 51% once the Chinese and Australian governments approve the deal, exchanging its brand and technology to be used in the JV company.

The JV company will produce solar PV modules with integrated operating systems, for which Tianwei will provide exclusive manufacturing rights for the equipment in Australia to the company. The initial annual production capacity is set to 50MW of modules with anticipated revenue of US$100 million.

The MOU additionally states that solar products from the manufacturing operation will be primarily sold to ecoKinetics projects in Australia and international locations or to internationally located joint projects with Tianwei. Further, any technology improvements will remain in the JV venture. The MOU also outlines that manufacturing rights in Australia will be solely for the JV and that Tianwei's PV laminates will be used in manufacturing and purchased at agreed prices. Finally, CBD will disclose its knowledge with Tianwei for assistance in engineering and construction for international projects that Tianwei pursues.

Government approval and a formal agreement are expected to be obtained and completed by the end of March 2011.

Wagner & Co forms joint venture with UK equipment supplier

Wagner & Co has teamed up with UK photovoltaic equipment supplier AC Solartechnic to form the joint venture Wagner Solar UK. The new company will start business in November 2010, working from AC Solartechnic's current site located in West Sussex, UK.

AC Solartechnic founders Carsten Pump and Mark Osborne will lead the work at the new facility as Managing and Finance Directors of the company. Alexander Storek, sales manager from Wagner, Germany will also join the board. The new joint venture already has a market share of approximately 12% of all photovoltaic systems installed in the UK in 2010, with significant potential for further growth.

Product Briefings

P.Energy

P.Energy's FC200V film-cutting machine provides precise and automated operation

Product Briefing Outline: P.Energy has introduced the FC200V film-cutting machine for EVA and backsheet materials used in the lamination process. The FC200V can work with standard rolls of a maximum weight of 60kg but it can also work with rolls up to 200kg by installing an external loading system. Being fully automatic, the system can be easily set up by the operator and is suitable for both industrial mass production as well as small manual assembly lines .

Problem: Maximizing the use of a full roll of expensive backsheet material with exact and safe cutting can lower production costs and material wastage.

Solution: P.Energy's FC200V can be used to cut at the right length of EVA and backsheet films for photovoltaic applications. The foil material is cut by cross-cutting spring-loaded blades to a get a precise 'scissors effect'; the bottom blade is fixed while the top blade is hinged and pushed towards the bottom one. With the die-cutting unit connected to a pneumatic cylinder, it is possible to cut a shape on the EVA/backsheet foils so that the ribbon wires can pass outside the photovoltaic sandwich. The minimum cutting length is 20mm. As an option, the intralayer of EVA can be re-winded on a rewinding shaft. The sheets stack on the pivoting bar that is synchronized with the machine-cycle. The maximum load of this pivoting bar is 20kg.

Applications: EVA and backsheet film cutting.

Platform: P.Energy FC200V is an automatic film cutting machine that permits easy set-up and handling. The machine unrolls the films automatically up to the set length. An optional external loading system can be used for rolls up to 200kg.

Availability: Currently available.

Dow Chemical

Dow Chemical's Enlight encapsulant films reduce cycle times by up to 30%

Product Briefing Outline: The Dow Chemical Company has launched its 'Enlight' Polyolefin Encapsulant Films, which are claimed to enhance efficiencies in PV module production and lead to lower conversion costs. The films also can provide greater module stability and improved electrical performance versus traditional encapsulants, and are suitable for c-Si and thin-film modules.

Problem: Modules made with Enlight films can retain efficiency levels after more than 10,000 hours of damp heat exposure, whereas Dow testing shows that modules made with EVA typically show a sharp drop-off in efficiency levels after more than 2,000 hours in damp heat.

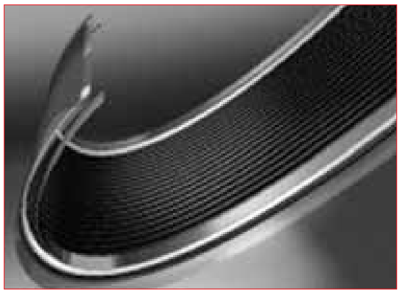
Solution: The films' chemical composition gives these materials a very stable backbone, allowing an efficient process. The physical property profile of these films includes their good tensile strength and melt index, which can help reduce conversion costs. The films contain no liquids or additives that can cause hydrolysis and damage the lamination equipment, therefore bubble formation is virtually eliminated, minimizing the potential for rejects, and there is no acetic acid formed that could cause damage to equipment and modules. The encapsulant films have built-in temperature resistance, even at short lamination cycles.

Applications: Suitable for rigid modules that use crystalline silicon or thin-film technologies, as well as many flexible module configurations.

Platform: Enlight films are based on Dow's proprietary polyolefin resin and film technologies, and claim a significantly lower Water Vapour Transmission Rate (WVTR) – 10–20× lower than that of EVA encapsulant films in some cases.

Availability: Fourth quarter 2010.

Henkel



Henkel's electrically conductive adhesive enables fast curing at low temperature

Product Briefing Outline: Delivering an alternative to high-temperature solder processes, Henkel has developed Hysol EccoBond CA3556HF, a silver-filled electrically conductive adhesive designed to offer fast cure at low temperature. The material is also designed for high-throughput production processes and applications that dictate high peel strength, such as the assembly of PV modules.

Problem: While solder is arguably the most common electrical interconnect material, its high temperature requirements make it impractical for certain applications. Fragile, thin, temperature-sensitive substrates are often subject to damage not only from the requisite soldering temperatures, but also from screen and stencil printing processes themselves.

Solution: Initially designed to address the unique requirements of the photovoltaic module assembly market, the new Hysol adhesive is also applicable to other processes such as c-Si and thin-film manufacturing. For c-Si cell production, the adhesive delivers an improved bond between the Ag and SnPbAg-coated tabs and the c-Si cells. Thin-film module manufacturers seeking a low-stress, fast cure electrical interconnection of cells with ribbons have also incorporated the material into their processes.

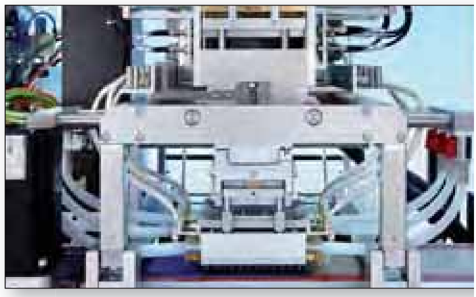
Applications: PV module assembly of c-Si and thin-film modules.

Platform: EccoBond CA3556HF includes high peel and shear strength, stress minimization properties to compensate for CTE mismatches, fast cure for high throughput and a no-mix, one-part formula which reduces operator error and speeds processing time.

Availability: Currently available.

SOMONT
CELL CONNECTING

CERTUS
Reliable stringing performance for 50-100 MW / year



The stringer CERTUS can be configured with a series of options as well as integrated in existing module production lines.

High Output	▪ From 2 800 – 4 900 cells/h
Successful Somont Soft Touch Soldering	▪ Very low breakage rates, high peeling forces and reproducible high quality soldering results
New user-friendly vision and HMI	▪ Intuitive operation combined in one user surface, improved precise detection of cell defects, easy to learn for the operator
Modular concept and compact design	▪ Fast installation and ramp-up times

A member of Meyer Burger Group

Somont GmbH / Im Brunnenfeld 8 / 79224 Umkirch / Germany
Phone +49 7665 9809 7000 / www.somont.com

Madico

Madico's Protekt backsheet material offers performance and endurance

Product Briefing Outline: Madico's 'Protekt' backsheet material is claimed to offer maximum power and bond strength, superior electrical insulation, resistance to hydrolysis, flame resistance and good thermal stability characteristics. The UL-tested material is formed using a high-performance film cast in a special process. When applied to the base dielectric bonding layers of PET/EVA, this results in a laminate with excellent stability characteristics for vacuum laminating performance.

Problem: The rapid growth of the PV industry has led to the development and introduction of numerous new materials for PV applications. Increased demand for PV backsheets has reached an all-time high, along with the pressure to offer more cost-effective solutions safely and reliably.

Solution: Madico's Protekt backsheets have a fluoropolymer base with performance-enhancing additives that have undergone extensive internal and third-party testing to validate and certify performance to exceed industry standards. This ensures that the backsheets perform at the highest level, providing safety for the life of the panel. Protekt has undergone testing to meet UL certification in the area of flame resistance and electrical insulation and has high dielectric strength. It has also undergone extensive damp heat testing, exceeding the 1000-hour industry standard set by UL and TÜV.

Applications: Protekt backsheets can be used for protecting c-Si and thin-film solar modules.

Platform: Protekt can be ordered in customized rolls or sheets. Certification has been received for ASTM E 162 & D257 by a third party; the backsheets are TÜV Certified for IEC 60664 and in compliance with IEC 612515 and IEC 61730.

Availability: Currently available.

Molex

SolarSpec junction box from Molex is specially designed for pick-and-place panel assembly

Product Briefing Outline: Molex has released the 'SolarSpec' junction box and cable assemblies designed for installation on the back of mono- and polycrystalline PV solar modules. These products provide the interface between the conductor ribbons on the panel and the DC I/O cables.

Problem: Tremendous growth within the solar market is fuelling competition in the manufacture of PV solar panels. The automated fabrication of PV modules improves efficiencies, product integrity and reduces production overhead. By utilizing automated production lines, assembly time of a junction box to a PV panel can be reduced.

Solution: The SolarSpec junction box from Molex is specially designed for pick-and-place panel assembly. It features spring terminals connecting the base directly to the PV ribbon conductors, without the need for retention clamps or clips. The optional patented 'Solder Charge' technology facilitates high-speed assembly and eliminates the need for hand-soldering of the ribbon, significantly reducing any process variation. Optional double-sided tape removes the need for curing time for silicone when attaching the connector base to a module.

Applications: Crystalline PV module junction box assembly.

Platform: The compact dimensional profile can supply current ratings comparable to traditional larger products. The SolarSpec Junction Box assembly is supplied with two removable DC cables available in dual-qualified (TÜV and UL) or single-qualified (TÜV) options. The junction box contains bypass diodes to protect the PV panel from reverse current during hours of darkness, shade or when covered by leaves or other debris.

Availability: Currently available.

Saint-Gobain

Saint-Gobain's foam module frame sealant reduces assembly time

Product Briefing Outline: Saint-Gobain Solar's new 'SolarBond' frame sealant brings new levels of efficiency and cost savings to photovoltaic module production. A pumpable sealant, the new SolarBond technology offers a unique, automated dispensing solution for framing modules. This automated process helps enhance operational safety while also achieving increased capacity and cost savings.

Problem: With traditional methods used to seal photovoltaic modules, excess silicone overflows onto the module's surface after the insertion of the photovoltaic laminate into the frame. Process time is longer due to the need for silicone to cure.

Solution: The SolarBond sealant consists of a foamable, reactive thermoplastic compound, presenting several benefits for manufacturers over the traditional silicone methods used to seal photovoltaic modules. The foaming SolarBond sealant allows an optimum cavity fill to be achieved without any overflow, reducing cleaning time and material waste. Applied warm, the foam is extruded directly into the frame channel using an automated robot or fixed nozzle under moving frames. High bonding strength is achieved immediately after contact with the glass, backsheet and frame, eliminating the setting time needed for silicone products to cure, increasing productivity and shortening production cycles. Module assembly should be completed within two minutes of the sealant being applied.

Applications: C-Si module framing.

Platform: SolarBond frame sealant consists of a non-toxic, environmentally friendly foamable, thermoplastic compound, which does not require venting. Available in grey and black in 20 litre pails to 200 litre drums.

Availability: Currently available.

Saint-Gobain

Saint-Gobain's LightSwitch material is designed for flexible and lightweight solar modules

Product Briefing Outline: Saint-Gobain Solar has launched a new 'LightSwitch' portfolio of solutions, including LightSwitch Frontsheet, LightSwitch Encapsulant, and LightSwitch Frontsheet Complete, as well as a design program for photovoltaic module manufacturers. LightSwitch film products claim to provide manufacturers with enhanced performance, durability, and a reduction in total systems cost.

Problem: PV module manufacturers are always seeking new materials that retain performance criteria for long lifetimes, while also being suited to different applications.

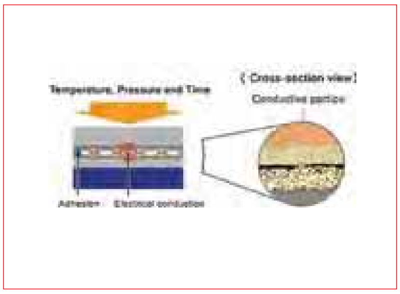
Solution: LightSwitch Frontsheet is a melt processable fluoropolymer providing superior weatherability and UV resistance, ideal for flexible and lightweight solar modules. These highly transparent films offer improved resistance to chemicals and weathering, low flammability, stress crack resistance, and insulating properties. It is also surface-treated to ensure superb adhesion to LightSwitch Encapsulant, which in turn provides cushioning and structural support to solar cells and circuitry. LightSwitch Frontsheet Complete is a pre-laminate that incorporates the LightSwitch Frontsheet ETFE and LightSwitch Encapsulant EVA in one package.

Applications: LightSwitch Encapsulant provides cushioning and structural support to solar cells, and is suitable for both flexible and rigid modules, with excellent adhesion to other PV module components.

Platform: The portfolio also includes the LightSwitch Module Design Program and engineering design services for PV module manufacturers.

Availability: Currently available.

Sony



Sony offers low-temperature conductive bonding material for c-Si solar cells

Product Briefing Outline: Sony Chemical & Information Device Corporation has commercialized and commenced full-scale mass production of the SP100 Series, Solar Cell Conductive Film for photovoltaic modules. The material has passed high-temperature/high-humidity testing (85°C/85%RH, 1000 hours) and temperature cycle testing (-40°C–85°C, 200 cycles) regulated by IEC61215. The product has been verified to provide the long-term conduction reliability required by photovoltaic modules.

Problem: Solar cell strings, which compose photovoltaic modules, are generally bonded by soldering which requires heating to a temperature of 200°C or higher. Differences in the thermal and mechanical characteristics of the silicon used in cells and metal ribbon can cause residual stress around the bonding area, leading to problems such as cell breakage after bonding.

Solution: The SP100 Series is a film-type conductive bonding material that bonds the solar cell with the metal ribbon that acts as a transmission line for electricity generated by the cell. Compared with conventional soldering (200°C or more), it is capable of low-temperature bonding at 180°C, enabling significant reductions in residual stress after bonding on cells. In addition, the SP100 Series is also capable of bonding thin cells (approximately 150μm) that are weaker against thermal stress during soldering than standard thick cells.

Applications: Bonding and tabbing of c-Si solar cells; capable of bonding thin cells (approximately 150μm).

Platform: The SP100 Series is a bonding material that uses Anisotropic Conductive Film (ACF) technology utilized for applications such as the mounting of a driver IC on an LCD panel.

Availability: Fourth quarter 2010.

STMicroelectronics

STMicroelectronics provides direct upgrade for bypass diode integrating control and power electronics

Product Briefing Outline: STMicroelectronics has introduced the SPV1001, which replaces the simple bypass diode with an intelligent device that enhances efficiency and offers the same package outline. The new device is said to be capable of contributing to a fast return on investment in terms of releasing additional energy for solar panel applications.

Problem: High-efficiency solar cells that produce increased output current demand improvements in the supporting power electronics. Compared to the use of diodes, the integrated power switch provides negligible leakage current when the PV module is producing energy.

Solution: STM's new SPV1001 contains a low-loss power switch and a precision controller. Directly replacing bypass diodes, which are used to prevent hotspot effects, the SPV1001 protects the energy normally lost in each diode. It has low conduction losses when operating in bypass mode, a low leakage current which minimizes losses in bypass standby mode, low operating temperature, which can help optimize junction box design, and also features high robustness to surge and lightning currents.

Applications: Integration of power and control functions for high-efficiency solar modules.

Platform: In addition to package options enabling one-for-one replacement of bypass diodes in the solar panel's junction box, the SPV1001 is available in an MLPD package that can be laminated directly into the panel.

Availability: The SPV1001 is in production now in the industry-standard TO-220 and ultra low-profile MLPD packages.

Snapshot of spot market for PV modules – quarterly report Q3 2010

pvXchange, Berlin, Germany

ABSTRACT

Solar enterprises will each be faced with the occasional surplus or lack of solar modules in their lifetimes. In these instances, it is useful to adjust these stock levels at short notice, thus creating a spot market. Spot markets serve the short-term trade of different products, where the seller is able to permanently or temporarily offset surplus, while buyers are able to access attractive offers on surplus stocks and supplement existing supply arrangements as a last resort.

Those eagerly anticipating rising or falling prices will be disappointed on reviewing the figures for the third quarter in comparison with the two previous quarters. In Q2 we saw the descending prices of Japanese modules on the spot market. For the same period, Chinese module prices shot up, while the European module prices stood still. At the end of Q2, we were told by many producers that new sales records were reached. But what effect did the actions of July 1st have, the date when Europe's biggest market, Germany, cut percentages in the FiT? The price for PV modules has effectively frozen, with only European manufacturers seeing small weekly decreases in their module revenues.

"Most players in the business expected demand for solar panels in Europe's biggest market to go down in July."

International demand is still high, as can been seen by the amount of deals traded on pvXchange in Q3. Another 50MW will go from one hand to another hand in these three months. The reason behind this jump is that most players in the business expected demand for solar panels in Europe's biggest market to go down in July. Many companies set their focus on multinational project portfolios for the second half. In addition to Italy, France and the Czech Republic are proving to be the most attractive photovoltaic markets in Europe. In July, therefore, a significantly larger portion of the items traded on the spot market was sold in Italy and later in the Czech Republic.

August saw the introduction of new European brands in Germany, which has led to a drop in the average price of European solar modules. Crystalline modules from Europe that had been available for €2.03/Wp in January were now costing an average of about €1.85/Wp. Chinese prices reached €1.63/Wp in the last weeks of September. The prices earned by European manufacturers are approaching those of the top producers in China. These manufacturers are responsible for the relatively high average module prices, as strong demand persists for branded modules from China.

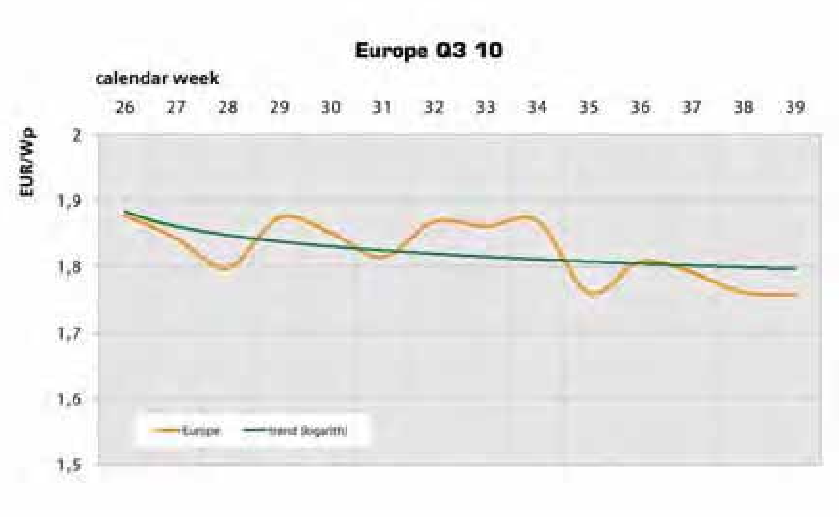


Figure 1. Development of module prices for modules produced by European manufacturers from July to beginning of October 2010.

After losing nearly €0.10/Wp in Q2, Japanese products showed a significant improvement in performance at the end of the summer owing to a slight increase in prices implemented by the Japanese manufacturers. The rise in the Yen and the steady growth of the domestic PV market

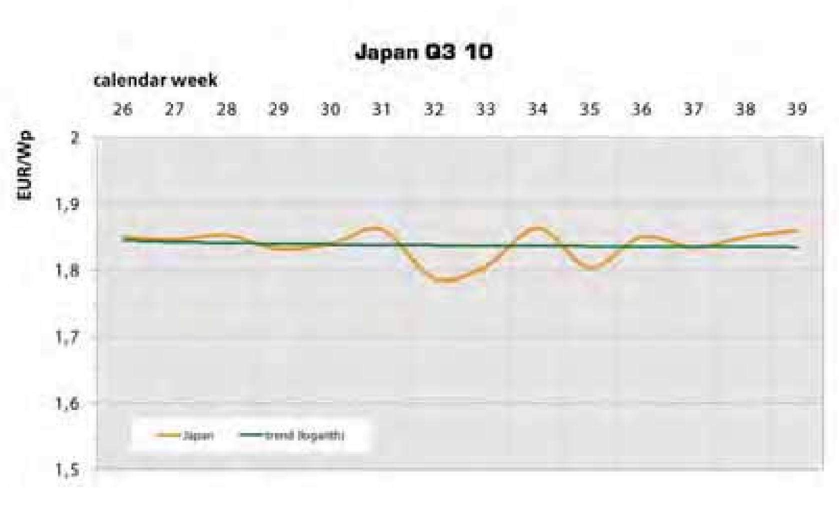


Figure 2. Development of module prices for modules produced by Japanese manufacturers from July to beginning of October 2010.

since the third quarter of 2009 have led to increasing interest and purchases of Japanese-made modules from Chinese and Taiwanese solar cells.

"With the massive demand for wafers for global cell production, the scope for price reductions this year is very limited."

PV Modules

However, there is another reason why module prices are not decreasing at the moment. Wafer and polycrystalline silicon suppliers announced new price increases in September – a result of the huge demand on the commodity market – from US$3.80 to US$4. Furthermore, with the massive demand for wafers for global cell production, the scope for price reductions this year is very limited.

"Crystalline modules still account for at least 80% of global cell production."

Nevertheless, the latest market forecast is more optimistic than ever before. Analysts expect growth of 100% in 2010 (between 14-16GW, depending on the source), and predict that 80% of these new plants will be situated in Europe. China, which could very well take over in the next few years, has been predicted by MS Research to be the global PV market leader by 2014. Installation of plants with a total capacity of 300MW was planned in 2010. Market research firm iSuppli's recent estimate showed that some 580MW of solar power capacity will be built by the end of this year in China. In addition, two incentive programs will ensure that in the next three years, plants with a total of 3GW will be connected to the grid, while further solar incentives are also said to be on the way.

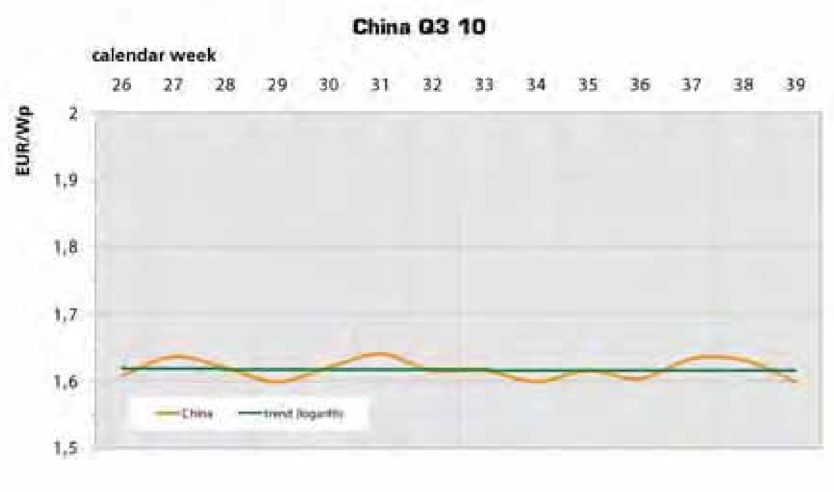


Figure 3. Development of module prices for modules produced by Chinese manufacturers from July to beginning of October 2010.

These price changes are particularly interesting from an analyst's perspective studying the shares of traded technologies produced for the market. Crystalline modules still account for at least 80% of global cell production, followed by First Solar's CdTe modules which, even taking into account the loss of some revenue compared to 2009, are still strong on the spot market. Microcrystalline and amorphous silicon followed at a considerable distance. For these thin-film technologies, the price difference now rests at an impressive €0.40/Wp with similar output efficiencies. Still significantly behind, but exhibiting great potential, are CIS thin-film modules. Those large companies employing this technology type are investing great effort in development, and look set to offer very competitive prices. Despite the further development and growth of the industry, crystalline PV technologies will dominate the market. The thin-film portion will account for approximately 15%, notwithstanding a significant increase in efficiency being achieved at a reasonable cost.

About the Authors

Founded in Berlin in 2004, **pvXchange GmbH** has established itself as the global market leader in the procurement of photovoltaic products for business customers. In 2010, the company will broker solar modules with an output of around 180MW and inverters of around 100MW (AC). With its international network and complementary services, pvXchange is constantly developing its position in the renewable energy market, a market which continues to grow on a global scale. Based in Europe, pvXchange also has a presence in Asia and the USA.

Enquiries

pvXchange GmbH
Obentrautstr. 57
D-10963
Berlin
Germany
Tel: +49 (0) 30 236 31 36 0
Fax: +49 (0) 30 236 31 36 23
Email: info@pvxchange.de
Web: www.pvxchange.com

Fluorescence imaging: a powerful tool for the investigation of polymer degradation in PV modules

Jan Schlothauer, **Sebastian Jungwirth** & **Beate Röder**, Humboldt-Universität zu Berlin, Berlin, Germany, & **Michael Köhl**, Fraunhofer Institute for Solar Energy Systems (ISE), Freiburg, Germany

ABSTRACT
This paper presents fluorescence detection as a new tool for the investigation of the degradation of EVA. The superior sensitivity of the setup contained herein allows an early assessment of the changes of the EVA after only 20 hours of damp-heat exposure. A newly developed scanning system allows the spatially resolved inspection of entire PV modules. Degradation of the encapsulants was detected after two years' outdoor exposure, as was the effect of cracks in c-Si cells, which coincide well with cracks made visible by electroluminescence.

Introduction

Photovoltaic modules are designed to have a service lifetime of more than 20 years. Manufacturers normally specify the limit of the module's performance at the end of its life as 80% of the initial value [1]. While the majority of crystalline silicon-based modules produced during the last decades seem to meet these requirements, further cost reductions of PV are needed to successfully compete with traditional electrical power generation. Novel, less expensive materials and more cost-effective manufacturing must be introduced, but not to the detriment of the performance and durability of the final products. The performance-to-cost ratio and the integrity of the performance over the lifetime, namely, the total energy yield and the measure of durability, must be improved.

Service life testing of products that have a lifetime of a matter of decades is a challenge in itself. Accelerated life testing in the lab is required to simulate the passage of time, but the test procedures have to be validated via a comparison with real outdoor exposure testing. As material changes are closely linked to the performance of the module itself, sensitive methods for the detection of degradation-induced material changes – so-called degradation indicators – are urgently needed for an early recognition of ageing phenomena and the comparison of accelerated indoor with real-time outdoor testing. Electroluminescence has played this part, allowing for non-destructive observation of changes in the semiconductors and the other electrical

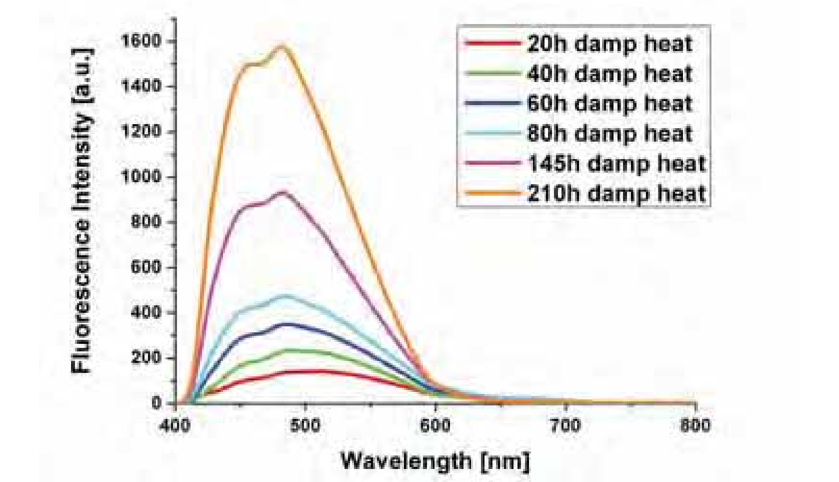


Figure 1. Fluorescence spectra of a damp heat-aged mini module at early ageing states.

PV Modules

parts of the module. However, degradation of the polymeric components of the modules remains a point of interest.

Polymeric materials are used for the encapsulation of solar cells in order to provide protection against the environment and to buffer mechanical tensions caused by the daily temperature variations and the differences in the thermal expansion coefficients of the module components, mainly silicon and glass. The most common encapsulant is EVA (ethylene vinyl acetate), which can be found in various brands and grades (normal cure, fast cure, ultra-fast cure, etc.) on the market and in modules. The main differences between these brands and grades are their basic compositions (degree of vinyl acetate in ethylene), the per-oxide used for cross-linking during the lamination process, the additives used for stabilization against photo-degradation caused by UV-radiation and oxidation, and additives for processing. The degree of cross-linking of the EVA, usually measured as the gel-content after lamination, also depends on the lamination parameters like temperature and time. The back-sheet that is glued to the encapsulant usually consists of a stack of laminated foils, and plays the role of providing protection against the environment and controlling the water permeation into the encapsulant.

The most common methods for EVA degradation analysis are destructive methods like thermo-gravimetry, thermal analysis or transmission and reflection measurements [2]. These methods neither give information about the exact degradation process, nor are they suitable for an inline investigation of PV modules showing degradation before being visible or electrically measurable. Browning of the material is a degradation effect that is visible to the eye, but only after long-term operation close to the end of the service life. Results of long-term reliability and performance testing of PV modules have been published elsewhere [3]. Even though the various degradation mechanisms of EVA have been investigated for the last three decades, the ageing process under the influence of heat, humidity and UV radiation is not yet fully understood [4–7].

Previous studies conducted by Fraunhofer ISE investigated mini modules comprising one single cell. These mini modules were tested with different combinations of glazing, encapsulants and back-sheets which were exposed to various combinations of degradation factors including temperature, humidity and UV radiation, indicating the feasibility of fluorescence detection [8–10]. We also inspected seven commercially available PV modules with crystalline silicon solar cells and the traditional composition with EVA as encapsulant and a Tedlar/PET/Tedlar back-sheet produced by different manufacturers with different material suppliers [3]. The modules had been exposed to two years' outdoor weathering at four different locations representing different climatic conditions: 1) Urban climate: Cologne, Germany; 2) Mountain: Zugspitze (2,650m), Germany; 3) Desert: Israel; 4) Tropic: Indonesia.

Fluorescence as an indicator for polymer degradation

Fluorescence is a physical effect that may occur after a substance has absorbed light. In the case of so-called 'fresh' EVA, the probability of light emission after absorption is very low – this material can be considered to be non-fluorescent. Chemical changes occur as EVA ages, leading to the emission of a characteristic spectrum on excitement of the material by a suitable light source. The main thermal and photochemical degradation processes of EVA lead to the formation of conjugated polyenes and α-, β-unsaturated carbonyl groups, which may show strong fluorescence.

Laboratory investigations were conducted on mini modules as a modelling system for PV modules. A typical 90° geometry for measuring the fluorescence was chosen, while UV light of 375nm was used for excitation. The setup allowed the measurement of the fluorescence on single spots. The sample holder was suitable for positioning of 10 × 10cm^2 mini modules, which were aged under damp-heat conditions (85°C/85% r.h.). The exposure was interrupted for measurements from time to time. Six spots per module were measured and averaged.

The spectra of the mini module shown in Fig. 1 display the general behaviours of the measured fluorescence. The fluorescence intensity grows monotonically with increasing ageing time. It is clear from the image that signals are visible after times of only about 20 hours of accelerated ageing. The high sensitivity of the setup would even allow earlier fluorescence detection. A continuous growth of the signal was observed during test periods up to 2,000 hours (see Fig. 2), a common duration for service life tests. Fluorescence was detectable on any polymer encapsulant of the modules investigated so far. The results show the applicability of fluorescence detection as a method of assessment of the degradation of the polymer in a PV module [7,8].

Scanning fluorescence spectroscopic imaging system

A scanning device was constructed to allow fluorescence spectroscopic imaging of complete PV modules. For commercially available module types, a total scanning area of about 2m × 1m is necessary. The height of the module varies within the range of a few centimetres, requiring a complete three-dimensional positioning system. A scanning concept was chosen to minimize negative effects of motion on the optics, consisting of a scanning head that is moved across the module parallel to the shorter side. The module is then moved line-by-line on a trolley parallel to its long side. The head contains a UV laser for excitation and the collection optics. Any detected light is guided via fibre optics to a stationary spectrometer. The positioning accuracy is substantially below the measurement spot size of about 1mm and the depth of focus.

The height of the scanning head can be adjusted for focusing with respect to the height of the construction frame and the module glazing. The tolerance is very comfortable, since the extension of the focus is bigger than the EVA thickness. The focus is adjusted in z-axis for maximum intensity over the whole module before starting the measurement. The laser excitation energy is adjusted for maximum dynamic resolution. Scanning is performed by moving the scanning head at constant speed. During scanning, the spectra are repeatedly collected with a constant integration time. The spatial coordinates are computed by taking into account the velocity of the


Isn't it a great feeling to
have everything under control?...
Higher up-time in a smaller process window, using **efficient metrology** for all critical PV process steps:
√ inline micro-crack
√ inline wafer thickness
√ inline wafer reflectivity
√ inline dopant weight
√ inline SiNx thickness and R.I.
√ inline cell EL & sorting
√ inline string & module EL
...now you can!
Interested in COO, ROI and references? Visit www.nowyoucan.biz for more information or meet us at 5th SNEC in Shanghai, booth E4-802 for a live demo!
www.op-tection.com
p-tection


ECOPROGETTI
SPECIALIST IN PRODUCTION PROCESS
WWW.ECOPROGETTI.IT
ECOLAM 08 S
ET20MW3B
ECOPROGETTI
Ecoprogetti produces since 1998 single equipments and complete turnkey lines of various levels of automation and capacities for the production of photovoltaic modules.
• Complete production lines on a ready to use basis with capacities from 10 to 100 MW.
• Modular machines and design for a quick and cost competitive production ramp up.
• In house design and production of all equipments from stringer machine to sun simulator and electroluminescence inspection.
AN ISO 9001
CERTIFIED COMPANY
Via dell'Industria e dell'Artigianato, 27/C - 35010 Carmignano di Brenta (PD) - ITALY - Phone +39 049 5991959 - Fax +39 049 9459210

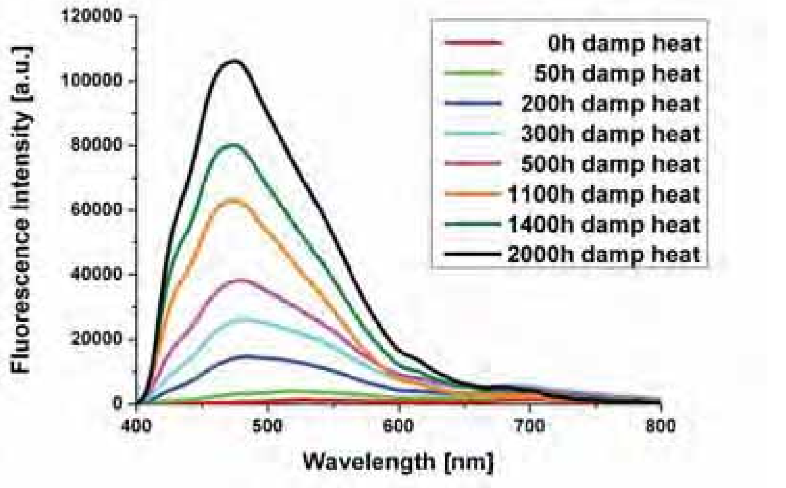


Figure 2. Fluorescence spectra of a damp heat-aged mini module during 2,000 hours of exposure time.

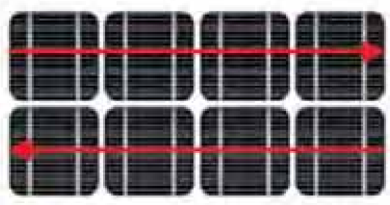


Figure 3. Illustration of the scan path across the PV modules.

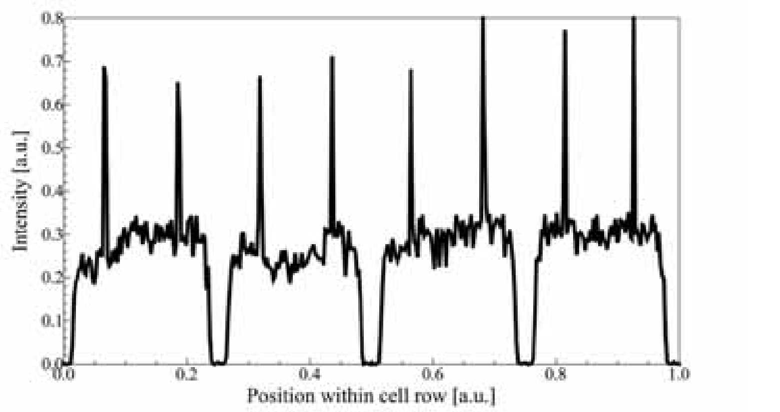


Figure 4. Total fluorescence intensity for scanning of a single line from module C1. The module was exposed at Zugspitze for two years. For anonymity reasons, a clipped section in arbitrary units is shown. The cells appear as plateaus of high intensity; the trenches of low fluorescence between them are actually wider than the spacing of the cells. The bus bars appear as high spikes.

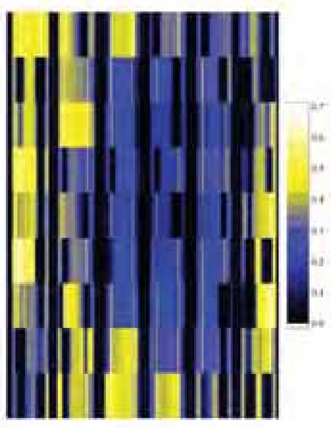


Figure 5. False colour image of the spatially resolved fluorescence intensity for module C2 (rows and/or lines were clipped for anonymity reasons). The module was exposed to Indonesia's tropical climate for two years. The intensity is normalized, showing lower fluorescence at the centre of the module.

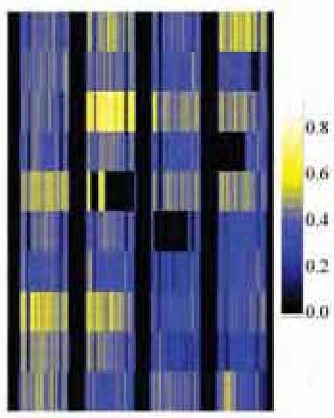


Figure 6. False colour image of the spatially resolved fluorescence intensity for module C3 (rows and/or lines were clipped for anonymity reasons). The module was exposed to a desert climate for two years. The intensity is normalized; peculiar spots appear on cells in lines 2 and 4 to 6 where the fluorescence on the cell disappears.

scanner. For module analysis, only one scan per cell row could be performed for the investigations presented here because of time constraints. The scanning direction is alternated for every other cell row (see Fig. 3). A low scanning speed can be chosen for high resolution. As the fluorescence spectra were integrated yielding the total fluorescence intensity, the data are then translated into a false-colour image showing the spatial fluorescence intensity distribution. Because the colour scales are normalized and selected for best visibility for all following figures, the differences in the excitation energy must be computed separately for absolute intensity comparison.

Comparison of the fluorescence measurements of complete PV modules

Figs. 1 and 2 show the ageing time-dependent fluorescence signal without spatial variation. Conducting measurements with spatial resolution on complete PV modules allows for the display of fluorescence intensity over the spatial coordinate, as shown in Fig. 4. Plateaus of high fluorescence intensity separated by trenches of low fluorescence intensity can be clearly distinguished. Spikes rising up from the plateaus spatially coincide with the position of the bus bars.

Several processes can be said to cause this spiking effect: excitation UV irradiation might be reflected by the bus bars yielding a higher fluorescence; the fluorescence itself may be reflected, explaining the strong signal increase; or there may be a real difference in the local condition of the polymer due to the bus bars.

The trenches of low fluorescence between the plateaus are significantly wider than the spacing of the cells. A general assumption could be made that this behaviour is caused by a diffusion process. The degradation products which normally seem to be fluorescent are then chemically altered into non-fluorescent species.

Combining all scanned lines of a module and translating the intensity into colours yields a complete image of the module. Fig. 5 shows the results of two years of outdoor exposure in Indonesia, indicating the occurrence of fluorescence across the entire module with a significantly higher intensity near the edges. Higher fluorescence

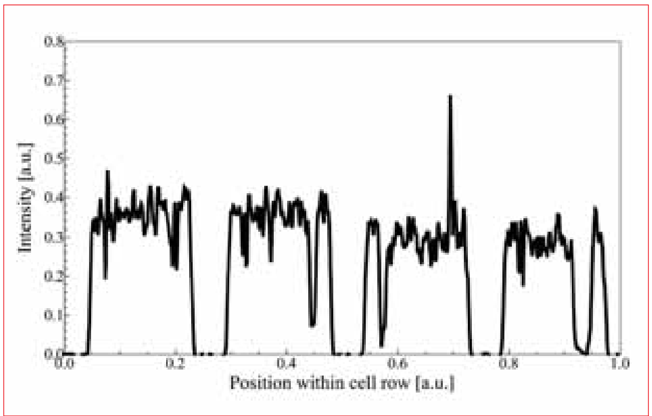


Figure 7. Total fluorescence intensity for scanning of line 2 of module C3. The spatial coordinate is the same as for the x-axis in Fig. 6. The cells appear as plateaus of high intensity; an additional trench of low fluorescence appears on cell number 4 (right-hand side).

intensity on the cells is associated with higher degradation of the polymer.

Fluorescence imaging was performed for numerous modules [11,12]. Another module was selected to demonstrate the ability of the fluorescence analysis to evaluate distinctive features. Fluorescence intensity suddenly drops to a very low level on certain cells. This effect can be seen for several cells on the C3 module in Fig. 6, though no visible changes were apparent. A line scan illustrates the difference between fluorescence intensities on the cell and the peculiar spot for cell number four in line two (Fig. 7).

Combination of fluorescence and electroluminescence

The distinctive features of cells with areas of low fluorescence were also investigated more thoroughly. The fluorescence imaging was performed at a higher resolution using 15 scan lines for one cell, acquiring approximately 500 spectra for each scan, for the investigation of the distinctive cell features. An electroluminescence (EL) image was taken to assess electrical peculiarities of this cell, the results of which are shown in Fig. 8. The electroluminescence image reveals a crack in the silicon wafer from the lower left end to the top centre. A clearly recognizable area of low fluorescence can be seen in the FL image all along the crack. The spatial correlation is quite apparent in the combination of the two images.

The width of the non-fluorescent area around the crack and the distance from the edge of the cell to the beginning of high fluorescence seem to be closely related. Assuming that diffusion can take place from the side of the module and through the crack in the silicon wafer in a similar manner, such a process may be causing the bleaching of the fluorescent species.

Taking a closer look at Fig. 9, strong browning is visible on a module following outdoor exposure at the Joint Research Centre (JRC) in Italy for an extended period of time. The browning on the cells has reached a state which normally should not occur during the service life. The fact that the browning is visible to the naked eye indicates that the polymer is being tested at a very late stage. A bleaching of the colorant species occurs around the cracks in the cover glazing. It can be assumed that similar processes of diffusion through cracks in the wafer and in the glazing are the reasons behind the bleaching in the browning image (Fig. 9) and in the fluorescence image of Fig. 8.

Conclusions

Fluorescence detection can be a sensitive and non-destructive method for the investigation of the degradation of the encapsulant polymer, EVA in this case. Changes in the fluorescence can be closely tracked, from directly after production until an ageing state resulting from damp-heat testing of more than 2,000 hours.

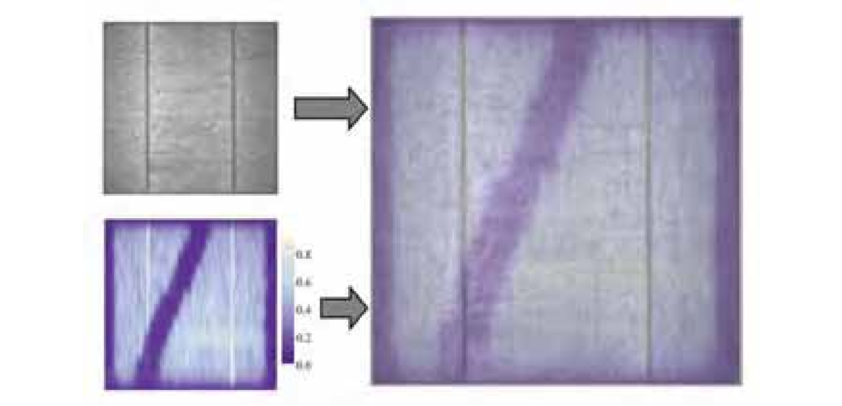


Figure 8. Data from cell number 4 in line 2 of module C3.
Top left: electroluminescence image.
Bottom left: fluorescence intensity image in false colours from dark blue to white.
Right: overlay of the fluorescence image over the electroluminescence.

Spatially resolved fluorescence spectra are collected for complete modules, and in the future this may also occur at high resolution. The total fluorescence intensity gives the first information about the local polymer degradation. Complex spectral information has the ability to provide much more information about ageing processes. The fluorescence can be used as an indicator from a very early stage regarding the ageing state of the polymer. Differences in the spatial distribution of the fluorescence over modules can be seen, leading to the assumption of spatially inhomogeneous ageing.

Fluorescence and electroluminescence are strongly correlated in the vicinity of cell cracks. This paper showed that a diffusion process takes place around cracks either in the glazing or in the wafer affecting the local fluorescence intensity. In the case of the presented modules, a bleaching was visible in the defined area around cracks.

Figure 9. Photograph of a module after extended outdoor exposure at JRC (Italy) showing strong browning caused by photo degradation of the EVA and bleaching effects around the cracks in the cover glass. (This module is unrelated to other modules investigated in this project.)

Acknowledgements

This work was supported by the BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety), under the project title: Reliability of Photovoltaic Modules, FKZ 0329978A. The authors would like to thank Steffen Fahnauer and his colleagues from the mechanical workshop of the Humboldt-Universität for their excellent support in building the scanning equipment.

References

[1] Wohlgemuth, J.H. et al. 2006, "Long term reliability of photovoltaic modules", *Proc. 4th World Conference on PV Energy Conversion*.

[2] Marín, M.L. et al. 1996, "Thermal degradation of ethylene (vinyl acetate) – Kinetic analysis of thermogravimetric data", *Journal of Thermal Analysis*, Vol. 47, pp. 247–258.

[3] Herrmann, W. et al. 2010, "Results of a German four-year joint project - Part II, results of three years module weathering in four different climates", *Proc. EU PVSEC*, Valencia, Spain.

[4] Allen, N.S. et al. 2001, "Aspects of thermal oxidation, yellowing and stabilization of ethylene vinyl acetate copolymer", *Polymer Degradation and Stability*, Vol. 71, pp. 1–14.

[5] Pern, F.J. & Czanderna, A.W. 1992, "Characterisation of ethylene vinyl acetate (EVA) encapsulant: Effects of thermal processing and weathering degradation on its discoloration", *Solar Energy Materials and Solar Cells*, Vol. 25, pp. 3–23.

[6] Pern, F.J. 1997, "Ethylene vinyl acetate (EVA) encapsulants for photovoltaic modules: Degradation and discoloration mechanisms and formulation of improved photostability", *Die Angewandte Makromolekulare Chemie*, Vol. 252, pp. 195–216.

[7] Allen, N.S. & Edge, M. 1994, *Fundamentals of polymer degradation and stabilisation*, Elsevier Science Publishers Ltd., Essex, UK.

[8] Röder, B. et al. 2008, "Observation of polymer degradation processes in photovoltaic modules via luminescence detection", *Proc. SPIE Vol. 7048*.

[9] Jungwirth, S. et al. 2010, "The influence of different back sheet materials on EVA degradation in photovoltaic modules investigated by luminescence detection", *Proc. SPIE-Conf. 7773*.

[10] Röder, B. et al. 2010, "The influence of different ageing factors on polymer degradation in photovoltaic modules investigated by luminescence detection", *Proc. SPIE-Conf. 7773*.

[11] Röder, B. et al. 2010, "Investigation of outdoor degradation of photovoltaic modules by luminescence and electroluminescence", *Proc. SPIE-Conf. 7773*.

[12] Röder, B. et al. 2010, "Combined luminescence and electroluminescence as powerful tool for the inspection of polymer degradation in photovoltaic modules", *Proc. EU PVSEC*, Valencia, Spain.

About the Authors

Beate Röder studied biophysics at the Gorki-University in Kharkov (Soviet Union). Since 1993 she has had a professorship in experimental physics at the institute of physics at the Humboldt-Universität zu Berlin. In 2007, she began the investigation of luminescence as a method for non-destructive detection of polymer ageing processes. Her main area of interest is the detection of extremely low light fluxes.

Jan Schlothauer and **Sebastian Jungwirth**, both attending Humboldt-Universität zu Berlin, studied physics and began working on their Ph.D. theses on the theme of ageing processes of polymer encapsulants in PV modules under the supervision of Beate Röder in autumn 2009.

Michael Köhl, physicist, has been working in the field of development, characterization, analysis and service life testing of components for solar applications since 1977. Recently, his main focus has been on the durability of PV modules as he has taken the role of coordinator of the German 'PV-reliability' project and of Subproject 5 'Lifetime assessment of PV modules' within the EU-funded 'Performance' project.

Enquiries

Dept. PV-Modules, Systems and Reliability
Fraunhofer-Institut für Solare Energiesysteme (ISE)
Heidenhofstr. 2,
79110 Freiburg,
Germany

Tel: +49 761 4588 5124
Fax: +49 761 4588 9124
Email: michael.koehl@ise.fraunhofer.de
Web: www.ise.fraunhofer.de

Examining the cost manufacturing advantages of 'solar breeder' factories for deployment in utility-scale solar farms

Kevin Wolter, Eric Tobin & **Michael Nowlan**, Spire Corp., Bedford, Massachusetts, USA & **David Jimenez**, Wright Williams & Kelly, Inc., Pleasanton, California, USA

ABSTRACT
This paper, the fourth in a series covering cost modelling studies for photovoltaics [1–3], examines a new approach to module assembly based on the concept of 'supersized' 1kW PV modules. Using supersized modules (1.6m × 3.8m) and integrated microinverters, this novel approach has the estimated potential to save utility solar installations up to US$0.55/watt. The paper will conclude with a detailed cost and resource case study comparing two 40MW module lines, one employing 'solar breeder' technology and the other producing conventional-sized modules.

Conventional PV module overview

The PV module is an assembly of electrically interconnected solar cells enclosed in a weatherproof package to protect it from the effects of the environment. The module circuit design specifies the number of cells connected in series, the number of cells connected in parallel, and the frequency of parallel interconnects. The number of cells in series determines the module operating voltage. The cell area and the number of cells in parallel are proportional to the module current output. Any practical series-parallel configuration can be fabricated to meet specific module design requirements.

A cutaway view of a standard module is shown in Fig. 1. Tempered low-iron glass is used for the front cover (or superstrate) to provide permanently transparent protection for the optical surface of the module. The remainder of the laminate consists of clear ethylene vinyl acetate (EVA) encapsulant, the cell circuit, a second layer of EVA, a fibreglass sheet, and a back-cover film.

"Larger modules could provide significant cost savings by lowering materials, balance of system and installation expenses."

EVA, which is supplied in sheet form, acts as both a transparent soft encapsulant and an adhesive for bonding the layers together. The lamination process is designed to thoroughly remove air from between all layers. The fibreglass sheet prevents the cell circuit from damaging the cover film during the module's lifetime. When the EVA encapsulant is heated for lamination, it melts and impregnates the fibreglass, providing a strong bond that extends from the cell backs, through the fibreglass, to the back cover. A foam tape gasket protects the module edges, where the back-cover film meets the glass. This tape cushions the glass panel and decouples it from the module frame to prevent degradation of the edge by daily thermal cycling.

Electrical output leads are brought through the encapsulant and backsheet. The leads go to a junction box mounted on the back of the module. Weather-tight intermodule wire connections are made at the junction box.

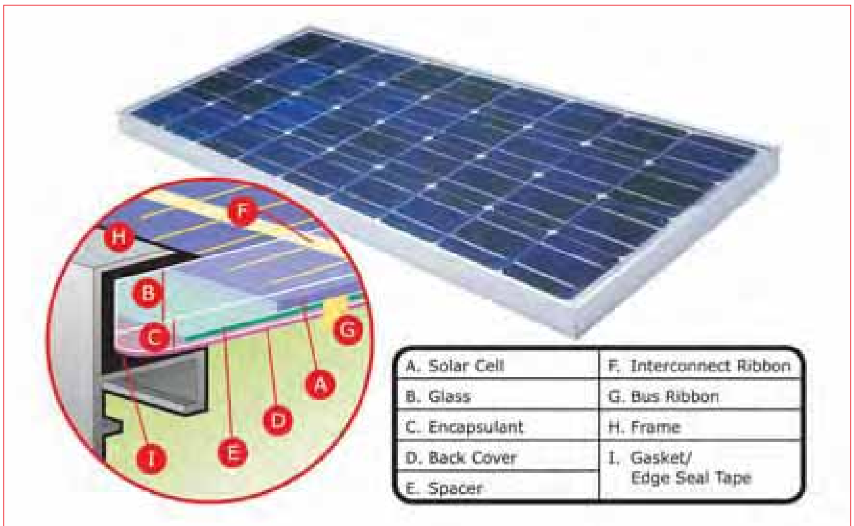


Figure 1. Cutaway view of a standard solar module.

Conventional module process sequence

The manufacturing process uses solar cells and module materials as inputs and produces functional PV modules, ready for use. The process, shown in Fig. 2, consists of the following steps:

- Sorting solar cells into performance groups (current groups at load voltage) using a cell sorter.
- Washing, rinsing, and drying the glass superstrate.
- Cutting EVA and placing it on the glass.
- Assembling and soldering cell strings interconnected with metal ribbons using an assembler/stringer.
- Aligning and placing strings onto the EVA (previously placed on the glass).
- Completing the module circuit by soldering bus ribbons to connect the strings together and provide output leads at a busing station.
- Visually inspecting and electrically testing the module circuit by measuring its dark I-V characteristics at an inspection station.

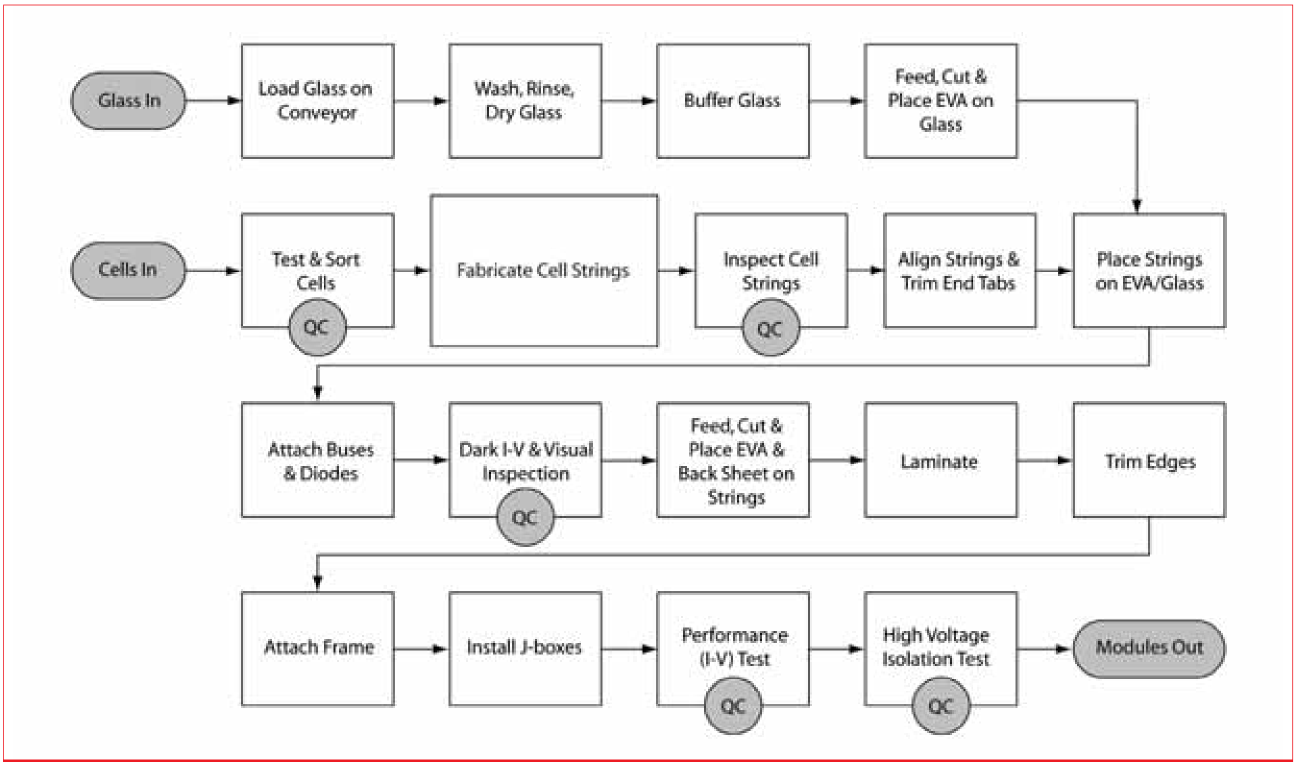


Figure 2. Standard solar module process sequence.

- Cutting EVA, fiberglass, and back sheets to length and assembling them with the glass and module circuit, using an EVA/back sheet layup station, in preparation for encapsulation.
- Laminating the assembly and curing the EVA.
- Completing final assembly, which includes edge trimming, installing an edge gasket and frame, and attaching a junction box.
- Performing a high voltage isolation test to measure the voltage isolation between the cell circuit and the module frame, and testing the frame ground continuity.
- Electrically testing the module under simulated sunlight with a sun simulator to measure its electrical performance.
- Visually inspecting the completed module for quality of materials and workmanship.

New solutions for the utility PV market

The solar utility PV market is experiencing significant growth that will continue through the foreseeable future. Utilities are expected to add at least 20GW of solar PV to their generation portfolios by 2020. The rapid growth in market demand is driving development of utility-scale solar projects such as grid-tied solar farm systems of 25 to 200MW. These farms will consist primarily of crystalline silicon (x-Si) modules, due to utility demands for reliability, high efficiency, a proven track record, and demonstrated 20-year life span, as well as overall cost considerations. Cost remains a major consideration in these growth projections, and further cost reductions will be necessary for additional growth to be achieved.

A new solar cell assembler and associated technology is being developed for the production of supersized 1kW utility PV modules. Such larger modules could provide significant cost savings by lowering materials, balance of system (BOS) and installation expenses. Furthermore, a single, larger panel-integrated microinverter utilized on the 1kW modules will provide cost advantages compared to a larger number of smaller units on conventional modules. Total predicted savings are near US$0.50/watt. This cost reduction would translate into billions of dollars in cost savings over the next decade for this rapidly growing market segment.

The maximum output for a conventional PV module is about 230–245W. Larger modules, up to 400W, have been recently introduced and are targeted specifically at the utility market. Supersized modules, more than double this size, could provide

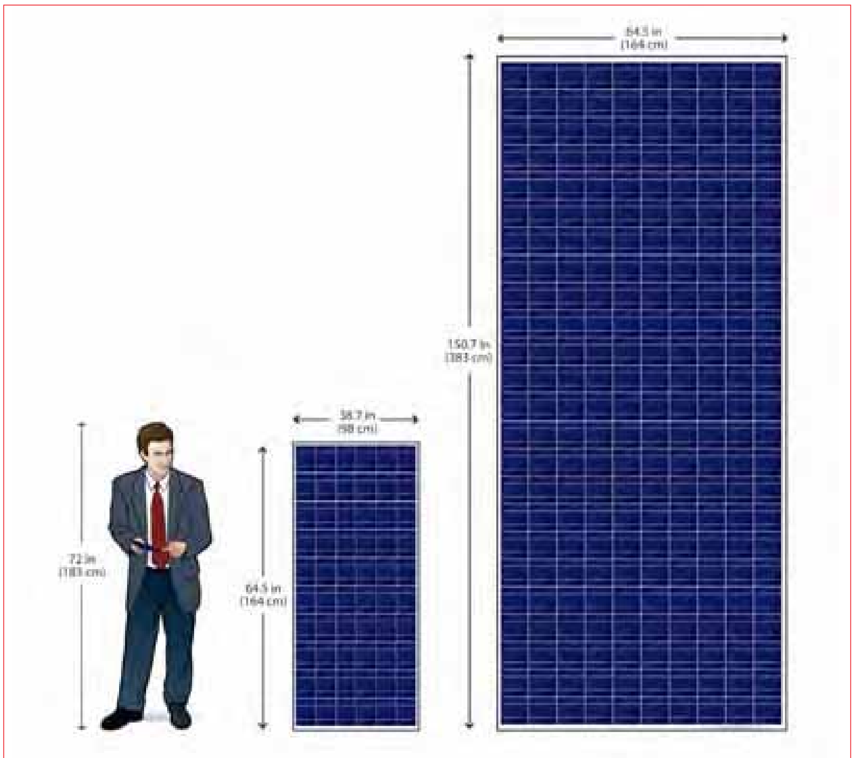


Figure 3. Comparison of standard (230W) and supersized (1kW) modules.

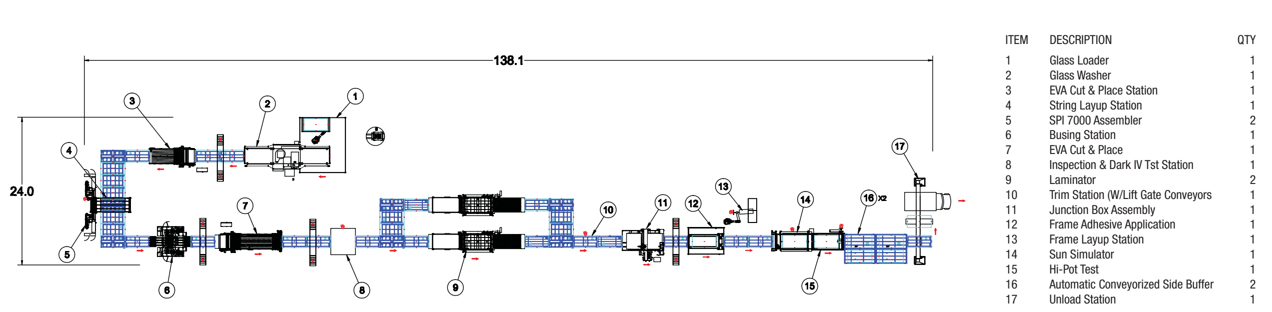


Figure 4. Layout of a 40MW module production line for 1kW supersized panels.

even greater benefit for PV utilities. But very large modules are impractical if they require transportation over significant distances. Importantly, the transportation constraint does not apply to the key materials that go into a module – the solar cells, which are small and light, and can be tightly packed. The transportation complexities for the supersized module provide an incentive for local module manufacturing at the solar farm site or at centralized locations with multiple customers nearby. The expenses associated with building a local factory would be quickly offset by savings realized from the larger module design.

An important consideration in the rethinking is how to address a factory designed to service a very limited, exclusively local customer base. Simply put, the production plant can be moved every few years. At the completion of the project, the factory can be decommissioned and the equipment relocated to another solar farm site to continue manufacturing.

Supersized PV modules

A preliminary design has been created for the supersized module, which will be nominally 5.5-ft × 12.5-ft (1.6m × 3.8m) and made with 240 standard 156mm crystalline silicon solar cells connected in 10-cell strings. Using cells with a nominal output of 4.19W/cell (with 17.2% cell efficiency) will produce a module power of 1kW (see Fig. 3).

Supersized module process sequence

The major steps required in the supersized module process sequence are very similar to those used in a standard module production line. As currently planned, the major differences between the two production lines are as follows:

- Size of production equipment. Producing modules that are four times the size of a standard module requires larger assembler and string layup, laminator, sun simulator, and conveyor stations.
- Increased automation. Expected to weigh approximately 330lb (150kg), the production line for the supersize module requires a high degree of automation.

A layout schematic (with dimensional units in meters) for an automated 40MW line capable of producing 1kW modules is shown in Fig. 4.

Case study

The following case study will evaluate the cost and resource models for supersized 1kW PV modules and conventional PV modules. Both models are based on a 40MW annual factory output. The data used in the supersized module analysis are based on information available to Spire. The standard 40MW module line analysis is based on the National Renewable Energy Laboratory (NREL) Solar American Initiative (SAI) public model. All results were generated through Wright Williams & Kelly's (WWK) Factory Commander cost and resource software. Where differences in model approaches existed (overhead, cell costs, etc.), the authors standardized the approach to provide like-for-like results.

Cost and resource modelling history

Cost and resource modelling is a comprehensive approach to understanding a wide variety of factory-level issues. The methodology was originally pioneered by semiconductor consortium Sematech in the 1990s and then adapted and extended by Sandia National Laboratories. The concept was developed to initially assist two capital-intensive industries – integrated circuits and then flat panel displays (FPDs) – to improve their ability to compete globally and maintain a U.S. supply of high-tech components. Sematech, in particular, considered it such a strategic asset that only members and select suppliers had access to the software.

> "Cost and resource modelling is a comprehensive approach to understanding a wide variety of factory-level issues."

Factory Commander is a commercialization of the factory cost model (FCM) developed at Sandia in the mid-1990s. The model was expressly developed for the U.S. display industry for making cost-competitive decisions regarding new FPD manufacturing initiatives. FCM was one of several cost modelling tools and projects developed under the National Center for Advanced Information Components Manufacturing

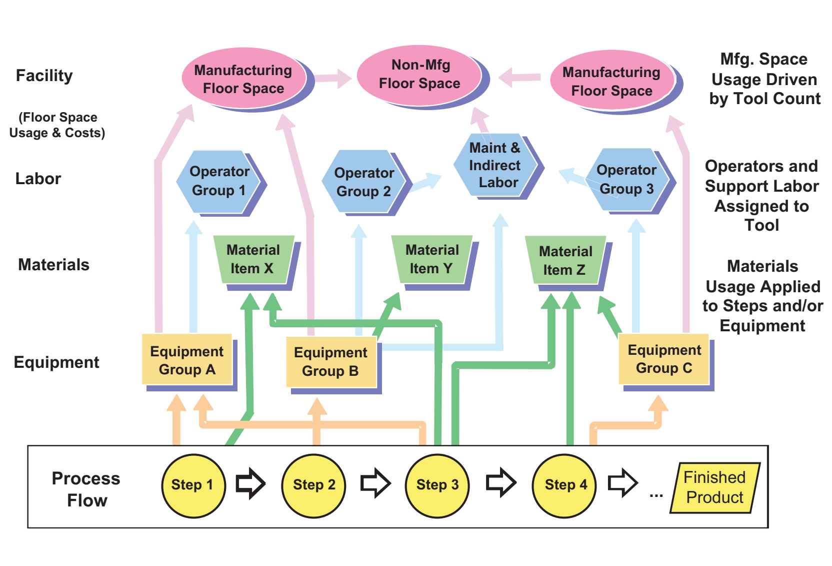
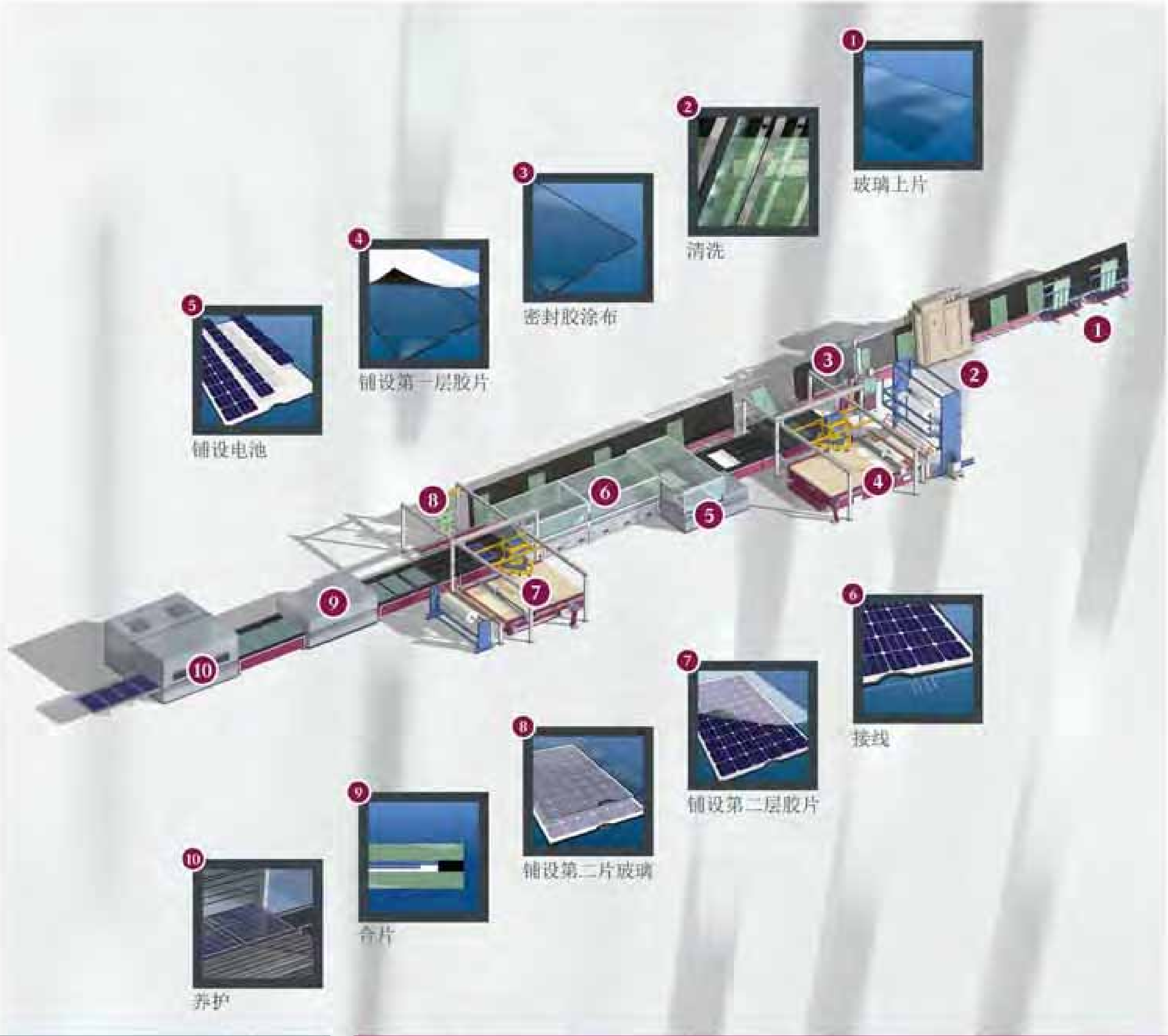


Figure 5. Chart of activity-based resource relationships.


1 玻璃上片
2 清洗
3 密封胶涂布
4 铺设第一层胶片
5 铺设电池
6 接线
7 铺设第二层胶片
8 铺设第二片玻璃
9 合片
10 养护

Parameter	1kW Module	SAI Public Model (NREL)
Factory size	40MW	100MW scaled to 40MW
Production demand/year	40,000 modules	163,265 modules
Module size	1kW	245W (mean)
Cell cost	US$5.03	US$5.82 (US$6.67 when scaled)
Cell size	156mm	156mm
Yield loss	4%	4%

Table 1. Major cost and resource model inputs. (Cell costs were assumed to be equal between the two scenarios at US$5.03.)

1kW module	SAI Public Model (NREL)
	Incoming cell inspection
Glass washing	Glass washing
EVA cover cut and place	Tab and string cells
String assembly	Module layup
String inspection and layup	Busing and inspection
Busing	Module lamination
EVA backsheet cut and place	Module curing
Prelamination inspection	Module trim and taping
Prelamination buffer	Frame module
Lamination	Module termination
Postlamination buffer	Module power test
Trimming	Module safety test
Framing	Package and label module
Boxing	
Simulation	
Hipot	
Pre-packaging inspection	
Sorting and packaging	
Installation	

Table 2. Process routes for two module production models.

Product cost summary, year 3

Model name: SAI public model 40MW, v101910
Model start date: 01/01/2010
Product: Module) PV module
Process: Module) PV module

Evaluation date: 11/10/2010 11:20 AM
Modeling timeframe: Uniform annual
Annual units out : 163,265 modules

Cost categories	Total annual cost $ x 1000	Unit cost $/module out	% of product total	Normalized unit cost $/watt	Scrap cost $ x 1000
Depreciation	**791**	**4.842**	**1.1%**	**0.020**	**14**
Equipment	595	3.646	0.8%	0.015	11
Building	195	1.196	0.3%	0.005	3
Operation and maintenance	**399**	**2.442**	**0.6%**	**0.010**	**6**
Equipment	399	2.442	0.6%	0.010	6
Facility	0	0.000	0.0%	0	0
Labour	**2,106**	**12.897**	**2.9%**	**0.053**	**12**
Direct labour	1,436	8.798	2.0%	0.036	7
Indirect labour	669	4.099	0.9%	0.017	6
Materials and supplies	**68,448**	**419.243**	**94.6%**	**1.711**	**243**
Starting material	51,184	313.501	70.7%	1.280	104
Direct process	16,982	104.017	23.5%	0.425	132
Indirect material	282	1.724	0.4%	0.007	7
Total production	**71,743**	**439.424**	**99.1%**	**1.794**	**2,106**
Overhead and non-production	**632**	**3.869**	**0.9%**	**0.016**	**5**
1) DL overhead	431	2.639	0.6%	0.011	
2) IDL overhead	201	1.230	0.3%	0.005	
Product total	**72,374**	**443.293**	**100.0%**	**1.809**	**2,112**

Table 3. Cost summary for 245W module.

(NCAICM) program. The NCAICM initiative was located at Sandia and was a collaboration with members of the United States Display Consortium (USDC).

The NCAICM cost modelling project originally planned to adapt the Sematech cost and resource model (CR/M) for application in the FPD industry. The model's main purpose was to assist in greenfield fab planning or early-stage analysis for semiconductor products in existing factories. The plan at NCAICM included using the CR/M as is or with minor modifications, and introducing the software and the concept of cost and resource modelling to the U.S. FPD industry.

However, as a result of the initial research into the needs of the potential FPD clients, it became clear that using the CR/M, even with modifications, would not suffice for FPD manufacturers. Items such as detailed material tracking/costing, modelling of rework loops, mergers of multiple process flows, and better output reporting capabilities would have required significant changes to the model. As a result, the NCAICM cost modelling project set out to develop its own application called FCM.

WWK acquired the intellectual property rights to Sandia's work in 1996 and commercialized FCM. With nearly 15 years of further enhancements, cost and resource modelling has been rendered technology neutral and applicable to all discrete manufacturing and assembly operations, including photovoltaics.

Cost and resource models

Cost and resource models assess the resources needed – people, equipment, materials, etc. – to complete a process or task, which in turn have roles, availability and costs associated with them. Cost and resource models are demand-based applications, and to the extent possible, all resource requirements are tied to the production demand. As such, cost and resource models calculate all the resources required to meet the specified production schedule.

At the heart of cost and resource modelling are activities. Each activity requires resources, and resources cost money. Activities are summed together to determine costs. Revenues are determined by selling prices of products. By including all inflows and outflows of cash, a complete financial analysis can be performed (net present value, breakeven, payback period, net cash flow, pro forma income statement, etc.) in addition to traditional industrial engineering metrics (floor space, tool counts, etc.). Four common business practices are subsets of cost and resource modelling.

- Cost of ownership (COO) is essentially the cost of an individual activity [1].

Product cost summary, year 3

Model name: Breeder module rev c - 40MW adjusted cell cost 101910
Model start date: 01/01/2010
Product: 2) PV module 1005W, 240 156mm cells, 40 MW
Process: 2) PV module 1005W, 240 156mm cells, 40 MW

Evaluation date: 10/20/2010 04:49 PM
Modeling timeframe: 8 quarters + 8 years
Annual units out : 41,571 modules

Cost categories	Total annual cost $ x 1000	Unit cost $/module out	% of product total	Normalized unit cost $/watt	Scrap cost $ x 1000
Depreciation	**1,462**	**35.16**	**1.9%**	**0.035**	**36**
Equipment	1,462	35.16	1.9%	0.035	36
Building	0	0.00	0.0%	0	0
Operation and maintenance	**1,136**	**27.32**	**1.5%**	**0.027**	**32**
Equipment	678	16.32	0.9%	0.016	21
Facility	457	11.00	0.6%	0.011	11
Labor	**2,048**	**49.27**	**2.7%**	**0.049**	**57**
Direct labour	1,329	31.96	1.8%	0.032	36
Indirect labour	720	17.31	1.0%	0.017	21
Materials and supplies	**70,163**	**1,687.75**	**93.0%**	**1.679**	**2,654**
Direct process	70,163	1,687.75	93.0%	1.679	2,654
Indirect material	0	0.00	0.0%	0	0
Total production	**74,809**	**1,799.51**	**99.2%**	**1.791**	**2,779**
Overhead and non-production	**615**	**14.78**	**0.8%**	**0.015**	**23**
1) DL overhead	399	9.59	0.5%	0.010	
2) IDL overhead	216	5.19	0.3%	0.005	
Product total	**75,423**	**1,814.29**	**100.0%**	**1.805**	**2,802**

Table 4. Cost summary for 1kW module.

- Capacity analysis determines the total resources needed to meet the production demand. Typically, capacity analysis refers to equipment, but it can also include staffing, support and material needs.
- Budgeting, including capital budgets, is a function of the capacity needs and the costs associated with meeting them.
- Product planning, where product demand is the key driver of the resource requirements and may involve product-mix variability (ramp up/ramp down).

What both Sematech and Sandia determined is that while this type of modelling had been done previously with spreadsheets, this approach was akin to taking a two-dimensional approach to a four-dimensional problem. There was a need for a relational database system that was not limited to simple factories or start-ups but could analyze complex situations, including multiple products with multiple process flows, rework loops and yield loss at specific points in the line.

Factories are dynamic, with near-constant change in product volumes, product mix, yields, productivity rates (cycles of learning), process flows, material costs, labour efficiency, product value and other factors. There are non-products run in the factory, such as R&D, engineering evaluations and monitor units, as well as re-entrant process flows, rework, merged process flows, and sophisticated process monitoring plans. Products can be binned into different levels and are often transformed (cells turn into modules, wafers into die, large panels of glass into small displays). Equipment can be underutilized and even pulled offline; material consumptions can change; labour requirements can change; and the price paid for any of these items can change with inflation and volume pricing contracts. Outside factors, such as licensing IP, overheads, and currency rates, all have an impact on product cost.

Once these factors are identified, the cost and resource model quantifies resource requirements and allocates those resources to individual products (see

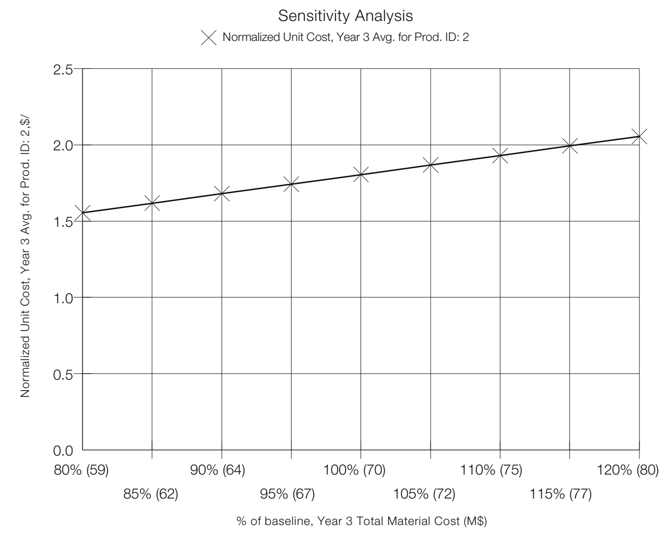


Figure 6. Sensitivity analysis of cell costs.

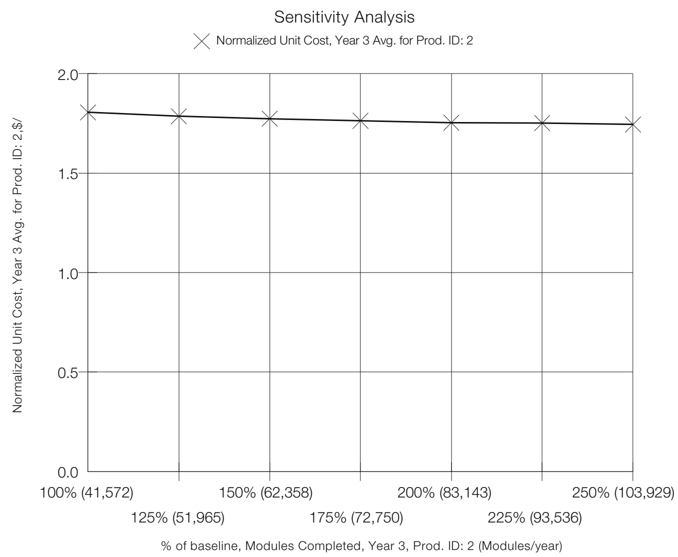


Figure 7. Sensitivity analysis of production demand.

Fig. 5). It should be noted that cost and resource models are deterministic and cannot explicitly estimate the dynamic aspects of production such as product queuing or work in process (WIP).

Several challenges reside in the midst of all these complexities. First, cost and resource models need to speak multiple languages and conform to differing standards. Accounting standards and nomenclature are much different from the standards and language used at the process-step (equipment and process engineering) level. One could consider a cost and resource model as a translation vehicle that transforms technical considerations into business results, allowing engineering and finance to communicate more clearly. Cost and resource modelling allows a new dynamic in decision-making – a virtual business model as an enabling technology.

Cost and resource modelling software inputs

The following are the results of the cost and resource analysis run on the 1kW and 245W lines. Table 1 details the high-level input parameters. While the data available from the SAI Public Model suggest a cell cost of US$5.82, both scenarios were evaluated using a cell market price of US$5.03/cell (or US$1.20/W). In addition to the Table 1 parameters, there are highly detailed inputs for both models including process routes, equipment performance and costs, labour requirements, facilities costs and utilities. Table 2 provides the process routes used in both models. While not identical, there is a reasonable match between the major functions as would be expected.

Cost drivers

An examination of the product summary outputs in Tables 3 and 4 highlights the

Unit cost per process step, year 3

Model name : SAI public model 40MW, v101910 — Product : Module) PV module — Annual units out : 163,265 modules

Model start date : 01/01/2010 — Evaluation date : 11/10/2010 11:20 AM — Unit costing method : Total cost per completed units at end of process

		Total unit cost ($/module)		Cost categories ($/module)								
Process step	Tool group ID	All categories	Cumulative production cost	Equipment depreciation	Building depreciation	Operation and maintenance	Direct labour	Indirect labour	Materials	Supplies	Overhead and non-production	Scrap cost
Starting cost :		313.501	313.501						313.501			
21) Incoming cell inspection	Tool 21	1.382	1.382	0.722	0.148	0.212	0.000	0.240	0.018	0.000	0.041	3.149
22) Glass washing	Tool 22	2.670	4.052	0.072	0.095	0.443	0.000	0.052	1.927	0.000	0.080	0.032
23) Tab and string cells	Tool 23	4.478	8.529	1.299	0.239	0.458	0.354	0.452	1.542	0.000	0.133	4.830
24) Module layup	Tool 24	27.895	36.424	0.007	0.050	0.002	0.715	0.312	25.978	0.000	0.832	0.000
25) Bussing and inspection	Tool 25	34.552	70.977	0.010	0.080	0.002	1.430	0.468	31.533	0.000	1.030	3.845
26) Module lamination	Tool 26	4.410	75.387	1.271	0.526	1.224	0.429	0.669	0.160	0.000	0.131	0.778
27) Module curing	Tool 27	0.029	75.416	0.005	0.010	0.001	0.007	0.005	0.000	0.000	0.001	0.000
28) Module trim and taping	Tool 28	3.724	79.140	0.010	0.020	0.002	1.430	0.462	1.689	0.000	0.111	0.039
29) Frame module	Tool 29	34.039	113.179	0.087	0.008	0.037	1.430	0.462	31.001	0.000	1.015	0.043
30) Module termination	Tool 30	9.087	122.266	0.005	0.010	0.001	0.715	0.231	7.854	0.000	0.271	0.000
31) Module power test	Tool 31	0.407	122.673	0.144	0.001	0.055	0.143	0.051	0.000	0.000	0.012	0.000
32) Module safety test	Tool 32	1.004	123.678	0.014	0.010	0.004	0.715	0.231	0.000	0.000	0.030	0.219
33) Package and label module	Tool 33	6.114	129.791	0.000	0.000	0.000	1.430	0.462	4.040	0.000	0.182	0.000
Total unit cost :		443.293		3.646	1.196	2.442	8.798	4.099	419.243	0.000	3.869	

Table 5. Unit cost per process step for 245W module.

product cost differences between the two models. One difference between the models is that the SAI line specifies the raw wafer as a starting material since it is an integrated cell and module line, while the 1kW line has modelled it as part of the total cell cost, which is an input into the first module process step. The important numbers to compare are the normalized unit costs, which represent the module cost per watt and are US$1.809 and US$1.805 for the SAI and 1kW models, respectively – identical for all practical purposes.

A deeper look at the data provides insight into which process steps are the main cost drivers and which components of cost are the most important. Tables 5 and 6 show this comparison in terms of the unit cost per process step, which is the equivalent of the COO for each step [1]. Both models share the layup station as a top cost driver. The extremely high cost of this step in the 1kW model results from the cost of finished cells being introduced at this step, as opposed to this cost being categorized as a starting material in the SAI model. Also among the top three cost

Unit cost per process step, year 3

Model name : Breeder module rev c - 40MW adjusted cell   Product : 2) PV module 1005W, 240 156mm cells, 40 MW   Annual units out : 41,571 modules

Model start date : 01/01/2010   Evaluation date : 10/20/2010 04:49 PM   Unit costing method : Total cost per completed units at end of process

		Total unit cost ($/module)		Cost categories ($/module)								
Process step	Tool group ID	All categories	Cumulative production cost	Equipment depreciation	Building depreciation	Operation and maintenance.	Direct labour	Indirect labour	Materials	Supplies	Overhead and non-production	Scrap cost
SP10) Glass washing	CRYS-T002A	159.80	159.80	0.62	0.00	1.08	0.52	0.13	156.15	0.00	1.30	0.00
SP15) EVA cover cut and place	CRYS-T005B	30.28	190.09	1.89	0.00	1.34	0.52	0.13	26.16	0.00	0.25	0.00
SP18) String assembly and in...	CRYS-T007B	13.29	13.29	2.29	0.00	1.82	7.36	1.72	0.00	0.00	0.11	0.00
SP20) String inspection and ...	CRYS-T008A	1,283.61	1,486.99	1.15	0.00	1.88	0.00	0.03	1,270.08	0.00	10.46	14.87
SP30) Busing	CRYS-T009A	31.47	1,518.46	3.52	0.00	2.51	0.52	1.16	23.50	0.00	0.26	0.00
SP40) EVA backsheet cut and ...	CRYS-T0010B	87.24	1,605.70	2.45	0.00	1.69	0.52	0.33	81.54	0.00	0.71	0.00
SP50) Pre-lamination inspection	CRYS-T001AM	6.01	1,611.71	1.27	0.00	0.84	3.68	0.17	0.00	0.00	0.05	0.00
SP55) Pre lamination buffer	CRYS-T0020	0.48	1,612.20	0.28	0.00	0.11	0.00	0.08	0.00	0.00	0.00	0.00
SP60) Lamination	CRYS-T0011B	36.30	1,648.49	10.13	0.00	10.52	4.17	11.18	0.00	0.00	0.30	16.48
SP65) Post lamination buffer	CRYS-T0020	0.48	1,648.97	0.28	0.00	0.11	0.00	0.08	0.00	0.00	0.00	0.00
SP70) Trimming	CRYS-T0012C	2.72	1,651.69	0.37	0.00	0.30	1.04	0.98	0.00	0.00	0.02	0.00
SP90) Framing	CRYS-T0013C	129.69	1,781.39	1.83	0.00	1.26	4.17	0.33	121.04	0.00	1.06	0.00
SP110) Boxing	CRYS-T0015C	12.39	1,793.77	0.63	0.00	0.36	2.09	0.33	8.88	0.00	0.10	0.00
SP120) Simulation	CRYS-T0016B	6.57	1,800.34	1.51	0.00	1.08	3.68	0.25	0.00	0.00	0.05	18.00
SP130) Hipot	CRYS-T0017B	0.30	1,800.65	0.02	0.00	0.12	0.00	0.16	0.00	0.00	0.00	0.00
SP140) Pre-packaging inspect...	CRYS-T001AF	4.26	1,804.91	0.23	0.00	0.16	3.68	0.16	0.00	0.00	0.03	18.05
SP150) Sorting and packaging	CRYS-T0018C	0.83	1,805.73	0.22	0.00	0.12	0.00	0.08	0.40	0.00	0.01	0.00
SP1000) Installation	CRYS-T0090A	8.55	1,814.29	6.44	0.00	2.02	0.00	0.02	0.00	0.00	0.07	0.00
Total unit cost :		1,814.29		35.16	0.00	27.32	31.96	17.31	1,687.75	0.00	14.78	

Table 6. Unit cost per step for 1kW module.

drivers is framing, which has a higher cost in the 1kW model as would be expected with a larger module size.

Cost driver sensitivities

This section focuses on two sensitivity analyses based on the 1kW model. The first analysis looks at the normalized unit cost as a function of cell costs. In this case, the term normalized does not mean reducing the base case to a factor of 1 but normalizing the per-module costs to an equivalent cost per watt. The cell cost was varied through a ±20% range, and the impact on the normalized unit cost is displayed. In this case, a 15% reduction in cell costs reduces the finished module cost per watt by approximately 10%. Fig. 6 compares the normalized unit cost ($/W) against the change in total material cost driven by the change in cell costs.

As a measure of line balance, the normalized cost per watt as a function of production demand was also examined. The start rate was varied from the initial 40MW plan to a +250%. In this case, a 250% increase in starts only reduces the finished module cost per watt by 3.3%. This indicates that the 40MW supersized-module line design has been appropriately balanced and the individual equipment throughputs well matched, as illustrated in Fig. 7.

Installation

As shown in Tables 3 and 4, the production of a supersized module matches the cost structure of the mature standard module. Given additional cycles of learning that could be employed in the supersized module line, it would be reasonable to assume that there is greater room for improvement in the long-term manufacturing costs for the supersized module. In addition, current estimates indicate that savings of US$0.30 to US$0.55 per watt can be achieved through the installation of PV systems greater than 20MW [4]. These savings can be attributed to decreased packaging and shipping costs, a significant reduction in required racking materials, decreased quantity of ground lugs and wire management, and a reduction of power inverter/conditioner units.

Conclusion

The photovoltaics industry has gone through immense changes in recent years, and continues to rapidly develop in many ways. While previous papers in this series focused on process step improvements in cell manufacturing using COO and overall equipment efficiency (OEE) measures, this paper examined a method of leveraging innovation in module assembly. These improvements required a more holistic approach to financial analysis as represented by cost and resource modelling, which allowed us to examine differences in process routes, equipment sets and materials.

One such innovation is the development of a supersized 1kW PV module with integrated microinverters, which has been shown to have a nearly identical cost compared to conventional 245W modules. Once the differences in installation costs are factored in, the modelled advantage for 1kW modules in utility-scale solar farms, in excess of 20MW, is approximately US$0.30 to US$0.55/watt.

References

[1] Jimenez, D. 2009, "Cost of ownership and overall equipment efficiency: a photovoltaics perspective," *Photovoltaics International*, Vol. 6, pp. 16–22.

[2] Kashkoush, I. & Jimenez, D. 2010, "Examining cost of ownership of crystalline-silicon solar-cell wet processing: texturization and cleaning," *Photovoltaics International*, Vol. 7, pp. 81–90.

[3] Brown, D. & Jimenez, D. 2010, "Examining cost of ownership for front- and back-side metallization of crystalline-silicon solar cells," *Photovoltaics International*, Vol. 8, pp. 93–99.

[4] Little, R., Nowlan, M., Bradford, R., & Hebert, D. 2010, "The Solar Breeder Factory: Minimizing the Cost of Photovoltaic Energy Generation", *35th IEEE PVSC*, Hawaii, USA.

About the Authors

Kevin Wolter is the assistant to the president of Spire Corp. He has spent seven years working in the clean energy space with much of this experience focusing on manufacturing operations, engineering development, and project management. He holds B.S. degrees in electrical engineering and mechanical engineering from Kettering University (Flint, MI) and has received an M.B.A. from the Harvard Business School.

Eric Tobin is a VP with Spire. He has been with the company for over 20 years, most recently involved with operational systems development, and evaluation and development of new market opportunities for Spire's solar equipment. He has B.S. and M.S. degrees in applied physics from the University of Massachusetts at Lowell.

Michael Nowlan is advanced technology manager at Spire Solar. He has been a member of Spire's technical staff for 33 years, working on photovoltaic module and equipment development for 32 years. He manages the Advanced Technology Center at Spire, which develops new module designs and assembly processes, evaluates new module materials, provides module process training for Spire's equipment customers, and produces limited productions runs of PV modules for a wide range of applications. He holds a B.A. in physics from the University of Massachusetts at Boston.

David Jimenez is president and cofounder of Wright Williams & Kelly, the privately held operational cost management software and consulting services company. He has approximately 30 years of industry experience, including management positions with NV Philips and Ultratech Stepper. Author of numerous articles in the fields of productivity and cost management, David has a B.S. in chemical engineering from the University of California, Berkeley and an M.B.A. in finance.

Enquiries

Kevin Wolter
Tel: +1 781 275 6000
Email: kwolter@spirecorp.com

Eric Tobin
Tel: +1 781 275 6000
Email: etobin@spirecorp.com

Michael Nowlan
Tel: +1 781 275 6000
Email: mnowlan@spirecorp.com.

David Jimenez
Tel: +1 925 399 6246
Email: david.jimenez@wwk.com

Power Generation

News

First Solar receives approval for pre-feasibility study of 2GW plants in Inner Mongolia

The Chinese National Development and Reform Commission (NDRC) has approved a pre-feasibility study for the construction of the first phase of First Solar's 30MW thin-film solar power plant located in Ordos City, Inner Mongolia. This phase marks the beginning of 2GW which are to be implemented in the area through 2019.

First Solar signed a memorandum of understanding (MOU) for the project with the Chinese government back in September 2009. The MOU stipulates that the parties will jointly invest US$4–60 billion U.S. dollars in order to scale up to 2GW in Ordos city. The project's 30MW stage is expected to be completed as soon as possible while the second, third, and fourth phases will comprise 100MW, 870MW, and 1GW, respectively, with phases two and three scheduled for completion in 2014, and the final phase finished by 2019.

The Ordos project's demonstration installation was scheduled to begin construction on June 1st, 2010. However, due to the industry's doubt surrounding the costs of thin-film technology and construction, the project was delayed without acceptance from the NDRC.

Once the entire project enters into operation it will become the world's largest photovoltaic power plant, the scale 20 times larger than the 80MW Sarnia plant in Canada. The company has also recently incorporated the First Solar (Beijing) Management Consultancy, which has the potential to become its next major investment department in China.

Source: First Solar

First Solar thin-film manufacturing.

Asia News Focus

Gehrlicher Solar, Greenforce Enviro form JV company Gehrlicher Solar (India)

Gehrlicher Solar and Greenforce Enviro have formed the joint venture company Gehrlicher Solar (India), which will provide engineering, procurement and construction (EPC) and other services for solar power plants in the country.

The newly formed company, which will be based in Mumbai, has drawn up a business plan which will be applied to the Indian solar market. As per the shareholding pattern, Gehrlicher Solar will hold a 51% stake in the JV while Green Force Enviro will hold 49%.

Suntech to supply modules, technical support for phase two of 44MW plant in Thailand

The second stage of a 44MW solar power plant in Thailand is to receive 9.43MW of solar panels and technical support from Suntech Power. Upon completion, the project, which is owned by Bangchak Petroleum Public and integrated by Solartron Public, is expected to be one of the largest in Thailand and Southeast Asia. The contract comes after Suntech was chosen to provide 34.5MW of solar panels and technical support for the project's first phase back in August 2010.

Source: Suntech

Suntech utility-scale VD solar module.

The renewable energy generated by the plant will be purchased and distributed by the Electricity Generating Authority of Thailand (EGAT) and the Provincial Electricity Authority (PEA) under long-term power purchase agreements. The plant is expected to create over 200 local jobs for the facility's development, installation and maintenance.

Upon completion, the solar facility will be opened to the community as an on-site visitor centre. The centre will feature an elegant Suntech building-integrated photovoltaic (BIPV) installation which will be viewed by local school pupils, residents, and tourists, who will learn about solar technology.

Solarpack and Codelco plan to build 1MW solar PV plant in Chile

Solarpack and Codelco are set to construct what they herald as South America's first industrial solar PV plant in Chile. The Calama Solar 3 project consists of a 1MW solar PV installation, which will be built across 15 acres of land with 4,080 silicon PV modules installed on single-axis trackers. The solar PV plant is expected to generate 2.69GWh of electricity per year, which will primarily power the mining company facilities in Chuquicamata, Chile.

Solarpack notes that this project will be constructed without using any subsidies or specific tax benefits for solar energy. Codelco has agreed to purchase the power generated at the solar plant under a PPA that specifies a long-term stable price at competitive rates in comparison to Northern Chile's electric system wholesale prices. Operation of the Calama Solar 3 plant is anticipated to start sometime in 2011.

Europe News Focus

Solon solar farms launched on nuclear ballistic missile pads

Solon has inaugurated its first ground-mounted solar power plants in France, located in Ferrassières near Avignon, in the Rhône-Alpes region. Solon Investments planned and constructed the two turnkey plants, with a combined nominal output of 3MWp, on the former site of two launch pads for intercontinental nuclear ballistic missiles.

The two separate photovoltaic systems, consisting of 14,500 Solon Blue 230 polycrystalline solar modules, have been developed for investor groups, International Energy Investments Group and Investricity Group, two Ireland-based Solar Investment Aggregators.

Source: Solon

Solon Blue 230 polycrystalline solar module.

SolarWorld opts into voluntary public offer for Solarparc

SolarWorld is to submit a voluntary public takeover offer to the shareholders of Solarparc in a bid to acquire the company shares needed to continue forward integration into the global project business. SolarWorld intends to offer Solarparc's shareholders one SolarWorld share in return for each Solarparc share.

The takeover offer will be made in accordance with the terms specified in the offer document, which will be made available on the company's website. This document will also outline the exact period for the acceptance of the takeover offer. SolarWorld currently holds 29% of the shares of Solarparc.

SunEdison's 70MW Rovigo plant goes live

The 70MW (DC) PV power plant in Rovigo, Italy has been successfully interconnected, according to SunEdison, a subsidiary of MEMC Electronic Materials. Hailed as the "the largest single-operating PV solar power plant in Europe," the project was completed in nine months and is expected to generate enough energy to power more than 16,500 homes.

The largest PV plant in Europe was touted as Q-Cells built, Finsterwalde project, which comprised a total of 82MW (DC), according to the company.

Recently, First Reserve acquired the Rovigo project, raising €260M with banks, including Banco Santander, Unicredit Corporate Banking, Dexia Crediop, Natixis, Societe Generale and Credit Agricole. SunEdison, which remains a minority investor in the joint venture with First Reserve, will manage the ongoing operations and maintenance of the Rovigo plant.

Colexon completes 2.4MWp rooftop installation in Germany

Colexon has completed a 2.4MWp photovoltaics installation on the 50,000m^2 rooftop of tile manufacturer Porcelaingres' factory, located in Brandenburg, Germany. The roof will be leased to Colexon for a period of 20 years. The company utilized modules from the thin-film specialist First Solar and inverters from SMA for the project, which is expected to be connected to the grid by the end of 2010.

S.A.G. Solarstrom begins work on the 2.13MWp system in Spaichingen, Germany

S.A.G. Solarstrom has begun the construction of a 2.13MWp photovoltaic installation on the site of a former excavated soil in the town of Spaichingen, Germany. The company signed a contract with the town whereby S.A.G. will work as system contractor while the town will lease the site to the future installation investor. Several purchase inquiries have already been received for the project.

The plant is to be built on a 3.2 hectare site of the former excavated soil landfill "Hofer Ried" in the town of Spaichingen in Baden-Württemberg. The 2.13MWp system is expected to be connected to the grid by the end of this year.

Source: S.A.G. Solarstrom

S.A.G. Solarstrom begins construction on the 2.13MWp plant.

U.S. News Focus

PSE&G starts work on 4.4MW solar project in Hamilton Township, NJ

Public Service Electric and Gas (PSE&G) said it has begun the first phase of construction at the 4.4MW Yardville Solar Farm in Hamilton Township, NJ. The power plant is one of four ground-mounted solar farms that the utility is developing as part of its US$515 million Solar 4 All program.

The company expects to develop more than 20 solar projects, which represents an investment of more than US$140 million that will create almost 300 jobs and provide New Jersey with 30MW of solar-generated power.

The Yardville project will be comprised of 15,750 crystalline-silicon solar panels covering 15.75 acres of PSE&G property and will be connected directly to the grid, eventually producing enough electricity to power about 720 average-size homes. The brand of solar modules to be deployed, other details on the balance of systems, and timeline for construction and activation of the power plant were not disclosed.

Along with the Yardville site, PSE&G is developing three other ground-mounted solar installations on properties it owns in Linden (3.2MW), Edison (2MW), and Trenton (1.3MW). The company is also building a 1MW system on the roof of its Central Electric headquarters in Somerset and a 700kW installation at its Edison Training and Development Center facility.

Southern California Edison inks deals with six firms to develop 240MW of PV sites

Southern California Edison has signed 20 contracts with six different independent power producer firms for nearly 240MW (AC) of solar photovoltaic systems to be deployed close to major transmission lines in various parts of the utility's service areas in Southern California. The agreements resulted from SCE's 2010 Renewable Standard Contracts "request for offers."

Ranging from 5MW to 20MW when completed, the installations are scheduled to come online in 2013 and 2014. Nine of the contracts were secured by Silverado Power, a unit of Martifer Solar, which is slated to build 100MW of ground-mounted PV projects in the Lancaster and Victorville areas.

Concentrator PV company Amonix landed four contracts totaling 28.5MW in installed distributed-generation capacity, while juwi solar's U.S. unit (38MW), Foresight Renewables (34MW), and Sharp Solar subsidiary Recurrent Energy (30MW) each won a pair of contracts. Clean Peak Energy scored a single 8.5MW offering.

The contract-winning IPPs are responsible for any required permitting and must conduct environmental impact studies in accordance with local, state, and federal jurisdictions, according to the utility, which added that there will be minimal transmission upgrades to accommodate the projects.

GCL and SolarReserve enter into JV for 1,100MW of solar PV development projects

GCL Solar Energy and SolarReserve have agreed to enter into a joint venture towards the development, building and operation of solar PV facilities in the U.S. The joint venture, titled GCL-SR Solar Energy, has a 1,100MW portfolio of PV development projects, which range in size from 5MW to 20MW at 40 different sites across the U.S. Construction is anticipated to start on up to 400MW of PV projects in the near future.

The joint venture will see SolarReserve manage the project development portion the projects, while GCL will take care of PV vendor selection, construction and long-term financing.

NFL team set to build US$30 million renewable energy power system for stadium

The Philadelphia Eagles are setting their sights on another prize other than Super Bowl XLV trophy this year with their commitment to power Lincoln Financial Field with wind, solar and dual-fuel generated electricity. The team claims that this will be the world's first major sports stadium to convert to self-generated renewable energy.

Establishing a partnership with SolarBlue, the Eagles will install 80 20-foot spiral shaped wind turbines on the rim of its stadium, 2,500 solar panels on the stadium's exterior and build a 7.6MW onsite dual-fuel cogeneration plant including a monitoring and switching technology for the operation of the system.

SolarBlue estimates that the year-long design and build of the facility will cost upwards of US$30 million and has a tentative completion date set for September 2011, just in time for the beginning of the 2011–2012 NFL season. SolarBlue will

maintain and operate the stadium's power system for 20 years with a fixed percent annual price increase in electricity.

Over the next 20 years, the Eagles and SolarBlue look forward to the system producing 1.039 billion kWh of electricity with the potential to sell back 4MW of surplus energy off-peak to the local grid.

Solar Millennium gets go-ahead from Secretary of Interior on large-scale CSP project

The U.S. Department of the Interior has given its approval to Solar Millennium for the construction of the Amargosa Farm Road Solar Project, the second large-scale solar energy project to be built on U.S. public land in Nevada. The 500MW facility will use concentrated solar power (CSP) technology, including two 250MW parabolic trough dry-cooled power plants with the ability to store 4.5 hours of thermal energy.

Located 80 miles outside of Las Vegas, Nevada on 4,350 acres of public land, which the Bureau of Land Management (BLM) oversees, the project is one of eight large-scale solar energy projects to be built on U.S. public lands in California and Nevada. Once completed, the combined seven projects will produce 3,500MW of energy.

Although Amargosa Farm has completed wide-ranging environmental reviews, which resulted in an Environmental Impact Statement published on October 15th, 2010, the project must still get final approval of the Section 404 Dredge and Fill permit from the U.S. Corps of Engineers and seek other State of Nevada and local permits. Solar Millennium expects to secure all required permits over the next few months and has a tentative construction start date aimed at for the end of 2011.

During their investigation, the BLM, U.S. Fish and Wildlife Service and National Park Service collaborated with Solar Millennium to create an original water mitigation plant that can serve as a model for future solar projects. The plan ensures that the solar project will have a net neutral benefit on the plants and animals who reside in close proximity to Amargosa Farm in the Ash Meadows National Wildlife Refuge and Devils Hole.

Solar Millennium CSP trough.

Source: Solar Millennium

Solar Millennium will be able to receive around US$1 billion in investment tax credits through the American Recovery and Reinvestment Act as well as becoming eligible for financing through the DOE Title 17 Loan Guarantee Program. Currently, the solar project is negotiating with NV Energy under the terms of a PPA to sell electricity produced at the site.

Perpetual completes 1.5MW solar project for San Francisco area high schools

Perpetual Energy Systems has finalized the 1.5MW solar project for the Jefferson Union High School District, south of San Francisco. The project included solar arrays being installed at four District high schools: Oceana High School, Terra Nova High School, Westmoor High School and Jefferson High School. In all, the solar project used more than 8,500 solar panels and is anticipated to produce 2,300,000kWh of energy during its first full operational year.

The project did not require the District to put up upfront capital outlay and was funded by Perpetual through project financing, sponsor equity and federal renewable energy tax credits. Any renewable energy certificates produced by the solar project will be owned by Perpetual, who will allow the District to buy the energy produced by the solar arrays under a PPA, which has a fixed discount from what the school district would have paid to a traditional utility company.

SMA Solar sales top €626.7 million: 5.7GW of inverter output sold in the first nine months

Solar inverter company SMA Solar almost reached its production capacity limit as semiconductor component supply constraints eased. Third-quarter sales reached a record €626.7 million and totalled €1.44 billion for the first nine months of the year. SMA reiterated that it still expects newly installed PV power of up to 17GW in 2010, with German solar installations running at about 5.3GW through the end of September.

SMA said that it had a maximum annual production capacity of approximately 11GW worldwide, a doubling of production capacity compared with 2009. However, the inverter manufacturer noted that its output in the quarter of 2.6GW was virtually sold out. In the first nine months, SMA said that inverter output had been 5,738MW.

Delivery lead times have fallen back to normal shipment cycles of two to three weeks for string inverters of the medium power solutions segment and to six to eight weeks for central inverters of the high power solutions segment.

SMA's managing board said it is expecting 2011 industry installed growth of plus 20% to minus 10% in 2011. Revenue guidance for 2010 was expected to be in the range of €1.5 to €1.9 billion. SMA reported 2009 revenue of €934 million.

SMA Sunny Island off-grid inverter.

Source: SMA Solar

REC Solar and SunEdison activate 1.1MW solar system at Madera's wastewater plant

REC Solar and SunEdison teamed up with Mayor Gary Svanda and Madera city council members to officially turn on the city's newest solar project: a 1.1MW solar installation at Madera's wastewater treatment plant. The new solar project will produce over 2.4 million kWh of energy per year and around 45 million kWh over 20 years.

The solar project was a joint development between REC Solar and SunEdison, which saw REC design and construct the system using its own dual-axis system trackers and solar panels. SunEdison completed a PPA with the city of Madera and will oversee the financing, operation and maintenance of the plant, while allowing the city to buy the produced energy at a predictable rate for 20 years.

Los Angeles's DWP to build largest PV array in city at 5MW

The Los Angeles Department of Water and Power (LADWP) approved the initial environment documents mandated by the California Environmental Quality Act (CEQA) this week, paving the way for the city's largest solar PV array to be built. The 5MW solar PV installation, called the Van Normam Bypass Reservoir Solar Project, is set to be built on the covered reservoir in Granada Hills at an estimated US$15.3 million.

Solar modules will be installed over the 575,000 square foot rigid roof that sits atop the potable water reservoir over six months, with an anticipated start date sometime in late 2011. The project is still subject to funding allocation, but when constructed will help Los Angeles reach its own renewable energy goals as well as state renewable energy goals.

Product Briefings

AMSC

AMSC offers first optimized utility-scale PV grid interconnection system

Product Briefing Outline: American Superconductor Corporation (AMSC) has launched its SolarTie Grid Interconnection Solution that combines the company's 'D-VAR' STATCOM solutions and 'PowerModule' power converter systems for megawatt-scale solar PV power plants. The company claims it as the first optimized utility-scale PV grid interconnection system that enables developers to meet the most stringent grid interconnection requirements while enabling centralized control of real and reactive power at the point of interconnection.

Problem: Utility-scale solar power is experiencing challenges when connecting to the grid, as operators want solar plants to act like traditional power plants, and therefore maintain grid stability and avoid blackouts. It is clear that upfront planning for renewable energy power plants can help establish grid stability.

Solution: AMSC's SolarTie system includes advanced photovoltaic inverters and a proprietary Smart Grid Interface (SGI) controller to provide centralized control of real and reactive power at the point of interconnection (POI). The SolarTie solution is claimed to provide instantaneous detection, accurate response and immediate results, ensuring efficient energy production and precise grid management. It provides sub-cycle (less than 16 milliseconds) detection and response to grid disturbances while many competing interconnection solutions have response times of 10 to 20 seconds.

Applications: Large-scale PV utility plants.

Platform: The SolarTie inverter is a stand-alone unit, which does not need any additional enclosure or roof to meet outdoor requirements.

Availability: Currently available.

OPEL Solar

OPEL Solar's wireless solar tracker enables cost-efficient network management

Product Briefing Outline: OPEL Solar has introduced a new wireless, utility-scale solar tracker control network developed in conjunction with its partner, FEiNA, in Spain. The new wireless tracker network will provide control and monitoring systems for solar fields currently being developed by utilities in the North American, European and North African markets.

Problem: Although solar tracker systems can provide improved solar module energy generation, they can also be responsible for higher maintenance costs throughout the lifetime of the solar plant.

Solution: OPEL's new wireless tracker control and management system can be more easily deployed in solar fields because it does not require cables, which are normally used for network management. While older tracker systems required people on-site for maintenance, problem-solving, and ongoing monitoring, the new wireless tracker control network allows key functions to be managed remotely and more cost-effectively. The tracker control network system is CE Certified for use throughout Europe. Tracker systems, ranging from large rooftop applications to industrial solar farms, can be networked together to provide unison tracking and remote monitoring capabilities

Applications: The wireless tracker control technology can be used for any solar panel technology.

Platform: The trackers can be easily assembled and equipped with solar panels in less than four hours by a crew of two to three individuals without the need for special tooling, cranes or welding.

Availability: The wireless tracker control is currently available for delivery in production volumes.

Soliant Energy

Soliant Energy targets commercial rooftop market with CPV module

Product Briefing Outline: Soliant Energy has launched its next-generation CPV commercial rooftop solar energy solution, the SE-1000X, which features eight CPV modules per tracking panel and delivers 504W. This high power coupled with the integrated 'TipTilt Tracking' is claimed to generate the greatest amount of energy, at the lowest price per kWh for commercial rooftop installations. The SE-1000X maximizes energy production per rooftop square foot when compared to flat-panel solar rooftop solutions.

Problem: Across the U.S., for example, there are more than five million commercial, industrial and government buildings with flat roofs that collectively represent more than 500GW of power generation opportunity. Most of these buildings are major energy consumers that need to maximize rooftop solar energy generation in order to make a meaningful impact on electricity bills.

Solution: The Soliant Energy SE-1000X represents a significant improvement over Soliant's earlier product, the SE-500X. Changes include eight modules on a single tracking panel instead of six, and several technology improvements that enable it to generate substantially more energy per panel, thus lowering the total cost of energy for a typical commercial rooftop installation. The concentration level has increased from 500 suns to 1000 suns, while using triple-junction cells with improved cell efficiency and improved thermal properties. Combined, the energy output per panel is increased from 335W per panel in SE-500X to 504W per panel in SE-1000X.

Applications: Flat commercial rooftops.

Platform: SE-1000X uses field-proven materials and components with a compact and lightweight construction intended to enable easy installation and maintenance.

Availability: Currently available.

Solyndra

Solyndra's 200 Series CIGS thin-film module requires no tools for flat roof installation

Product Briefing Outline: Solyndra has announced the first major upgrade to its CIGS cylindrical thin-film modules. The Solyndra 200 Series requires no tools for commercial flat rooftop installation and is the fastest and easiest to install, according to the company. Improved light collection makes the 200 Series rated as high as 220Wp and is larger in size (2.28m × 1.09m × 0.06m) than its predecessor.

Problem: Building owners with older or 'value engineered' rooftops can benefit from the lightweight panels (roof load of 2.8lbs per square foot) that have no need for penetrations or ballasting, and can be installed significantly faster than flat panels on a typical roof.

Solution: Optimized light collection and enhancements to the Solyndra module improve the 200 Series panels' ability to capture direct, diffuse and reflected sunlight across the 360° photovoltaic module surface. The wider spacing of the modules offers 'broader shoulders' or more uniform energy collection throughout the day than traditional flat panels. The cylindrical module shape also allows the panels to be placed horizontally and significantly closer together than conventional panels. Panels can be oriented in virtually any direction which offers greater flexibility for rooftop applications. Snap-together mounts dramatically lower labour costs and shorten project times for large rooftop solar installations.

Applications: Commercial-scale flat rooftops.

Platform: Certifications and listings: UL1703, IEC 61646, IEC 61730,CE Mark, CEC listing, Protection Class II Application Class A per IEC 61730-2, Fire Class C, MCS/BRE(UK). Warranty: 25-year limited power warranty; 5-year limited product warranty.

Availability: Currently available.

Vacon

Vacon's Solar Multimaster modular inverter concept improves efficiency

Product Briefing Outline: Vacon has entered the solar inverter market with the Vacon 8000 SOLAR inverter series, which have a power range of 10–1000kW. Vacon 8000 SOLAR is based on proven technology used in demanding wind energy and industrial applications.

Problem: In case of failure, utility-size central inverters will lose the whole power generation. If the issue is solved by modularity in the inverter power structure, having several smaller power modules connected in parallel, it often requires a special medium voltage transformer with multiple windings on the low voltage side.

Solution: Vacon 8000 SOLAR uses a unique solar 'multi-master' concept where the power of the inverter grows by paralleling identical inverter modules both on the DC and AC side. With the module synchronization, it is possible to connect the inverter module outputs to single windings in the medium voltage transformer, thus allowing the usage of a simpler and more standardized transformer. The Solar Multimaster will start only the required number of modules, depending on the available solar energy. The start sequence is altered to give equal usage of each module. It also allows the system to continue operations with the remaining modules and thus keep generating power to the grid in case of module failure.

Applications: Commercial and large-scale solar plants.

Platform: The Solar Multimaster uses a modular concept approach and employs optimized inverter usage according to sunlight with minimal power loss. Its altering start-up sequence is intended to extend overall lifetime of set-up. Repairs and maintenance are possible without complete shut-downs, enabling new inverter unit additions easily.

Availability: Currently available.

Control Techniques

Control Techniques' transformerless central inverter maximizes energy yield in low light conditions

Product Briefing Outline: Control Techniques has launched a 'transformerless' central inverter system for utility-scale photovoltaic power plants that is designed to maximize investor returns through optimized availability, efficiency and yield. Control Techniques' SPV is constructed using 145kWp, 176kWp and multiple 176kWp parallel-connected inverter modules to produce any desired power rating up to 1760kWp.

Problem: Conventional central inverters' efficiency levels can fall below 20% of rated power due to varying solar irradiation caused by the large fixed switching losses associated with bulk inverters. They can have limited capabilities to efficient operations in medium to low light conditions.

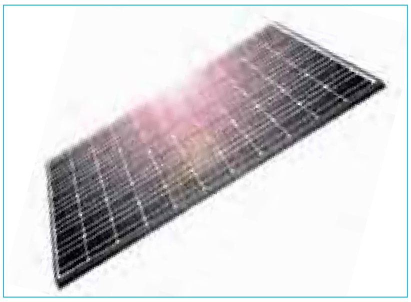
Solution: Control Techniques' SPV inverter achieves Euro- and CEC-weighted efficiencies of 97.6% and can maximize energy yield in low to medium light conditions. Regardless of power rating, SPV can turn on or off at a power threshold of only 900W, effectively extending the length of the operational day. The Maximum Power Point Tracking (MPPT) algorithm. The software is designed to track transient changes in irradiation whilst accurately determining the optimum condition across the operating temperature range of the PV plant. The MPPT range of the SPV is 400–800V (DC), with the planned UL version operating from 300–600V (DC).

Applications: All large-scale PV applications, with either thin-film or crystalline photovoltaic modules. Inverter maximum turn-on voltage is 1000V (DC).

Platform: The inverters are compliant with all key international grid connection standards offering both Mains Dip Ride Through and Anti-Islanding capability.

Availability: Currently available.

Sanyo



Sanyo's HIT N Series module uses 21.1% efficiency cells

Product Briefing Outline: Sanyo has launched its highest efficiency 'HIT' N Series solar module to date using cells with 21.1% conversion efficiency, generating a module output of 235W for its new HIT-N235SE10 design. The New N Series modules will be produced at Sanyo's factory in Hungary.

Problem: With an increasing number of European countries adopting attractive feed-in tariffs that favour residential rooftop installations, there is a growing need for high-efficiency modules that better match limited roof space with attempts to maximize FiT returns for consumers and commercial businesses. Within Northern Europe especially, low-light conditions reduce power generation, requiring modules that have unique characteristics that enhance performance in these conditions.

Solution: The HIT-N235SE10 has achieved an 18.6% module efficiency through adopting 21.1% efficiency HIT cells, new tab design and anti-reflection coated glass. This provides an 8.7% increase in efficiency over and above the 17.1% HIP-215NKHE5 and 7.5% increase in efficiency over and above the 17.3% HIT-240HDE4. The modules use three tabs, which reduces the electrical losses in the cell fingers. In addition to this, through designing new thinner tabs, the effective area is enlarged to capture more sunlight. New N series also uses anti-reflection coated glass, which reduces losses of reflection and scattering of sunlight.

Applications: Residential and commercial rooftops.

Platform: The 'HIT' cell structure is a monocrystalline wafer surrounded by ultra-thin amorphous silicon layers.

Availability: Available on the European market since September 2010.

Satcon

Utility-scale inverter from Satcon provides 98.5% efficiency

Product Briefing Outline: Satcon Technology has launched its next-generation power conversion solution, the Satcon 'Equinox.' The Equinox 500kW solution is designed to improve system-wide energy harvest and solar plant yield, enabling the large-scale solar industry's lowest LCOE.

Problem: The challenges of multi-megawatt installations demand a specialized set of technological and system design expertise. The ability to limit power losses while operating in a wide range of climate conditions enables the highest returns for utility power investors.

Solution: Satcon's Equinox solution delivers a best-in-class efficiency of 98.5% and is said to offer high levels of system-wide performance, uptime and reliability. Equinox comes complete with a NEMA 3R/IP54 enclosure and is available in three separate climate packages, enabling the large-scale commercial and utility-scale solar industry's broadest thermal operating range with fully rated performance at temperatures as high as 55°C/131°F, and as low as -20°C/-4°F. The combination of fine-grained power harvesting of each panel string along with a highly efficient central inverter design helps to ensure delivery of power over the lifetime of the PV system by increasing total system harvest optimization and system uptime and safety. This system is claimed to boost total system power production by 5–12% and lowers other BOS material costs by 20–25% compared to a centralized inverter system.

Applications: Utility-scale inverter applications.

Platform: Equinox's advanced utility-ready features enable simplified grid interconnection and can be easily integrated into SCADA systems through standardized communication interfaces.

Availability: Currently available.

STMicroelectronics

STMicroelectronics' Back-Current Circuit replaces SiC devices in 'boost-or-buck' converters

Product Briefing Outline: STMicroelectronics has released details of a patented high-efficiency circuit and dedicated optimized power components. ST's new design, called BC2 (Back-Current Circuit), is claimed to produce cost savings while helping designers comply with the highest power-efficiency standards. The new circuit and power components are ideally suited for 'boost-or-buck' converters, which are power devices usually used in solar inverters.

Problem: Many types of mains-powered equipment must be fitted with Power Factor Correction (PFC) circuitry to minimize energy loss and distortion. These PFC circuits typically combine a power MOSFET, a rectifier diode, an inductor, and a capacitor. Historically, engineers required expensive technology, such as silicon carbide (SiC) for the rectifier diode, to meet high efficiency certification levels such as 80 Plus Bronze, Silver or Gold.

Solution: This new technology now allows competitively-priced silicon diodes to be used in preference to SiC devices in boost-or-buck converters inside solar inverters or SMPS applications such as desktop PCs, servers or telecom base stations. Where the low recovery current of an SiC boost diode helps to minimize the MOSFET switching-on losses, BC2 fully removes these losses and recycles the energy linked to the recovery of the boost diode. This approach increases the efficiency by as much as 2% at approximately half the price of a solution using SiC devices.

Applications: Used in kits, these diodes permit the design of competitive high-efficiency circuits up to 2kW.

Platform: ST provides full design support for the new topology to help designers achieve the best performance and efficiency.

Availability: Currently available.

Comprehensive and advanced quality assurance measures for optimal yields from PV power plants

Klaus Kiefer & **Daniela Dirnberger**, Fraunhofer Institute for Solar Energy Systems (ISE), Freiburg, Germany

ABSTRACT

As it makes its way towards a non-subsidised market, the photovoltaic sector has to deal with decreasing margins. To ensure investment goals are met in spite of this, it is imperative that PV power plants generate optimal yields. Comprehensive quality assurance for PV power plants covers all phases of the completion process from the planning to system operation. This article explains the extent of standard quality assurance measures that include yield assessments, module measurements, system testing and yield monitoring. It outlines the potential of linking these quality assurance measures and stresses the importance of the measures themselves being of high quality. Up-to-date scientific findings from Fraunhofer ISE are presented in order to further optimise quality assurance measures.

Introduction

Comprehensive quality assurance covers all phases of the PV system completion process from the planning to system operation. The required measures of yield assessments, module measurements, system testing and yield monitoring are, in most cases, linked to the phases of planning, construction, handover of ownership and operation, respectively. These four measures form the PV Quality Assurance cycle developed at Fraunhofer ISE (see Fig. 1) where experts for all of these measures work closely together. Since 1990, Fraunhofer ISE has made important contributions to quality assurance of PV power plants [1] and has continuously improved quality assurance measures according to the latest scientific findings with its accredited laboratory for module measurements, CalLab PV Modules.

Yield assessments

Proper quality assurance begins in the planning phase, and an independent yield assessment is the mandatory first step along the route toward optimal yields. Once a site and a basic layout for a PV system have been chosen, yield assessments provide information on the site's expected performance. Two essential criteria to assess the PV system are provided: the specific yield and the performance ratio. The specific yield in units of kWh/kWp indicates the expected AC energy produced relative to the installed module peak power for a given site. The higher the expected site-specific sum of irradiance, the higher the specific yield. In contrast, the performance ratio is the parameter used to evaluate the technology used, and indicates how much of the energy that would be produced under ideal conditions is actually produced. The nameplate module peak power refers to ideal conditions that are described as Standard Testing Conditions (STC; 25°C, 1000W/m^2 and spectral distribution as in IEC60904-3 [2]). Furthermore, the result of a yield assessment includes exact information on the absolute yield as well as all contributing parameters affecting the yield, plus their uncertainty.

> "Modelling the influence of shading is a difficult task, as one shaded cell of one module can affect a whole string of modules."

The necessary input data for yield assessments are site-specific meteorological data, characteristics of the PV modules and inverters and details of the system configuration. High-quality yield assessments can only be performed with high-quality long-term meteorological data for the site in question. Fraunhofer ISE has extensive experience with evaluating data and compares different reliable data sources wherever possible.

The next step is the calculation of irradiance in the module plane with respect to module inclination and orientation as well as row shading and external shading. Modelling the influence of shading is a difficult task, as one shaded cell of one module can affect a whole string of modules. Fraunhofer ISE is currently developing a model to describe the electrical occurrences in a shaded solar generator at the cell level (see Fig. 2), for which initial results were presented at the 25th EU PVSEC in Valencia [3].

The second step is the simulation of the module's power at real conditions. Naturally, temperatures and irradiances under real conditions differ from STC, and as a result, the modules normally operate

Figure 1. A fully closed circle of quality assurance measures as provided by Fraunhofer ISE includes yield assessments, module measurements, system testing and yield monitoring.

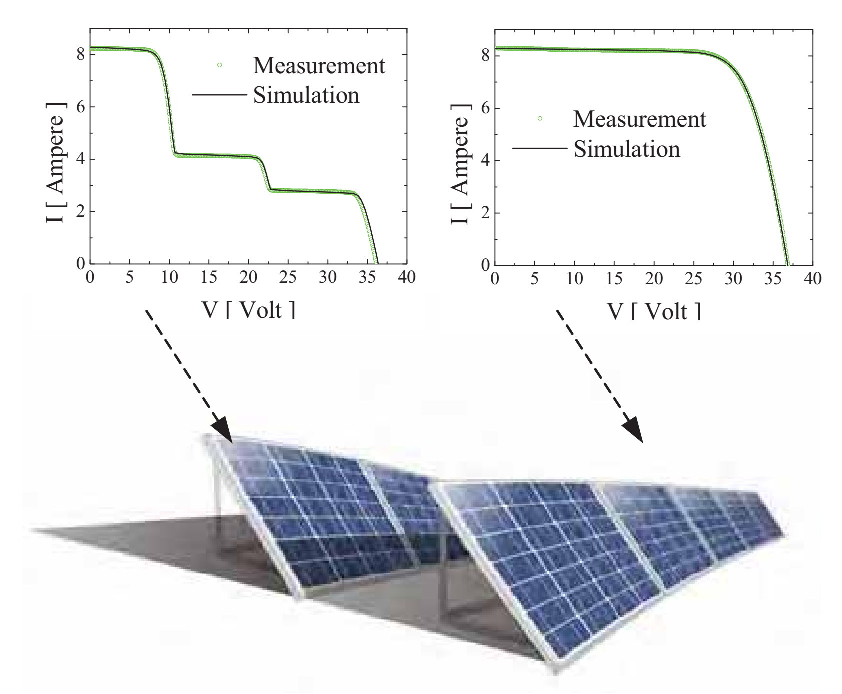


Figure 2. The first steps towards a comprehensive electrical model for the simulation of row-shading showed good results. The I-V curve of a shaded module (left) can be simulated just as accurately as thate of an unshaded module (right).

below nameplate power. The module characteristics needed for the simulation are temperature coefficient for module power and information on low light behaviour. Typical polycrystalline modules lose 0.45% of their STC power per degree and have about 95% of their STC efficiency at 200W/m^2 (20% of STC irradiance). Manufacturers' specifications are usually relied upon in the simulation of the components used, and judging and evaluating these specifications requires no small amount of background knowledge. Although there are several software solutions for PV system modelling commercially available where specifications are readily included, e. g. PVSYST or PVSOL, the most accurate results are to be expected from software which is continuously improved with new scientific findings.

A comparison of data sheet indications and measurements of CalLab PV Modules conducted in 2010 revealed considerable deviations. Deviating temperature coefficients do not have as large an effect on the estimated yield as deviations in low light behaviour, but from a scientific point of view, measurements are to be preferred compared to data sheet indications [4]. Fig. 3 shows the difference observed in calculated yield for two different sites when using measured data versus data sheet indications.

Module measurements

Once the planning of a PV system is finished and the module purchasing stage is approached, it must be assured that the modules meet their specifications. A reduction of 1% in the module's power over an operating period of 20 years represents a financial loss of around €60,000 in Germany for a plant 1MWp in size. In order to ensure that potential irregularities can be identified before system installation, measurements of module power in an accredited

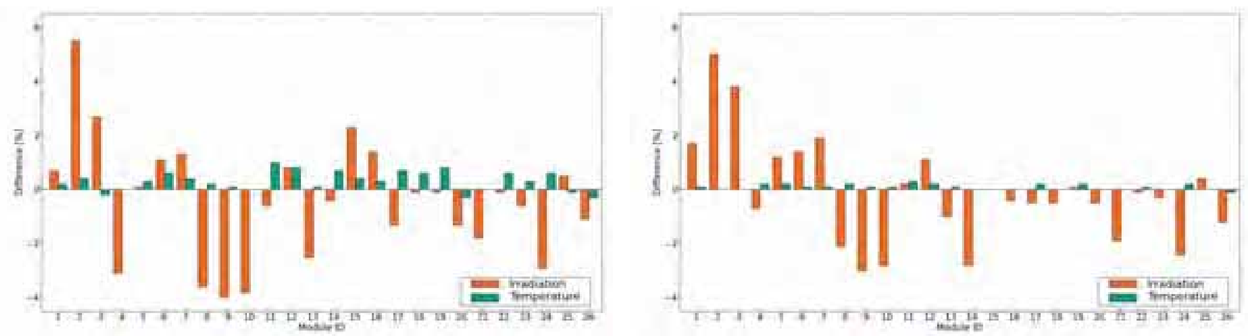


Figure 3. The predicted yearly energy yield differs for calculations based on measured and data-sheet-derived module parameters for a location in southern Spain (left) and northern Germany (right).

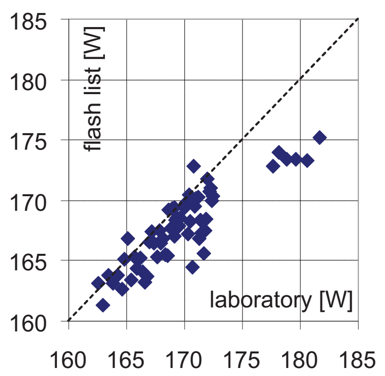


Figure 4. Module power according to flash list versus laboratory results. In this case, the manufacturer flash list underestimates the power of the modules, especially for modules with above-average power.

laboratory of a statistically representative number of modules are recommended. Since a purely number-related definition of "statistically representative" will result in an amount of measurements too high to be feasible, Fraunhofer ISE developed a special distribution-related procedure to select representative modules from the manufacturer's so-called flash list.

This flash list indicates the manufacturer-measured power of each module. For the selected sample of modules, which usually comes to about 0.1% to 1.0% of the total of modules, actual laboratory measurement results are compared to the flash list. This uncovers deviations between actual and manufacturer-indicated module power and thus enables reliable information on the power of all modules (Fig. 4).

Of course, it is crucial that the responsible laboratory works according to state-of-the-art standards [5–9] and can reliably provide small uncertainties. Prerequisites for the latter are traceable calibrations of all parts of the measurement equipment, an uncertainty calculation according to international standards [10, 11] and a thorough quality management including regular international round-robin tests. CalLab PV Modules provides measurement uncertainties of 2% to 3% for crystalline silicon modules and 3.5% to 5% for most thin-film modules, depending on the technology and measurement procedure chosen. Fig. 5 shows the results of a round-robin test conducted during the European Commission-funded integrated Project Performance (see also [12]).

Apart from module power, module characteristics as temperature coefficients and low light behaviour can also be verified in the laboratory. In 2009, CalLab PV Modules performed almost 4000 I-V curve measurements at STC, as well as more than 100 measurements of temperature-dependent module behaviour and around 80 measurements of low light behaviour.

Additional benefits of interlocking measures

Anonymously analyzed, this measurement database enables a detailed statistical overview on the state-of-the-art module behaviour which can be used for improvements of other quality assurance measures. The study in [4] for example would not have been possible without close collaboration of the responsible experts. For customers, this doubles the advantages: the close link boosts improvements which lead to smaller uncertainties for the standard quality assurance measures, and it also enhances the development of new services and flexibility with respect to special requirements. For example, smaller uncertainties of a yield assessment could be provided by basing it on measurements instead of data sheet indications. By performing laboratory measurements

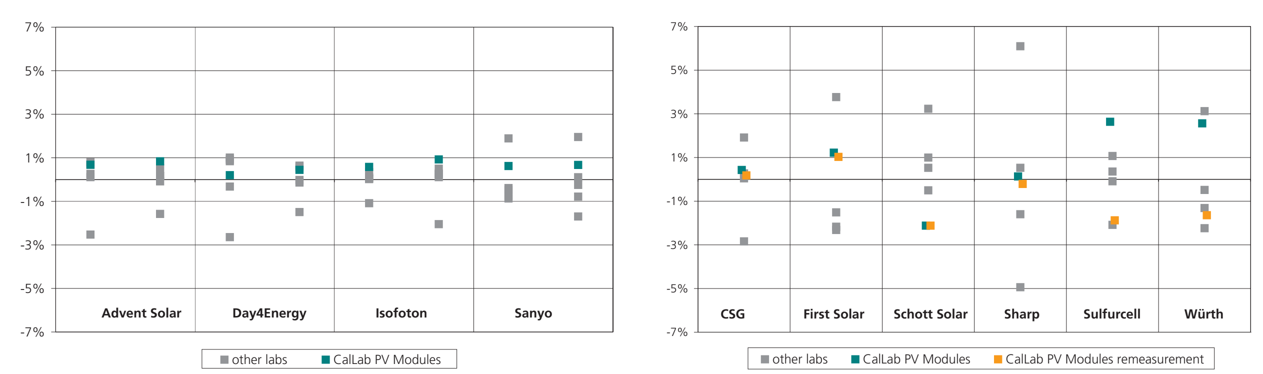


Figure 5. Left: Results of the final 'Performance' round-robin test for crystalline modules. CalLab PV Modules' results barely differ from the average of all participating laboratories. Right: Results of the final 'Performance' round-robin test for thin-film modules. CalLab PV Modules performed measurements at the beginning and at the end of the test in order to state the stability of the modules. The deviations in case of Sulfurcell and Würth modules are due to instability.

Figure 6. Fraunhofer ISE experts perform field I-V curve measurements.

of the modules, the actual power and the module characteristics can be determined and used as input for the yield assessment. In the case of modules performing slightly better than their nameplate power, which is no longer a rarity, the yield can be calculated more accurately. Using measured module characteristics further increases accuracy. As a result, the comparison of calculated Performance Ratio with results from PV system monitoring is more significant. Deviations can be relied upon as results of actual faults rather than uncertainties, and thus faults or non-optimal circumstances can be eliminated more comprehensively.

System testing

After the modules have been checked for their correct power, the focus turns to the installed system. Determining whether the PV system actually conforms to the specifications and delivers the predicted power requires comprehensive testing of the entire installed system. The test includes both general identification of defects and the documentation of deviations from the system specifications in the yield assessment, the latter being a not infrequent task. Specifications that strongly affect the yield, such as installed module power or system inclination and orientation, can also differ, leading to problems when the original yield assessment is taken as a reference for the altered system, for example in advertisements for closed funds.

In the event that doubts arise regarding to which aspect of a PV plant the yield assessment is referring, investors should always request an independent system test with a report comprising a comparison between the as-built and as-planned system. Getting yield assessments and system testing from one source can ensure that no significant false assumptions have been made about the plant. Concerning general defects or faults, stating and documenting them in an independent system test report facilitates taking timely measures and the lodging of possible claims against system suppliers or manufacturers. An independent test report confirming that a PV system is both in operation and free from errors is often a prerequisite for final payments.

> "The extrapolation requires module parameters such as temperature coefficients that have to be carefully determined for the module type in question."

System testing usually also necessitates a closer examination of the modules, which is carried out using an infrared camera in order to identify damaged modules or those that are not working optimally. Damaged modules register faults thermally by showing so-called hot spot effects, and can often be exchanged on a warranty basis.

Furthermore, system testing can involve an alternative to verifying the module power before installation. This might be necessary when no prior tests of module power were performed or when re-verification of module power is requested after a period of operation to check for degradation. In installed systems, module power is checked by measuring I-V curves of sub-arrays or individual strings of the solar generator (Fig. 6), which can reveal not only weak module power, but also faulty cabling.

The drawback of this approach compared to laboratory measurements is weather dependency: field I-V curve measurements can only be performed under clear blue skies with fairly high irradiance (> 800W/m^2), a result of the necessary extrapolation from actual operating conditions to STC [13]. The extrapolation requires module parameters such as temperature coefficients that have to be carefully determined for the module type in question. Close cooperation with CalLab PV Modules enabled a study on the variation of these parameters [14], benefitting the customer by providing both outdoor measurements with an indoor module characterization for minimal uncertainties of the outdoor measurements.

When field I-V curve measurements are performed according to international standards using primary calibrated measurement equipment and using thoroughly determined parameters, as presented in [14], measurement uncertainties of roughly 2.5% to 5% – depending on the conditions – are possible. Additionally, external influences such as soiling of the modules or electrical losses

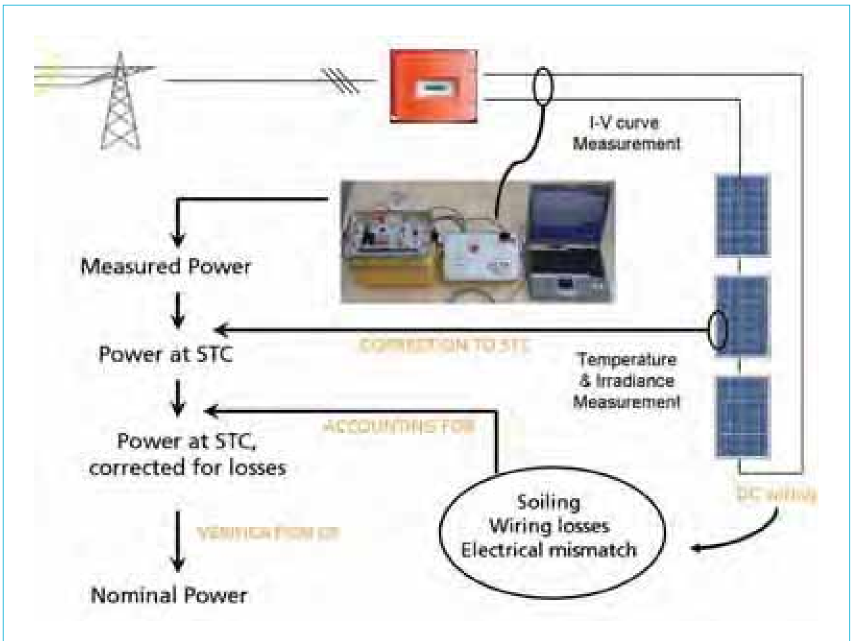


Figure 7. The three steps involved in verifying module power in the field I-V curves.

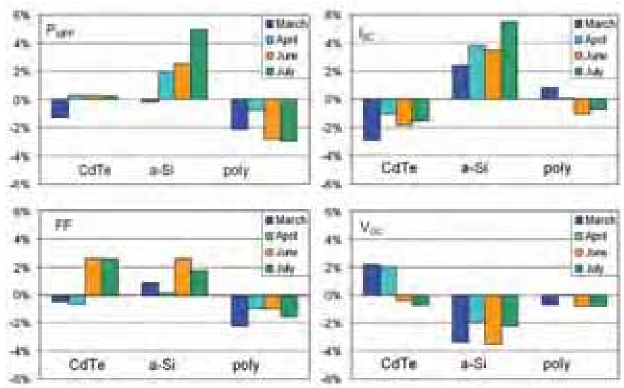


Figure 8. A good agreement of outdoor measurements performed on small PV strings during 2010 with CalLab PV Modules' measurements confirms the accuracy of thoroughly performed field measurements.

have to be considered (see Fig. 7). A comparison of outdoor and laboratory measurements performed at Fraunhofer ISE demonstrates that outdoor measurements are a reliable alternative for crystalline and thin-film technologies if properly performed (see Fig. 8). Outdoor measurements were conducted at a test field at Fraunhofer ISE; indoor measurements were carried out by CalLab PV Modules.

Yield monitoring

Assuming these quality assurance steps are carried out correctly, the PV system is likely to be in an optimal condition. But will this be reflected in the performance, and will things stay the same for the next 20 years? Independent long-term confirmation of the

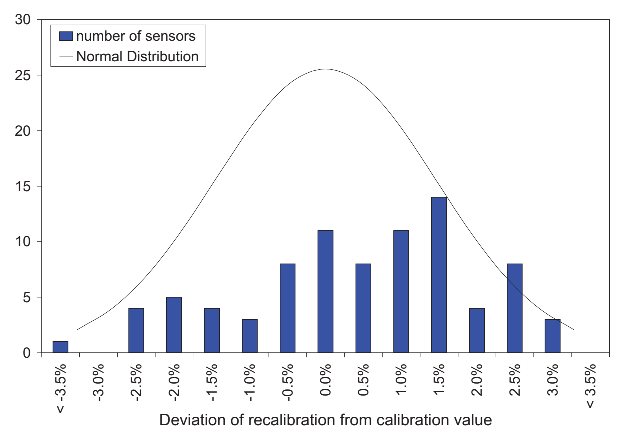


Figure 9. The recalibration value of the majority of recalibrated sensors lies within ±2%. The measurement uncertainty for cell calibrations is ±2% at a 95% significance level.
Below: A Fraunhofer ISE crystalline silicon reference sensor.

Figure 10. The Performance Ratio of the PV systems shown did not change significantly during several years of operation. Green dots are five-minute average values at high irradiance; orange dots are the reminders after outlier removal. The orange line is a regression line to the orange points and indicates the long-term change in Performance Ratio.

quality and performance of a PV system is provided by a state-of-the-art monitoring system. Such systems are comprised of at least one calibrated irradiance sensor – preferably a pyranometer installed to ensure coplanarity with the modules, measurement of AC system output and measurements of module and ambient temperature. Crystalline silicon cells can also serve as irradiance sensors in place of a pyranometer. Accurate DC measurements of one or several subsystems are recommended to enable a closer analysis of module and inverter operating behaviour.

The total electrical output is certainly the most important information provided by a monitoring system as the kWh level is the figure of most interest. However, optimal system performance cannot be judged from the yield because the yield is dependent on the available irradiance. An irradiance sensor with traceable calibration makes it possible to calculate the Performance Ratio, the value that indicates how close to the optimal level the system is running. The benchmark today is around 90%, based on a crystalline silicon sensor for systems in Germany. Needless to say, the reliability of the results depends fully on the irradiance measurement: if regular sensor recalibrations are not performed, or the calibration is not accurate, the results will be questionable. Fraunhofer ISE recommends recalibrations every two to three years as a state-of-the-art interval and applies sensors with a calibration uncertainty of ±2%. Fig. 9 shows the results of the recalibrations performed at a total of 85 irradiance crystalline silicon sensors.

Most monitoring solutions include data analysis where experts analyse the operating ranges of system components and inform clients of faults and underperformance if they occur. As a result, the client recognizes sub-optimal operation quickly and counter-measures can be taken to avoid loss of valuable yields. Internet access to the operating data of the system is offered by many providers.

Nevertheless, monitoring PV systems is not enough. Major project developers have been able to improve the performance of their systems significantly by continuous co-operation with Fraunhofer ISE – as has been documented by comparisons of the Performance Ratio of systems with continuous, comprehensive quality assurance and those which are subjected only to monitoring. Fraunhofer ISE has 20 years of experience in monitoring PV systems, starting in 1990 with the German 1000-Roofs-Programme [1]. Today, the number of Fraunhofer ISE-monitored PV systems has risen to more than 200, which comes to a total installed power of more than 38MWp.

Benefits of monitoring

The vast font of knowledge that is formed by the monitoring data is not only valuable to customers, but also to the providers of quality assurance measures. The data allows for answering questions about long-term behaviour, provides the unique possibility of 'quality assurance' for yield assessments by comparing estimated and actual yield, and offers the opportunity to compare the output of different plant concepts.

The results of yield assessments are compared to real-life system performance on a regular basis; for example, deviations of Fraunhofer ISE-predicted and -observed Performance Ratio in a study from 2009 were less than 2% for systems with no technical problems [15,16].

In order to officially confirm the findings that crystalline silicon PV systems operate on a stable level over many years, Fraunhofer ISE conducted a degradation study in 2010 [17] that comprised a cumulative total of 125 years of operation from 17 PV systems that had been in operation for five to 15 years individually. The results were promising: on average, no systematic degradation for poly- and monocrystalline silicon modules could be detected (Fig. 10). Therefore, it is unnecessary to assume any degradation for this kind of module in yield reports. The study included sensor recalibrations, which is not the case for other studies that are in conflict with the Fraunhofer ISE result [18].

In a similar cross-section analysis, the output of PV systems with the central and distributed converter concept were analysed [19]. Systems with distributed inverters in practice did not seem to offer a clear advantage, although there may be instances where they deliver a higher potential.

Conclusions

Each measure described in this article applies mainly for one phase of implementation of a PV project. Nevertheless, comprehensive quality assurance accomplishes additional benefits by closely interlocking the different measures. This refers, in the first instance, to the fact that none of the measures covers the examination of all relevant components and specifications. The location and layout of a PV system being approved by a yield assessment does not guarantee profit – the predicted yield can only turn into actual profits in the event that the modules meet their specifications. Even 'flawless' modules will not be capable of working optimally if system installation is not performed thoroughly.

> "Only a fully closed quality assurance circle guarantees that the full potential of a PV system is tapped from the beginning."

Similarly, an impeccably installed system will underperform in the long run if output-decreasing effects such as inverter problems or increased shading remain undetected because of a lack of system monitoring. Closing the loop, the average performance of a system with the potential to perform at an above-average level might not be recognised as insufficient without comparing monitoring results to a yield assessment. It becomes obvious that, on omission of any step of the quality assurance process, it may become harder to detect the reason for any underperformance of the system as the investment fails to pay off as planned after some years of operation. Only a fully closed quality assurance circle guarantees that the full potential of a PV system is tapped from the beginning.

Naturally, comprehensiveness of quality assurance can only be one side of the coin that buys optimal yield. It is just as important that the quality assurance measures themselves are of high quality, otherwise the results are unlikely to take a real step forward. Quality assurance measures must be subject to continuous improvements based on both up-to-date scientific findings and long-term real-life experiences. This challenge can be best met if the different quality assurance measures are provided from one source, as Fraunhofer ISE's up-to-date scientific findings show. The additional knowledge that is built up by the close interconnection between the measures is a surplus for every customer.

References

[1] Becker, H. & Kiefer, K. et al. 1997, "Five years of operational experience in the German 1000-Roofs-PV Programme – results of monitoring and system inspection", *Proc. 14th EU PVSEC*, Barcelona, Spain.

[2] IEC60904_3 Ed.2 (2008-04): Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data.

[3] Elies, S. et al. 2010, "Influence of row-shading on the performance of PV systems – simulation and measurement", *Proc. 25th EU PVSEC*, Valencia, Spain.

[4] Müller, B. et al. 2010, "Simulation of irradiation and temperature dependent efficiency of thin film and crystalline silicon modules based on different parameterization", *Proc. 25th EU PVSEC*, Valencia, Spain.

[5] IEC60904-1 Ed.2 (2006-09): Photovoltaic devices – Part 1: Measurement of photovoltaic current-voltage characteristics.

[6] IEC60904-2 Ed.2 (2007-03): Photovoltaic devices – Part 2: Requirements for reference solar devices.

[7] IEC60904-4 Ed.1 (2009-06): Photovoltaic devices – Part 4: Reference solar devices – Procedures for establishing calibration traceability.

[8] IEC60904-7 Ed.3 (2008-11): Photovoltaic devices – Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices.

[9] IEC60904-9 Ed.2 (2007-10): Photovoltaic devices – Part 9: Solar simulator performance requirements.

[10] ISO/IEC Guide 98-3:2008: Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement.

[11] Müllejans, H., Zaaiman, W. & Galleano, R. 2009, "Analysis and mitigation of measurement uncertainties in the traceability chain for the calibration of photovoltaic devices", *Measuring Science and Technology*, Vol. 20, No. 7, 075101, 1-6.

[12] Herrmann, W. et al. 2010, "PV module output power characterization in test laboratories and in the PV industry – Results of the European Performance Project", *Proc. 25th EU PVSEC*, Valencia, Spain.

[13] IEC60891 Ed. 2 (2009-12): Photovoltaic devices – Procedures for temperature and irradiance corrections to measured I-V characteristics.

[14] Dirnberger, D. et al. 2010, "Uncertainty of field I-V-curve measurements in large scale PV-systems", *Proc. 25th EU PVSEC*, Valencia, Spain.

[15] Müller, B. et al. 2007, "Are yield certificates reliable? A comparison to monitored real world results", *Proc. 22nd EU PVSEC*, Milan, Italy.

[16] Müller, B et al. 2009, "More insights from the monitoring of real world PV power plants – A comparison of measured to predicted performance of PV systems", *Proc. 24th EU PVSEC*, Hamburg, Germany.

[17] Kiefer, K. Et al. 2010, "A degradation analysis of PV power plants", *Proc. 25th EU PVSEC*, Valencia, Spain.

[18] Haeberlin, H. & Schaerf, P. 2010, "Long-term behaviour of grid-connected PV systems over more than 15 Years", Proc. *25th EU PVSEC*, Valencia, Spain.

[19] Kröger-Vodde, A. et al. 2010, "Distributed vs. central inverters – A comparison of monitored PV systems", *Proc. 25th EU PVSEC*, Valencia, Spain.

About the Authors

Klaus Kiefer (Dipl.-Ing.) has been working for Fraunhofer ISE since 1987. In 1994, he became leader of the Grid-connected energy systems group, which consists of 40 employees. He is one of the most experienced scientists in the field of quality assurance for PV systems and modules.

Daniela Dirnberger (Dipl.-Ing.) is doing her doctorial thesis in the field of characterization of thin-film modules. She joined Fraunhofer ISE's Grid-connected energy systems group in 2008.

Enquiries

Fraunhofer Institute for Solar Energy Systems (ISE)
Heidenhofstraße 2,
79110 Freiburg im Breisgau,
Germany
Tel.: +49 (0) 761 4588 5344
Email: stephanie.frey@ise.fraunhofer.de

Pre-construction, engineering and installation cost of utility-scale module installations – part 2

Angiolo Laviziano, **Josh Price** & **Ethan Miller**, REC Solar, San Luis Obispo, California, USA

ABSTRACT

PV industry module and component manufacturers have brought down costs significantly over the last four years. This trend is clearly evident as most publicly traded companies continue to grow revenue despite falling module and component prices. However, it is far less clear how downstream system integrators are handling the drop in system prices and contributing to value creation. System prices are generally higher in the U.S. than in Europe despite lower module prices in the U.S. This disparity often raises questions on the part of European PV professionals where these costs come from, and secondly, what have U.S. system integrators done to reduce costs. This article is the second of a two-part series shedding light on how U.S. integrators contribute to a decreasing installed-PV-system cost roadmap by championing value creation in the downstream segment. Focusing on the residential market segment, Part I delved into activity cost savings through innovation in engineering and construction [1]. Part II illustrates how changes in marketing and sales, rebates, interconnection, supply chain management and customer support have evolved considerably over the last several years to result in reduced costs.

Competitive pressures along with falling rebates in the U.S. residential market have forced a focus on cost reduction through the value chain. While the largest single cost reductions have been module costs, there have been major improvements in how PV systems are marketed, sold, installed and supported, resulting, in aggregate in a similarly high level of cost reduction. For PV system integrators, in addition to the direct project costs such as engineering and design innovation discussed in Part I of this article, indirect administrative costs are equally important including marketing & sales, rebates, interconnection, supply chain management, and customer support.

Based on analysis of internal REC Solar costs over the past five years, increased volume, process improvement and IT automation, particularly Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), and web-based applications and services have driven indirect project overhead costs down by about 40% as shown in Table 1.

Business process	2005 $/Watt	2010 (e) $/Watt	% Change
Lead acquisition	0.48	0.27	-44%
Sales close time	0.56	0.39	-30%
Rebate	0.09	0.03	-67%
Interconnection	0.06	0.02	-67%
Material handling	0.08	0.05	-38%
Customer support	0.04	0.02	-50%
Total	1.31	0.78	-40%

Source: REC Solar internal analysis/estimates

Table 1. Estimated reduction in cost for key indirect project costs in the downstream integrator business.

Changes occurring in each of these business processes are discussed further in this paper.

Marketing & sales

Marketing and sales activity centres on finding potential buyers, educating them, providing them with accurate proposals, and tracking the progress of opportunities to close sales predictably over time. Each of these processes has undergone and continues to undergo tremendous transformation primarily due to web and customer relationship management (CRM) software automation. This automation has become critical in creating more predictable, accurate demand forecasts tied to proper incentives and commission structures for the sales organization. Predictability is critical to achieving success in other areas of the business. Methods like sales and operations planning (S&OP) rely on frequently updated sales plans to drive production, inventory, and customer lead-time plans, so as to manage the resulting ongoing financial plan for the company.

Five years ago, finding buyers, or 'lead acquisition', relied heavily upon in-person seminars, home shows, and local print advertising. Home visits were often conducted in person by sales representatives to call on interested solar prospective customers. Today, channel partnerships with retailers like COSTCO, Home Depot and other major chain stores are common with in-store kiosks providing store visitors with information and the confidence that comes from a major brand name. Web advertising has become a major new source of leads with the emergence of 'pay-per-click' search-engine keyword buys and other increasingly sophisticated techniques. Search engine marketing is especially important as it allows for targeting of specific geographies. Google continues to drive down cost per lead from as much as US$200 or more from offline sources five years ago to as little as US$40 or less today. Radio and local television advertising are also increasingly common in more mature markets.

Once a lead turns into an opportunity, trained sales specialists are required to handle the opportunity. Five years ago, multiple home visits were required as prospects were educated in person on the various aspects of a solar electric system, resulting in a significantly higher cost of sales. Today, prospects are far better informed as they are initially routed to centralized call centres manned with pre-sales or inside sales representatives that provide solar education by phone. Representatives also typically use an online quote tool to provide customers with a preliminary evaluation of their rooftop and an approximate cost of a solar electric system. Such tools

Figure 1. An example of a quote tool used by customers online in advance of a home visit by a salesperson.

Figure 2. Online quotation tool example used by sales specialists in advance of a home visit.

combine Google satellite imagery with the customer's electricity consumption to provide a personalized quotation for their home (see Fig. 1). As a result, less time is required by field representatives to educate the customer and move a customer to close, thereby allowing for more calls and more closed sales by field representatives – and further driving down the cost of customer acquisition.

"The education and sales process has become more efficient and effective as the public has grown more familiar with solar estimation tools."

Automation is also available to support preparation of formal proposals used by sales specialists once they visit a prospective customer's home. These tools reduce the amount of time the sales specialist spends creating proposals and increases the amount of time spent closing sales. An example of a formal quotation tool involving a lease option used by REC Solar salespeople is shown in Fig. 2.

All in all, the education and sales process has become more efficient and effective as the public has grown more familiar with solar estimation tools and the web in general as a source of consumer research for major purchase decisions. Consequently, we regard web-based marketing and online quote tools, along with partnerships with major stores, to be primarily responsible for the cost reduction of an estimated 44% for Lead Acquisition as show in Table 1.

Furthermore, as an integrator grows in size, the number of potential sales leads grows into the tens of thousands and the number of sales opportunities into the thousands. Each must be tracked by both inside sales teams and outside sales specialists to ensure the sales process is managed, sales commissions are generated, and accurate demand forecasts are provided to management and other areas of the business. Only through tracking and the establishment of metrics that guide evaluation of respective sales and marketing activities can refinements be made to these activities to further reduce lead generation and customer acquisition costs. A dedicated CRM system like Salesforce.com or SugarCRM is essential to scaling a sales organization to the national level. As shown in Table 1, a reduction of as much as 30% in the Sales Close Time between 2005 and 2010 has occurred due to the successful implementation of CRM systems to support the sales organization.

Rebates

Rebate requirements differ from utility to utility and continually change as programs, policies and systems are adjusted and amended. Scaling operations nationally requires that PV system integrators have experts on staff to build relationships with the various utilities throughout the country.

Five years ago, firms could gain a competitive advantage by 'floating' the rebate portion of the system cost, thereby reducing end customers' up-front cash payment. Today, this has become common practice. The current sophistication is in maximizing cash flow in relation to rebate submissions across various utilities. To this end, the goal is to file rebate applications correctly and in a timely fashion. While this is easy for a small number of rebate applications, it becomes significantly more complex if the number of customers across various utilities increases.

Sophisticated installers incorporate the rebate information directly into the proposal tool, which allows for the uploading of necessary forms directly to those utilities that have online rebate systems. In California, for example, the three major, Investor-Owned Utilities – Pacific Gas and Electric, Southern California Edison, and San Diego Gas & Electric – have banded together to create PowerClerk, an online rebate tool for all installers. While these three utilities cover much of the state, there are many others territories that they do not cover (see Fig. 3).

Table 2 provides a summary of the number of utilities and county government organizations that must be managed from

State/Region	Participating utilities
CA-N	17
CA-S	14
AZ	3
CO	9
NJ	1

Table 2. Numbers of utilities involved in rebates in areas served by REC Solar residential business.

Figure 3. One aspect of managing rebates and interconnections is the submission of forms to the electric utility depending on region; in this case, for the State of California.

a rebate, interconnect, and permitting perspective in order to best serve the regions where REC Solar currently installs residential systems.

Keeping up with the complexity of rebates, interconnections and permitting requires dedicated staff and document management automation system. For larger integrators it requires integration of automated rebate application systems with an enterprise resource planning (ERP) system to ensure the seamless transfer of data between the different parts of the company, particularly sales, order management, rebate administration and finance. Only with this level of seamless connection and the ability to view associated metrics is a system integrator able to identify the levers to optimize the rebate-related cash flow.

The impact on cash flow can be sizable. The cumulative impact of a hundred or more system rebates floated over six, nine and, in a worst-case scenario, 12 weeks, is shown in Table 3.

As Table 1 shows, we attribute a 67% reduction in the rebate costs between 2005 and 2010 to the successful implementation of an ERP system to automate rebate processing, in addition to automation tools implemented by large utilities such as the PowerClerk system in California.

Interconnection and permitting

As with rebates, the utilities regulate interconnection in a variety of ways, each of which merit the employ of an interconnection expert dedicated to monitoring the changing environment of interconnection requirements. A key to achieving efficiency in this area is specialization which favours medium-sized and large system integrators that can both afford a dedicated team focusing on process administration and optimization, as well as the investment in fully-fledged ERP-systems like Great Plains or Oracle. An ERP system provides visibility into and management of sophisticated business processes, especially as these processes need to be integrated with tens, even hundreds of utility systems.

By maintaining centralized databases of requirements for each utility, the integrator is able to submit the proper documents the first time in any jurisdiction, avoiding costly corrections which consume additional time and prolong the time required to float the rebates.

Variations in policies and procedures occur regularly across the many programs nationwide. Staying ahead of these changes from an operational perspective requires dedicated expertise in monitoring policies and procedures; omitting this vigilance can increase the cost of operations significantly in terms of time spent by personnel tracking down documents or completing forms a second or third time. As with those permitting processes required by municipalities, interconnection involves submission of an application regarding the site, the customer, technical specifications of the equipment, along with a single line drawing and a site plan that shows where the array and the inverter will be placed.

For installers interconnecting more than one system a day, an automated document management system is essential to cost-effectively manage the process. Large, nationwide system integrators can interconnect more than six PV systems

	$30M in rebates	$50M in rebates	$100M in rebates
Six-week float	$103,846	$173,077	$346,154
Nine-week float	$155,769	$259,615	$519,231
Twelve-week float	$207,692	$346,154	$692,308

Table 3. Opportunity cost of rebate float for varying lengths of time assuming an interest rate of 3.0% (Source: REC Solar calculations).

State/Region	Utility interconnection	Counties
CA-N	31	43
CA-S	25	15
AZ	6	15
CO	57	64
NJ	4	21

Table 4. Approximate number of utilities and County Governments to be managed in areas served by REC Solar residential business.

a day. This would not be possible, or cost effective, without automated document management systems.

As shown in Table 1, we attribute a 67% reduction in the interconnection process between 2005 and 2010 to the successful implementation of an ERP system and other proprietary IT and document management systems.

Supply chain management

Increased residential volume has provided the opportunity for mature supply change management and distribution solutions to be applied to PV system integrators. By leveraging centralized supply chain management and distribution services, local inventories can be minimized. Variations in construction schedules caused by permitting delays, customer requirements, rebate application status and utility interconnection authorization can often lead to stagnant inventory in the residential branch. Centralized supply chain management provides consistent demand that would otherwise come at a potentially very high cost to the smaller integrator.

> "By leveraging centralized supply chain management and distribution services, local inventories can be minimized."

Further cost reduction advantages come from utilizing homogeneous product types within specific regional residential areas. This allows companies to accept a variety of module watt classes and product manufacturers while keeping consistency within a regional area. Aligning regional forecasts with manufacturer production capacity can result in a streamlined supply chain with minimized change orders. Nonetheless, change orders are common, costly and will continue to be a challenge in the future.

> "Through web-based tools, a branch or smaller integrator can check on inventory and shipping status to allow for just-in-time product delivery."

Small and sometimes also medium sized installers tend to rely on distributors as summarized in Table 5. Larger Integrators rely on a number of suppliers and manufacturers they deal with directly, up to 200 or more, requiring specialized, dedicated staff to administer.

For smaller and medium-sized system

Supplier type	Small installer (one installation per week)	Medium installer (five installations per week)	Large integrator (25 installations per week)
Commodity parts	10%	30%	5%
Distributor	90%	70%	10%
MIR manufacturer	0%	0%	80%
Internal pre-assembly	0%	0%	5%
Total # of suppliers	~30	~70	200+

Source: REC Solar analysis and estimates

Table 5. Variation in the supply chain for small, medium and large installers/integrators.

Photo courtesy of Karina Marchese

Figure 4. REC Solar monitoring operations incorporate special purpose monitoring software providing real-time status and alerting.

Figure 5. Value-added distribution partners provide easy access to the hundreds of suppliers via the web.

integrators, many of the benefits of the supply chain management strength of a large solar integrator can be gained through working with the right value-added distribution partner. This can allow a contractor to get the value of a broad product selection under a consolidated supplier who provides access to the right product, manages logistics and grants payment terms. Through web-based tools, a branch or smaller integrator can check on inventory and shipping status to allow for just-in-time product delivery, resulting in a lower cost for smaller integrators versus the alternative of carrying inventory and higher working capital investment.

Overall, the materials handling process between 2005 and 2010 saw a 38% reduction as a result of the implementation of an ERP system to support the supply chain management process spanning the organization and its suppliers (see Table 1).

Customer support & warranty

Handling customer service issues and addressing warranty work can be an expensive task with high opportunity cost. Large-scale residential integrators have centralized this service allowing for minimal interruption to field installation teams. Through standardized techniques (as are common in many other industries), the customer service department can minimize on-site troubleshooting by solving a majority of issues over the phone. If an on-site visit is needed, required equipment and the schedule is coordinated with a cross-trained and certified local installer to eliminate the need for dedicated local service technicians. Ideally, this would be combined with commissioned replacement inventory for components like inverters in order to avoid multiple on-site visits. The combination of more efficient means of service, minimization of on-site visits, and a perspective that considers longer-term system maintenance all combine to minimize customer service costs.

Additionally, low-cost advanced monitoring systems allow for increased consumer intelligence regarding system performance. Consumer-facing web-based monitoring solutions minimize customer inquiries by way of self-service data availability. Monitoring solutions that are tied to a centralized monitoring service also allow the customer service team to quickly identify and resolve issues. The result of this data availability across the various parties is usually higher and more immediate service at a lower cost.

The data in Table 1 show that a 50% reduction in the cost of customer support between 2005 and 2010 was brought about by the successful implementation of a proprietary monitoring and tracking system in conjunction with the CRM system.

Conclusions and outlook

As the PV industry continues to mature in the U.S., there will continue to be opportunities for streamlining the integration business. System costs would not be at the levels they are today and we would not have such a thriving residential solar market without a laser-focused effort on reducing system costs with respect to marketing, sales, rebates, interconnect, supply chain management and customer support functions. Between 2005 and today, the total cost for these functions has come down by 40% from US$1.31/W to US$0.78/W, with the largest contribution being made via internet-based automation of marketing and sales tools.

Furthermore, the ability to scale operations to the national level requires implementation of an ERP, CRM and other enterprise software systems to effectively manage the complexity of the operations as they span the many suppliers, warehouses, trucks, sales people, installers, utilities and government entities involved in any single project. Finally, based on the improvements made over the last five years projected over the near future, we are confident in stating that combined with continued innovation in the design and engineering efficiencies discussed in Part I of this article [1], the total cost reductions required to maintain a healthy residential market in the US should be achievable despite the rapid decline of rebates.

Reference

[1] Laviziano, A. & Miller, E. 2010, "Pre-construction, engineering and installation cost of utility-scale module installations – part 1", *Photovoltaics International*, Vol. 9, pp. 207–210.

About the Authors

Angiolo Laviziano is the CEO of REC Solar and has over 10 years' experience in the global solar market. He joined REC Solar in 2005, prior to which he was one of the founding members at Conergy AG and worked as CFO and Chief Sales Officer. Before that he worked at an investment bank in Hong Kong and at the Prime Minister's Office of Laos. Angiolo has presented several papers in the PV field, and has a Master's degree in business from the Koblenz School of Corporate Management in Germany and a Ph.D. degree in financial economics from the University of Hong Kong.

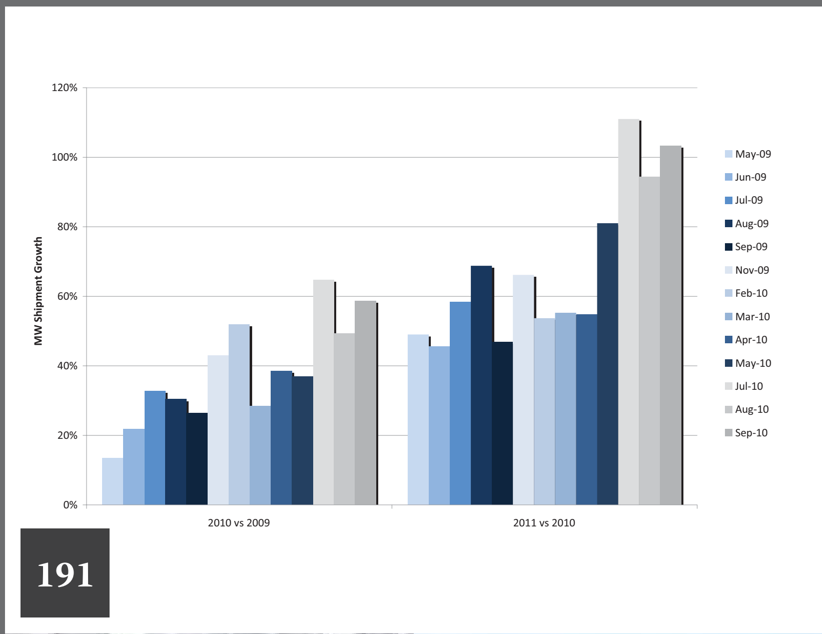
As VP of Operations at REC Solar, **Ethan Miller** oversees the implementation of all solar projects, including branch operations, engineering, installation and service, as well as driving the company's expansion and product development. Since 2001, he has managed the engineering and installation of all REC Solar projects, and has a certification from the North American Board of Certified Energy Practitioners (NABCEP). He has a B.S. in mechanical engineering with a focus in renewable energy from California Polytechnic State University.

Josh Price is Vice President and General Manager, Residential and Light Commercial for REC Solar including P&L, sales, engineering and construction for all branches in California, Oregon, Colorado, New Jersey and Arizona. Since joining REC in 2007, Josh has over 20MW of roof and ground mount solar experience. He also has over eight years of construction project management experience including his prior experience while at Pulte Homes Inc, the nation's largest home builder. Josh holds a B.S. in construction management with a minor in business from California Polytechnic University, San Luis Obispo.

Enquiries

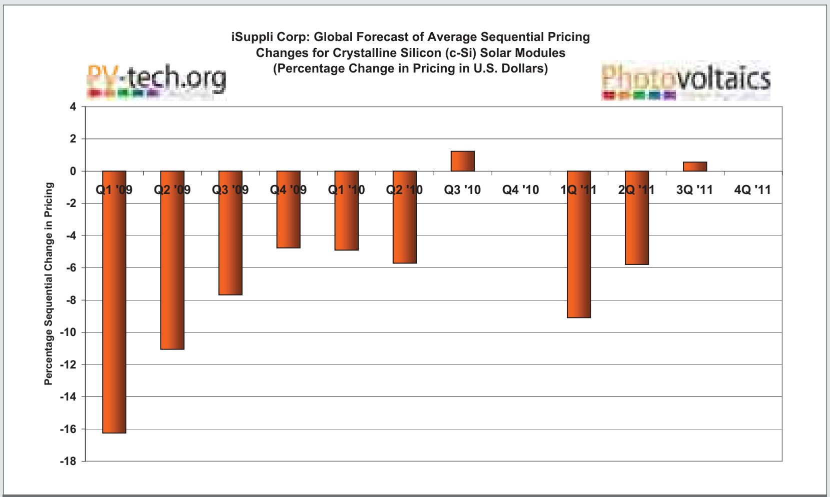
Tel: +1 805 709 2768
Email: p.kerans@mainstreamenergy.com

Market Watch



iSuppli trims solar installation forecast but 2010 remains strong

Feed-in tariff changes are to negatively impact photovoltaic installations in France, Belgium, Spain and Czech Republic in 2011, according to a new report from iSuppli. However, the robust and stronger-than-expected growth of the German market for 2010 and 2011 will keep overall installation figures up compared with previous years. The market research firm expects worldwide installations in 2010 will amount to 15.8GW up from iSuppli's previous outlook of 14.2GW, representing 118.7% growth from the 7.2GW installed in 2009. In 2011 installations will amount to 19.3GW, down slightly from its previous forecast of 20.2GW.



Global forecast of average sequential pricing changes for c-Si solar modules.

Stefan de Haan, senior analyst for iSuppli, said, "In the first half of 2010, Germany installed 3.9GW worth of solar systems. Germany's surprising performance was driven by excellent investment conditions and demand pull-forward prior to a cut of the country's feed-in tariff incentive program in July."

The strong market performance next year is expected to be followed by a seasonal slowdown in installations during the first six months of 2011, with module prices declining enough to stimulate demand. "The solar market frequently suffers a slowdown in the first quarter of a year, and 2011 will be no exception," de Haan said. "This deceleration will cause inventories of PV solar modules to rise – and pricing for solar modules to drop, boosting sales for the entire year."

The market research firm is expecting average worldwide pricing for crystalline solar modules to decline by 9% in the first quarter and by 6% in the second quarter. The result will produce system prices of €1.9 to €2.7/W in Germany - depending on the system size. Once this level is reached, demand will pick up again. iSuppli is reiterating its expectation of a strong market in Germany next year with 9.4GW worth of new installations.

Premier Power 2010 revenue to date exceeds the whole of 2009

Premier Power Renewable Energy has reported strong third quarterly results for the period ending September 30th, 2010. Revenue for the quarter increased 350% to US$28.3 million, up from US$6.3 million in the same period of 2009, and US$19.3 million, or 213% higher than revenues achieved in the second quarter of this year.

These positive revenue results were driven by strong performance from Premier Power's European segment, which posted revenues of US$21 million from its distribution and value add consulting (DVAC) practice, as well as from ongoing EPC work on the company's European projects pipeline. The North American Commercial segment also posted revenue of US$3.6 million in the third quarter, its largest quarter since 2008.

Daqo New Energy reports strong operating results for Q3'10

Daqo New Energy, the China-based polysilicon manufacturer, has revealed positive financial results for the third quarter ended September 30th, 2010. As well as recording new revenues over 20% higher than the previous quarter, the company also brought in US$17.7 million net income, attributable to Daqo New Energy shareholders.

Total net revenues for the quarter reached US$63.2 million, an increase of 108.5% year-over-year. Gross margin came in at 42.5%, compared to 37.0% in the second quarter of 2010 and 31.6% in the third quarter of 2009.

Polysilicon shipments were approximately 973MT, representing an increase of 8.6% from the second quarter of the year, and a 118.8% increase year-over-year. Diluted earnings per share were recorded at US$0.13, compared to US$0.08 in the second quarter of 2010, and US$0.06 in the third quarter of the year before.


Raw polysilicon.

Suniva granted US$15 million loan guarantee from U.S. Export-Import Bank

Suniva has received a US$15 million working capital loan guarantee from the U.S. Export-Import Bank. The company will use all three of the Bank's products, which include project financing, receivable insurance and a working capital loan guarantee. The Export-Import Bank will guarantee 90% of a US$15 million line of credit imparted from Comerica Bank, which allows Suniva to lock in supplementary working capital towards the expansion of its export business.

SunPower moves headquarters to larger premises in San Jose

SunPower has revealed that its new headquarters will remain based in San Jose, CA. The company is to relocate to an existing three-building site on Rio Robles next year in order to accommodate long-term growth plans. By renovating the buildings, with a rooftop solar system and solar carport alongside other renewable features, SunPower aims to achieve Leadership in Energy and Environmental

Design (LEED) gold certification.

In order to accommodate the move, the City of San Jose has prepared a US$2.5 million economic incentive package for SunPower over five years for permitting, workforce assistance, and utility and sales tax reimbursement, which is subject to approval of the City Council. The company is additionally investigating a US$30 million low-interest loan that would go towards building improvements and capital equipment. This loan would be funded by stimulus dollars made available by the American Recovery and Reinvestment Act of 2009, and provided to the State of California. SunPower employs approximately 300 employees at the San Jose headquarters, with expected growth to more than 500 over the next few years.

Etrion acquires final Montalto park tranche, reports US$7.0m in revenues for Q3'10

Etrion has released its interim consolidated financial statements and related management discussion and analysis for the three and nine months ended September 30th, 2010 and 2009. Highlights for the third quarter include closing the acquisition of the 24MW first tranche of the 33MW Montalto solar park in Italy – subsequently closing the final 9MW tranche – recording US$7.0 million in revenues and completing a US$15 million private placement of shares to meet Toronto Stock Exchange listing requirements.

Etrion also reported a net loss of US$6.4 million (loss per share of US$0.04) compared to a net loss of US$50.9 million (loss per share of US$0.32) for the three months ended September 30th, 2009. For the nine months ended September 30th, 2010, the company reported a net loss of US$14.1 million (loss per share of US$0.09) compared to a net loss of US$54.1 million (loss per share of US$0.34) for the nine months ended September 30th, 2009.

Due to the company's new business focus, the results for the first nine months of 2010 are not comparable to the prior year. Revenues from the Montalto 24MW solar park have only been recognized since the date of acquisition on August 5th, 2010. The acquisition of the Montalto 9MW solar park has not been included in the company's financials for the third quarter as the transaction closed after September 30th, 2010.

The 33MW Montalto solar park in Italy.

Bernreuter Research projects 27.5GW of solar-grade polysilicon available in 2011

Regardless of what market research data you rely on, the analysts agree: the photovoltaics market is expected to grow considerably in 2010. Even the most hawkish of forecasts would therefore expect PV installations to almost double from 2009, creating a demand somewhere near 14GW in 2010. According to Bernreuter Research, which specializes in tracking the polysilicon market, polysilicon production in 2010 should be sufficient to produce the equivalent of 17GW of c-Si modules.

However, the continued rapid growth in demand for solar PV is putting supply pressures back onto the polysilicon producers as supply and demand tightens. For several years, polysilicon was in short supply, forcing prices to reach as high as US$450/kg in mid-2008. Although multibillion-dollar investments have been made in new polysilicon production by established as well as new entrants to the market, PV growth has intensified and spot-market prices for polysilicon have been rising since midyear to over US$70/kg, compared with US$50/kg previously.

The firm recently evaluated more than 40 market analysts forecasts from 2008 through 2010; almost all of them show installation figures well below the actual results in 2008 and 2009, which Bernreuter thinks will happen again in 2010. As the PV industry continues its strongest growth cycle ever, the huge investments in new polysilicon production capacity are keeping pace.

Solar installations in Germany slowing, says Barclays Capital

The rapid growth in solar PV installations in Germany is slowing down as the effects of the EEG FiT reductions and farmland restrictions begin to bite, according to Barclays Capital financial analyst Vishal Shah. New figures released by Germany's Bundesnetzagentur, for September 2010, show that 493MW was installed, while the figure for August (361MW) was not much higher. Cumulative installations through September 2010 were said to have reached 5.3GW, significantly higher than the total for 2009, which was approximately 3.7GW, suggesting 2010 levels could be in the range of 7GW to 8GW, according to Shah.

Shah noted that Germany installed a total of 1.5GW in the third quarter of this year, while only 236MW of the projects were greater than 1MW in size. Large project installations actually declined from 452MW in the second quarter (vs. total Q2 installations of 3.1GW), indicating that the EEG revisions are indeed hitting large-scale ground-mounted projects.

Barclays Capital analyst said in a note to investors that he expected large-scale installations to decline sharply in the fourth quarter, which suggests the market may have peaked entirely. However, Shah also noted that there were some positives from the data. He believes that the feed-in tariff cuts are working and decreases the probability of a potential hard cap being introduced in 2011. Also, the weaker-than-expected German installations suggest German PV firms will further focus business expansions overseas, helping to develop more markets overall.

GTM Research issues new report stating 92% growth in module manufacturing during 2010

GTM Research released a new report, PV Technology, Production and Cost Outlook: 2010-2015, which among other research, concluded that global solar PV panel production will surpass 15GW this year alone. The report details forecasts for production volume, component prices, an examination of PV technology characteristics, producer-specific manufacturing costs and business model analysis among other investigative studies for the whole PV supply chain.

Shyam Mehta, the report's author and a senior solar analyst at GTM Research, said, "The supply chain has been bombarded with opportunities from scaling demand, and the industry has responded to this competitive dynamic with new, low-cost technologies and more sophisticated business models."

In Mehta's report, he advises that subsidy cuts in key PV markets will lead to slower growth starting next year, but panel production is on track to go above 25GW by 2013. Additionally, panel prices have the potential to be less than US$1 per watt by 2012 for select technologies as the competition between suppliers stiffens. The report specifically forecasts that "the industry will reach its next economic milestone by 2012 when panel prices for the retail market will themselves fall below US$1/W."

In addition to its forecast research, GTM also compiled a list of the top 15 most successful firms measured by panel production, manufacturing costs, efficiency and bankability by 2013, with First Solar, Trina Solar and Yingli Green Energy rounding out the top three.

Bloomberg report puts U.S. solar sector on brink of immense growth

According to a new report, "Quantifying the US solar market: system returns and new build projections", by Bloomberg New

News

Energy Finance, the U.S. solar market is poised to make impressive growth over the next decade. Bloomberg estimates that solar-powered generating capacity could reach 4.3% of the country's power capacity by 2020. However, its success in reaching such a lofty goal lies in the industry's ability to draw US$100 billion in investments.

The decrease in equipment costs and the increased support from the government have helped lead the country to be at this point of significant growth and research from Bloomberg suggests that the 1.4GW of installed solar capacity the U.S. holds today could go up to 44GW by 2020. Large-scale solar thermal projects have the potential to increase from the current 0.4GW to 14GW by 2020, while PV can see an annual growth rate of 34% to 30GW in the next 10 years.

Bloomberg acknowledged that the typical PV module's cost has dropped by more than 50% over the past two years, but they also deduced that solar power is still a pricey option. During its analysis, Bloomberg found that the unsubsidized cost of best-in-class PV and solar thermal electricity production was just below US$200 per MWh compared to US$56 per MWh for a coal-fired power plant. Nevertheless, Bloomberg foresees tax credits, capital, expenditure grants, generation incentives and renewable electricity credits continuing to help the solar market increase over the next three years.

The report predicts that the commercial division will lead on PV installations during the next 10 years and anticipates that by 2020, over 3% of commercial rooftops will have solar power installations if solar incentives continue.

Global Tariff News

Germany

The German Federal Network Agency or Bundesnetzagentur has published the country's new tariffs for photovoltaic systems in the *Federal Gazette*. All PV systems due to begin operation in 2011 will face a 13% cut in subsidy compared with current tariffs. Installation operators will therefore receive between €0.2111 and €0.2874 for each kilowatt hour of solar electricity fed into the mains, depending on size and location of the installation.

Under the arrangements in the Renewable Energy Souces Act (EEG), the Bundesnetzagentur annually determines the tariffs and degression for the upcoming year based on the data supplied by the PV system operators on new installations. The EEG sets forth a range of threshold values for a higher or lower degression level.

UK

The UK's Chancellor of the Exchequer, George Osborne, announced the coalition Government's Comprehensive Spending review, revealing that there will be no immediate cuts to the country's solar feed-in tariff.

After much speculation that the coalition government would slash the FiT set by the country's Department of Energy and Climate Change, it was finally announced by the Chancellor that the efficiency of FiTs will be improved at the next formal review, rebalancing them in favour of more cost-effective carbon abatement technologies. This will save £40 million in 2014–15. Support for lower value innovation and technology projects will also be reduced, saving £70 million a year on average over the Spending Review period.

Czech Republic

The political battle over consequences of the solar boom in the Czech Republic has resulted in a 'legislative storm' that will significantly harm the local photovoltaic industry. Politicians are keen on punishing so-called 'solar barons,' which has become a popular nickname for operators of PV systems over 30kWp coined by the country's main media. These solar barons are being blamed for a possible increase in electricity prices from 2011, caused by the amount of PV being installed in the country.

At the end of October, the Czech parliament took the first set of measures against locally installed PV:

- End of a tax holiday for all operators of PV plants to be applied retroactively.
- Change of write-off scheme (its deterioration) applied retroactively to all PV plants.
- New FiT will be applied only on rooftop PV installations with maximum capacity of 30kWp from March 2011.
- Abolition of the FiT for off-grid PV systems and for ground-mounted PV plants from January 2011.
- A 500% increase in fees paid to the authorities for using land in order to discourage investors from building ground-mounted PV plants.

Spain

The Spanish government has now confirmed the country's reduced feed-in tariff rate, which will be paid to new solar-power projects. Ground-mounted plants' tariffs will be cut by 45% while residential rooftop systems will be paid 5% less than before. All existing installations will receive the tariff quoted at the time of connection, for the full period of 25 years.

While the existing installations will continue to receive their set rate for 25 years, the government is likely to restrict the number of hours during which existing generators may earn above-market prices.

Australia

The New South Wales (NSW), Australia state government has revealed that it will dramatically cut the incentive for installing solar power, admitting that the scheme could end up costing the state over AUD$4 billion, which is double the original estimate. The Government plans to further decrease the multibillion-dollar capital spending plans of power companies, again in an effort to prevent escalating electricity prices before the state election in March 2011.

More than 35,000 rooftop units have been installed since the scheme began, resulting in more than 100MW of renewable electricity generation capacity. Applications are still being processed that will increase this figure to 193MW over the next few months. The NSW government expected the scheme to introduce 300MW of new generation capacity over the six-year life of the scheme.

India

The Indian Government recently warned that all companies that have been placed on the shortlist to qualify for incentives under the country's program to boost solar power generation had to submit final bids by Nov. 16. The program, which offers incentives such as special tariffs and a power-bundling arrangement designed to assure projects of buyers, has so far received applications from solar project developers to build at least three times the proposed capacity of the National Solar Mission's first set of projects.

Due to this large amount of interest, the government has agreed to select developers based on the discount they offer for the rate at which they sell their electricity. The commission set a price of 17.91 rupees (US$0.40) per kilowatt hour for solar photovoltaic projects and 15.31 rupees for solar thermal projects.

The National Solar Mission aims to increase India's grid-connected solar capacity to 1000MW by 2013 and 20,000MW by 2022. The invitation for applications to build the first round of projects, including 150MW of solar PV plants and 470MW of solar thermal plants, closed on September 24th.

U.S. solar PV market – an overview

Joseph CG Eisenberg, Renewable Analytics, San Francisco, California, USA

ABSTRACT
The U.S. solar PV market is suffering not from a lack of demand or high prices, but rather from an inconsistent labyrinth of rules and regulations which complicate and prolong uptake. There is significant pent-up demand in the U.S. among developers and especially manufacturers; there is not, however, a commensurate regulatory framework that will enable and encourage this demand to be realized. This paper takes a closer look at the obstacles and costs associated with large-scale implementation of PV in the U.S.

There is major optimism among developers and manufacturers that the U.S. will contribute significantly to 2011 global demand and shipments, and thus help absorb the ~50% increase in capacity coming online and decelerating growth in Europe.

Renewable Analytics' (RA's) September North American Survey of Dealers and Installers indicates an average expected 103% year-over-year growth in 2011 (Fig 1). RA estimates the U.S. market will grow substantially next year, from 813MW of sell-in in 2010, to 1.5GW in 2011, an 84% increase. While promising, this comes off a relatively low base, and comes with many caveats.

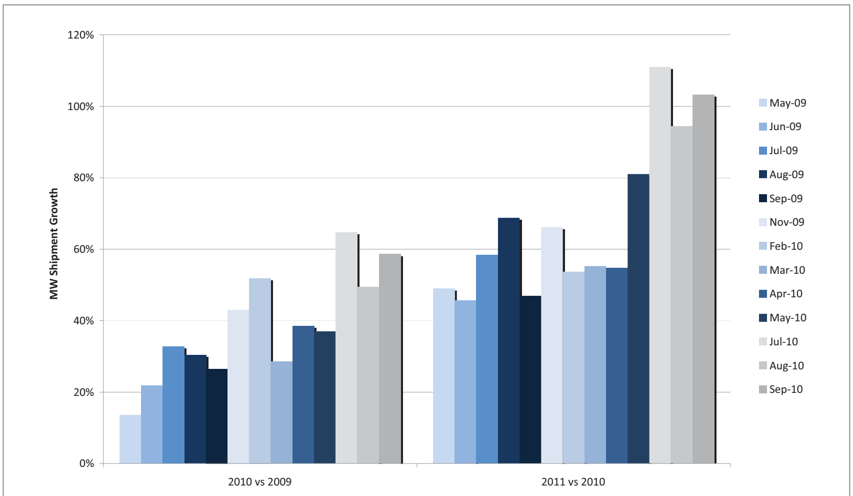
There are variables facing project developers in the U.S. that would seem anachronistic in any mature European market. RA believes the U.S. may begin to be a global leader when it turns toward grid parity in 2012, which corresponds with when the U.S. may begin to structurally mature. The next big PV cycle will be driven by pure economics – not EU feed-in tariffs. The U.S. should largely lead that cycle.

Cost of capital remains high in the U.S. compared to Europe. Interest rates of 4–5% are common in Germany, where banks have designated funds and operations that accommodate solar PV customers. Banks in the U.S. are still relatively naïve to the economics of PV. Financing will typically require higher down-payments, and interest rates of 8–9%. This is largely due to the perpetually shifting and uncertain regulatory market. Each State has a different incentive structure and interconnection model, and thus it is difficult for large banks to develop a national strategy. In Germany, incentives are the same nationwide, and the government has a structured and credible system for adjusting the framework; there is trust and continuity that lowers the perception of risk.

California

There are myriad examples. In California, each jurisdiction interprets the national electric code differently. Angiolo Laviziano, CEO of REC Solar, said in an interview that in Germany the code is a hard law and can only be changed or challenged in courts. In California, a building inspector has the power to interpret it differently. "The U.S. is obsessed with grounding codes, which can vary dramatically. Some municipalities even require the usage of equipment which has been certified by municipality-specific sanctioned labs to conduct grounding tests," he said. Similarly, in New York State, each municipality has its own electrical licensing body.

Adam Rizzo, CEO of Buffalo, NY-based Solar Liberty, remarked: "I have someone in my office that finds electricians that are licensed in whatever town we are evaluating a project, it's kept guys out, and adds costs... permitting takes four days in Germany, and 40 days in New York, and that's for a small project."



Source: RA September North American Dealer & Installer Survey

Figure 1. Renewable Analytics' industry shipment comparison (2009–2011).

California interconnection assessments are expensive, particularly for large projects, and the order in which they are processed is more or less arbitrary. Lead times required to secure interconnection are significantly underestimated. Hans Isern, VP of engineering for San Francisco-based Silverado Power LLC, one of the largest developers in California, said: "Despite regulatory efforts to streamline the interconnection process in California, there is still a significant backlog of about 35GW of renewable capacity, much of which is unlikely to be built. For new projects seeking interconnection, study processes can be lengthy, with timeframes exceeding 420 days for small projects (<20MW) and 1,000 days for large (>20MW) systems. Combined with potentially expensive upgrades to the power grid, this can be a major risk for new solar projects' development schedules and budgets." There is also no guaranteed buyer of electricity, which adds to the risk of wasting time and money.

At the local level, there is still little familiarity on how PV works. Deep Patel, CEO of California-based GoGreenSolar.com, says that "in one municipality a permit that is rubber stamped will be deeply scrutinized in another. Plan checkers don't know much, they require corrections on plans that are just wrong. The developer has to explain to the person issuing the permit basic aspects about a PV system. It took me US$1,000 and several weeks to get a permit to build a 1.3kW system in my own backyard."

An incrementally positive regulatory development was the recent clarification issued by Federal Energy Regulatory Commission on its interpretation of the Public Utilities Regulatory Policies Act. FERC previously allowed (but did not require) utilities to purchase electricity produced at or below the "avoided cost," a benchmark set by States. In California this is pegged to the cost of natural gas generation, about US$0.09/kWh. A ruling issued in October allows States

New Jersey SREC Data								
Month	Year	Active kW DC	Issued in Month	Traded in Month	High ($/MWh)	Low ($/MWh)	# SRECs Traded	Weighted Avg. Price ($/MWh)
Sept	2010	168,254	20,236	9,483	$685	$205	15,615	$603.56
Aug	2010	157,129	18,137	6,132	$685	$209	6,132	$606.97
Jul	2010	151,850	5,024	43,358	$691	$170	134,909	$605.97
Jun	2010	140,709	26,275	15,636	$690	$170	91,551	$588.96
May	2010	132,956	16504	8,737	$700	$170	75,915	$578.80
Apr	2010	123,892	12,546	6,773	$700	$170	67,178	$573.95
Mar	2010	119,829	5,814	9,522	$700	$209	60,405	$568.66
Feb	2010	113,770	6,784	9,720	$685	$170	50,883	$552.69
Jan	2010	103,857	5,249	11,731	$675	$110	41,163	$533.15
Dec	2009	100,086	7,862	7,582	$700	$195	29,432	$566.91
Nov	2009	97,491	6,191	7,292	$688	$170	21,850	$559.45
Oct	2009	93,412	8,085	7,004	$680	$170	14,558	$549.84
Sept	2009	92,032	8,796	5,119	$700	$170	7,554	$524.90
Aug	2009	89,660	10,320	2,435	$685	$170	2,435	$492.18
Average		120,352	11,273	10,752	$690	$176	44,256	$564.71

Source: New Jersey Board of Public Utilities

Table 1. New Jersey's Solar Renewable Energy Credits (SREC) activity August 2009–September 2010.

with renewable portfolio standards to set source-specific avoided costs. This notably affects California Senate Bill 32, which established an FiT mechanism. SB32 has been stalled on the desk of the Public Utilities Commission. John Cheney, CEO of Silverado Power, remarked: "There has been a general ideological preference against SB32 at the CPUC, which has hindered implementation of a real FiT. The specter of FERC suing over jurisdiction supported this preference, or allowed them to deflect the issue. There will be some chaos now surrounding implementation." The program remains in limbo.

As an alternative, an administrative law judge at the CPUC recently recommended a "Renewable Auction Mechanism," which is effectively a reverse auction feed-in tariff. Projects 1–20MW in size would be allocated a total of 1GW through 2011–12, with 250MW allocated each 180 days. Only investor-owned utilities PG&E, SCE and SDG&E would be required to buy power under the plan. The mechanics are still being worked out, but it does not address the structural hurdles. It is not a substitute for a statewide or national FiT.

A complimentary mechanism, which existed four years prior to the RAM, is Southern California Edison's Renewable Standard Program. The program, which targets 250MW per year, provides a standardized template to developers for renewable power purchase agreements for systems 1.5–20MW in size. Hans Isern of Silverado Power says it offers "an attractive mechanism to bring cost-competitive solar on line with relatively low transaction times and costs." He added: "Programs such as SCE's RSC are especially important to ensure market continuity for distributed solar generation." The RSP in part addresses the structural issues, and should be considered by other utilities to accelerate uptake. 90% of its allocation has gone toward solar PV.

New Jersey

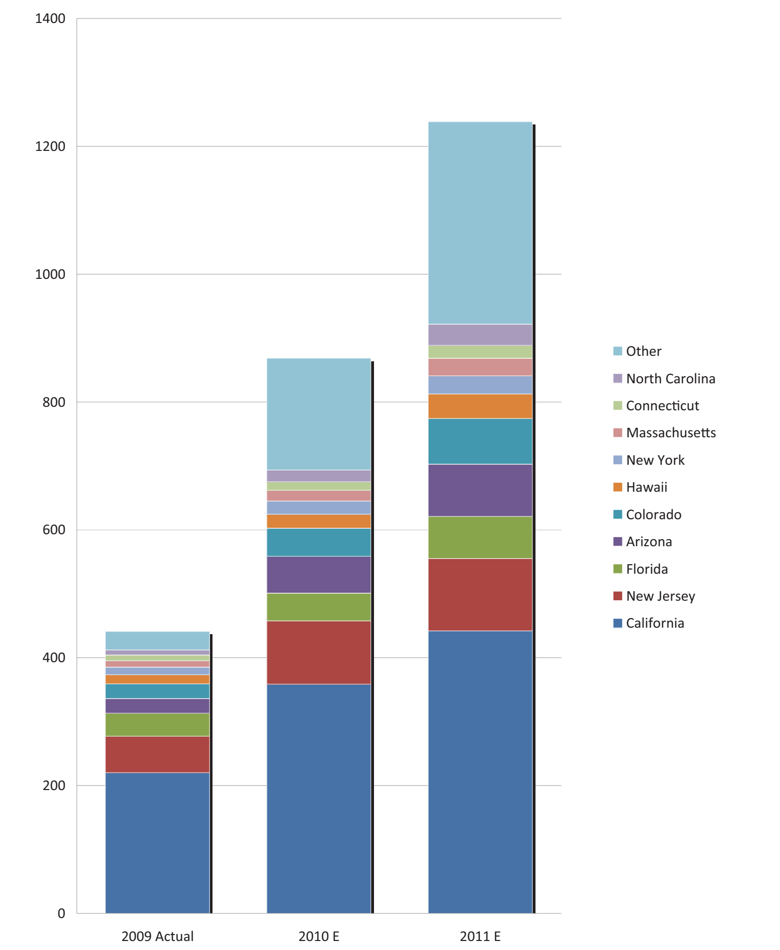
New Jersey provides an incentive scheme that may be a cleaner model to other States. Its renewable portfolio standard, which is set at 8.3% for 2011, moving to 22.5% by 2021, includes a specific carve-out for non-hydro renewables, and within that a solar-specific carve-out. Utilities must generate 306GWh of solar electricity in 2011, moving to 2.52TWh by 2021, and 5.3TWh by 2026. To accomplish this, the state has established its Solar Renewable Energy Credits program, spurring demand, making NJ the east-coast leader (Fig 2).

Utilities submit SRECs representing a certain portion of required solar PV generation. If a utility is not able to fulfill its requirement, it must pay a Solar Alternative Compliance Payment – which are set at a price that the Board of Public Utilities believes will provide adequate incentive to solar developers – or purchase SRECs on the open market from other utilities that have generated excess credits. SREC pricing from August '09 – September '10 averaged US$565/mWh (see Table 1). SACP pricing

SACP Prices – Set by the NJ Board of Public Utilities	
	$/MWh
2009	$711
2010	$693
2011	$675
2012	$658
2013	$641
2014	$625
2015	$609
2016	$594

Source: New Jersey Clean Energy Program

Table 2. Solar Alternative Compliance Payment (SACP) prices as set by the New Jersey Board of Public Utilities.



Source: RA September North American Dealer & Installer Survey

Figure 2. Renewable Analytics' PV installation estimates by state 2009–2010.

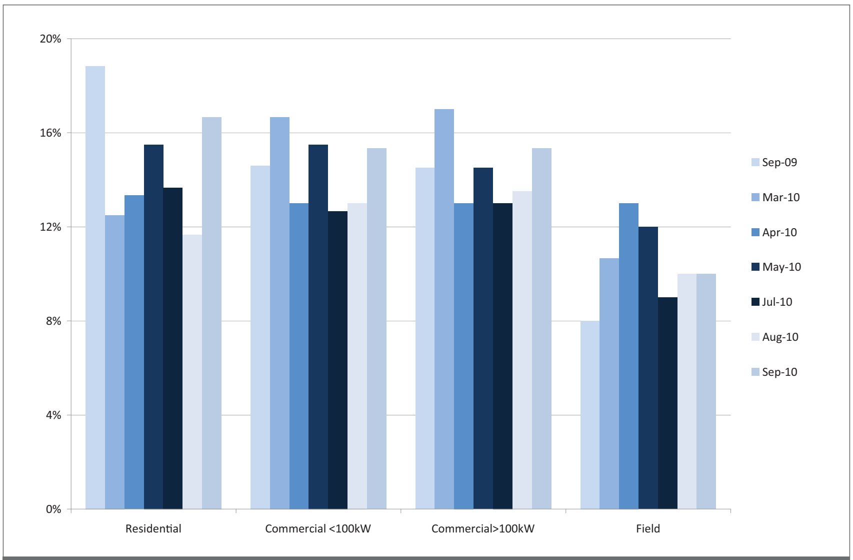


Figure 3. Internal rates of return (IRR) by system type September 2009–2010.

Source: RA September North American Dealer & Installer Survey

was set by the BPU at US$711/mWh 2009, US$694/mWh in 2010, and US$675/mWh in 2011 (see Table 2).

George Schaefer, CFO of New Jersey-based developer Soltage, Inc. said in an interview with RA that the whole pricing scheme is under review, and that this uncertainty makes it difficult to predict. "There is good availability of SREC contracts up to five years, but should be extended to provide more financial security." New Jersey Governor Chris Christie, who gained a national profile by taking a hard-line stance on fiscal austerity (in large part by killing a proposed US$9 billion train tunnel under the Hudson River to New York City), is reportedly "reexamining" the program. Mr. Schaefer said his company has given up predicting future pricing.

Federal

At the federal level, a big policy overhang is the expiration of the Investment Tax Credit cash grant program, which provides for a grant in lieu of the existing 30% investment tax credit. This will expire on December 31st 2010, if not renewed by Congress. On November 16th, a spokesman for Senator Jeff Bingaman (D-NM), chair of the Senate Energy and Natural Resources Committee, said in an interview with *Reuters* of the cash in lieu of credit program: "...[he] does not believe that we should be using the tax code for making grants, and also feels that the grant program is akin to corporate welfare." Chances of passing it in the next Congress are much lower, he said, in part because many incoming congressmen do not believe stimulus provisions overall have worked effectively.

Many solar PV projects do not have sufficient tax liabilities so that the 30% credit meaningfully adds to returns. For large, speculative projects designed to have annuity-like returns, this program is critical. A lot of large utility-scale projects in the U.S. were banking on the ITC. Financing projects through tax equity arrangements is more complicated and costly. REC's Laviziano said: "This is important, in these projects the third decimal in IRRs [internal rates of return] count. This will put some projects back to the drawing board."

The Republican takeover of the House of Representatives makes a comprehensive federal energy policy that may include an RPS or carbon cap unlikely in the mid-term. Sen. Bingaman has said: "I'd be surprised if that kind of a comprehensive climate and energy bill could pass both houses in the next Congress, since they've been unable to pass in this Congress..." John Shimkus of Illinois, the vice chairman of the Republican party's congressional campaign, is vying for the chairmanship of the House Energy and Commerce Committee. The *New York Times* reported that Rep. Shimkus said in a climate change hearing in 2009: "The earth will end only when God declares it's time to be over. Man will not destroy this earth...This earth will not be destroyed by a flood." In a recent interview in *Politico*, Mr. Shimkus said that debate on climate change would come to a halt: "The focus is not going to be climate... The climate debate has, at least for two years, ended with this election."

An RPS law may in any event be challenged on constitutional grounds by States, which still reserve the power, with some federal oversight, to regulate the electricity market.

Outlook

The U.S. has the ingredients to be a huge market. Despite the challenges, IRRs are quite good, in the 10–17% range as reported by installers (this does, however, include the investment tax credit). The most substantial inhibitors to PV uptake are structural, not economic – module prices are 10–15% cheaper in the U.S. than in Europe.

European developers, which could provide immediate scale and competence in the U.S., have not made inroads largely because the system is so convoluted. According to Mr. Laviziano, it is not only the most capable, effective or cost-efficient developer that has edge in the U.S.; rather it is the developer than can also get through the fragmented and jurisdiction-specific business licenses, interconnection applications and lead-times, electrician licensing, rebates, and worker safety laws.

This maturation process is typical for cyclical, subsidized growth industries. At the local level, there is still little familiarity on how PV works.

Overall, RA expects the U.S. to take longer than expected by manufacturers to be a primary global PV driver, or to reach its full growth potential. It is important to approach claims that U.S. allocation will substantially buoy demand and pricing in 2011 with some healthy scepticism. This will happen when the financial and political environment in the U.S. catches up to the economics, most likely in 2012.

Acknowledgements

Portions of this article were adapted from Renewable Analytics' Monthly Solar PV Report. For more information, please contact the author at the email address below.

About the Authors

Renewable Analytics LLC is an industry research firm formed to address the underserved need for objective and timely supply chain research in the solar photovoltaic industry. Almost all of the research available in the market today is either investment banking-driven or tends to focus on broad themes and long-term trends. The founding team of Renewable Analytics has more than 20 years of combined relevant experience, including management in the solar industry, technology supply chain research, and fundamental analysis. Renewable Analytics conducts its research via typical channel checks, combined with more systematic surveys. Research reports track the changes in the variables that impact growth and profitability including but not limited to: end customer and market demand per country, subsidies in each country, pricing of silicon and other key components, cell equipment utilization rates, solar equipment shipments, technology transitions, foreign exchange and interest rates.

Enquiries

Renewable Analytics LLC
268 Bush Street, #500
San Francisco
CA 94104
USA
Email:
joe.eisenberg@renewableanalytics.com

Photovoltaics International

Advertisers & Web Index

ADVERTISER	WEB ADDRESS	PAGE NO.
26th EU PVSEC	www.photovoltaic-conference.com	45
3M Renewable Energy	www.3m.com/solar	141
3S Modultec	www.3-s.ch	161
ACI ecoTec	www.aci-ecotec.com	135
Air Liquide	www.airliquide.com	33
Air Products and Chemicals, Inc.	www.airproducts.com/sunsource2	43
Alconox	www.alconox.com	51
ASYS Solar	www.asys-solar.com	57
Atlumin Energy, Inc.	www.atlumin.com	109
Bürkle	www.buerkle-gmbh.com	139
Cookson Electronics	www.alphapv.cooksonelectronics.com	31
Coveme Spa	www.coveme.com	137
CRS Reprocessing Services	www.crs-reprocessing.com	37
DEK Solar	www.deksolar.com	61
Despatch Industries	www.despatch.com	59
DuPont Tedlar	www.tedlar.dupont.com/pv	133
ECI Technology, Inc.	www.ecitechnology.com	73
Ecoprogetti	www.ecoprogetti.it	151
EPIA	www.epia.org	83
Eyelit, Inc.	www.eyelit.com	27
Festo	www.festo.com	67
GFE Coating Materials	www.gfe.com	111
Green Solar	www.greensolar.hu	125
GT Solar, Inc.	www.gtsolar.com	IFC
HC Starck	www.hcstarck.com	121
Heraeus Thick Films Group	www.pvsilverpaste.com	77
Otto Chemie	www.otto-chemie.de	153
Horiba	www.horiba.com	101, 125
ib vogt GmbH	www.ib-vogt.com	15
Innolas	www.innolas-systems.com	75
Intersolar Europe	www.intersolar.de	177
Intersolar India	www.intersolar.in	129
J.A. Woollam Co., Inc.	www.jawoollam.com	97
Kipp + Zonen B.V.	www.kippzonen.com	175
Komax Solar	www.komaxsolar.com	95, 157
Kuka Systems GmbH	www.kuka-systems.com	11
Laytec	www.laytec.de	113
Lisec Maschinenbau	www.lisec.com	159
Linde Group	www.linde.com/electronics	21, 59
M+W Group GmbH	www.mwgroup.net	17
Madico Specialty Films	www.madico.com	147
Manz Automation AG	www.manz-automation.com	73, 101, OBC
Meyer Burger AG	www.meyerburger.ch	39, IBC
MRL Industries, Inc.	www.mrlind.com	55
Oerlikon Solar	www.oerlikon.com	99
Ontario International Marketing Centre	www.investinontario.com	7
Op-tection GmbH	www.op-tection.com	151
PCO Imaging AG	www.pco.de	149
Prediktor AS	www.prediktor.de	19
Q-Cells	www.q-cells.com	169
Rena Solar GmbH	www.rena.com	65
REC Silicon ASA	www.recgroup.com/silane	3
Roth & Rau	www.roth-rau.de	13, 63, 157
Schmid Group	www.schmid-group.com	19, 163
SEMI PV Group	www.pvgroup.com	79
SENTECH Instruments GmbH	www.sentech.de	127
Sika Services AG	www.sika.com	135
SNEC	www.snec.org/cn	105
Somont GmbH	www.somont.com	143
Sovello AG	www.sovello.com	167
Spire Corporation	www.spirecorp.com	25
Sputtering Components, Inc.	www.sputteringcomponents.com	117
Sunconnex BV	www.sunconnex.com	179
Technic, Inc	www.technic.com	69
Testbourne Ltd.	www.testbourne.com	119
Trina Solar	www.trinasolar.com	5
Umicore SA Thin Film Products	www.thinfilmproducts.umicore.com	119
VON ARDENNE Anlagentechnik GmbH	www.vonardenne.biz	97

太阳能产业近距离观察：
Suniva实现离子注入、福思太阳能实现瓶颈突破、CIGS实现材料净化

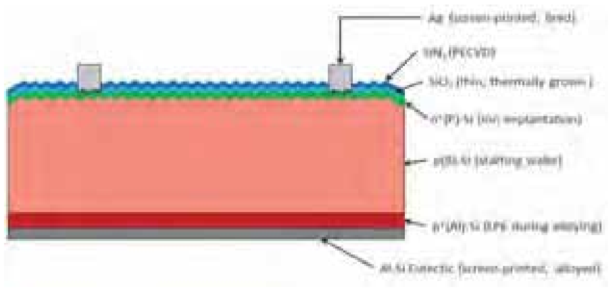
借助新年伊始不可阻挡的发展势头，以及中国农历春节的即将来临，是时候启动本期《太阳能产业近距离观察》2011博客了。本期专栏着重报道了美国电池制造商Suniva的相关新闻及其在高效太阳能电池量产中的启用离子注入技术的创举；同时还刊载了一些关于福思第一太阳能工程重点领域的珍闻；一些关于CIGS及相关材料净化方式的业内观点；以及一家中韩合资企业更名的消息。

近期电池制造商SpectraWatt公司受到的冲击及其持续的低迷态势造就了Suniva的成功，Suniva公司是一家十分值得关注的美国太阳能从业商(Team Solar USA)。该公司目前在亚特兰大附近有三条电池生产线正满负荷运转，并将在不久的将来宣布其产能扩张计划；Suniva除了有能力与中国及其他全球市场上的企业相竞争外，同时还将自身建设成为晶硅领域的技术领军企业。

在第本期*Photovoltaics International*所刊载的一篇独家技术文章中(第87页)，Suniva公司证实其已将离子注入技术引入了高效太阳能电池的量产工艺中，此举尚属业内首创。

该文章还透露：“此项技术相较于传统的三氯氧磷内联扩散技术来说，具有多项优势，包括：单面掺杂、表面钝化层的原位氧化、磷硅玻璃移除步骤的省略、结边缘隔离/绝缘处理(junction edge-isolation)步骤的省略、通过不同的注入剂量、注入能源和注入退火损伤配方而实现的精确的掺杂控制及创新性掺杂分布工艺，以及选择性发射极甚至交叉式背接触电池结构中的掺杂区域等。”

诚然，试图将离子注入技术应用于电池生产工艺并不是一件新鲜事，但该技术由于其自身显而易见的吞吐率和高成本的双重缺憾，并未获得太多的关注。上述技术文章指出：“随着离子注入技术被认为是一种可简化新型高效太阳能电池生产的潜在工艺，业内对于离子注入发射极技术的关注又有卷土重来之势。”



图一：Suniva公司离子注入同质发射极电池生产线

Suniva公司还就此技术与半导体设备供应商瓦里安半导体设备公司进行了合作，“从而实现了光伏产业内高束流、快速晶片处理、高吞吐量注入机的开发。”

作为首家启用碲化铬薄膜组件的公司，同时还是项目开发和工程、采购、建造领域内的大型光伏企业，福思第一太阳能是在谈及美国太阳能从业商时不得不提的企业。尽管福思第一太阳能在其研发领域及生产计划方面是出了名的守口如瓶，但该公司还是曾凭借其点滴的诱人信息跻身于博客专栏这道大餐之中。

作为福思第一太阳能在美国圣克拉拉科研重地进行重要技术研发的负责人，拉菲•加拉贝迪安(Raffi Garabedian)先生近日曾在旧金山薄膜峰会上进行了发言。加拉贝迪安先生的发言中大多数与降低成本的潜力相关的内容与其他产业内的降本先锋相比，并没有什么与众不同之处，只是强调了公司所制定的在2014年前将每瓦制造成本降至52美分，同时将各生产线的开工率提高至80MW以上的目标。

然而，在其发言接近尾声的时候，加拉贝迪安先生举出了一系列的例子用以阐述其是如何冲破技术瓶颈，并在开工率、转换率和产量上改善工艺流程。加拉贝迪安先生还表示，改善激光刻蚀的吞吐量、优化玻璃制程中温度的变化速度(加热及冷却)、提高组件层压循环周期等方面是其关注的重点领域。他还提及公司在背接触技术和被其称为“新材料系统”方面做了许多工作，而上述所有研发工作都是本着降低生产成本的宗旨而进行的。

在谈及新材料系统时，加拉贝迪安先生对于福思第一太阳能在CIGS领域进行研发这一心照不宣的秘密并未予以表态。“我们公司在研发方面并不会放过任何可能性。”在提及福思第一太阳能在技术研发方面所做出的持续不断的努力时，加拉贝迪安先生如是说，但他并不认为生产可行性是第四代薄膜光伏产品的关键技术瓶颈。“目前我们还无法证实CIGS技术可在量产中进行应用。”

在过去的几年内，许多CIGS设备均取得了重大的改善以应对快速发展的市场。液化空气集团(Air Liquide)的拉维•拉克斯曼先生(Ravi Laxman)在其发言中所提到的制造工艺的改善即是其中一个典型例子。该公司与许多薄膜企业在材料供应、运输及减排方面均有紧密的合作。

拉克斯曼先生在会上探讨了CIGS薄膜叠层中一个关键成分硒化氢使用的发展状况。在遭遇了若干制程瓶颈后，液化空气集团的许多主要客户停止了在各自材料提纯流程中对硒化二氢的使用，以避免由其所带来的气相中相对较高的湿度。

在清空气瓶之后，残留气体中水气的含量成指数性增长，严重影响了薄膜的质量，进而影响了组件自身的性能。随着杂质量的增加，相关联的输气管也被高含量的硒化二氢和水气所腐蚀，这对于长期发展来说，也是一个潜在的困扰。

据拉克斯曼先生表示，随着半导体产业的发展进入了一个新篇章，气体及化学原料经销商也意识到由于高纯度的气体可减少对设备的腐蚀，因此，保持企业发展的关键在于改善硒化二氢原料质量以及提高原材料的纯度。

液化空气集团及其客户所做的相关研究使得旗下技术人员的专长得到了很好的发挥，并在第37届IEEE光伏专家会议和欧洲光伏太阳能展会得到了展示。

最后，让我们再来关注一下近期太阳能领域中一个日益发展壮大的企业更名的讯息。

自从韩国化工巨头韩华石化收购了林洋新能源49.99%的股份后，该企业迅速跻身光伏业内公司前几名，并展现出其更为垂直化的产业定位在整个业内流程中的灵活性，此外，该企业还在近期公布了其2GW电池及组件产能扩张的计划。

林洋新能源董事会还决定在此次股权购销的同时，将为公司进行更名，十分高调地将使用了与集团名称押韵的名称，正式成为Hanwha SolarOne。

考虑到林洋新能源这一品牌日渐上涨的名气，笔者不禁对此更名行为产生了两点疑惑：其一，此前的名称是否还将用在公司所产的组件上？其二，还是说，林洋新能源这一品牌将逐渐消失在人们的视野中直至Hanwha SolarOne或者仅仅是SolarOne而完全取代？

而笔者则更倾向于继续使用林洋新能源这一名字或替换为简单上口的SolarOne。否则，人们会猜想公司的名称是“韩什么”来着？

本文为在线博客修订版，原载于*PV-Tech.org*

Tom Cheyney为***Photovoltaics International***杂志驻美高级特约编辑，为PV-Tech.org撰写在线新闻以及博客栏目。

MEYER BURGER
SWISS SOLAR SYSTEMS

Peak Performance in Solar Technologies

Expertise in each field of the PV manufacturing process creates solar power at best cost performance ratio. The Meyer Burger Group offers its customers lowest cost of ownership at premium quality.

- Leading solar technologies
- Best cost performance ratio
- Strong global service network with local support
- Industry proven process know-how

Meyer Burger Technology Ltd
www.meyerburger.com