Second Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS

CH2M HILL outlines cost benefits of conversion of used 200mm semiconductor fabs for the PV industry

Fraunhofer IWS proposes in-line plasma-chemical etching as an alternative to wet chemical processing

NREL presents design criteria for back- and front-sheet materials

Fourth Quarter 2008 www.pv-tech.org

Photovoltaics International

Publisher's foreword

A new year brings new opportunities for solar power.

By now, it is no secret that the regulation of securitised debt has let down the global financial system and we are all feeling the effects of an economic slowdown. China has dropped below double-digit growth for the first time in five years, and news in western countries varies from bad to worse.

It is also true that great challenges in business create tremendous opportunities. Governments have maintained their support for solar to help them meet climate and political objectives despite economic hardships. The US$700 billion bank buyout was only passed after it was combined with the job-creating investment tax credits for renewables, notably an eight-year extension on solar tax credits that will give investors and corporations a solid foundation upon which to complete large-scale facilities in reasonable timeframes.

While feed-in tariffs have their place in encouraging the creation of the solar industry, it will soon be time for manufacturers to drop the incentive crutch and drive costs down to commoditised levels using new manufacturing processes and technologies. With this in mind, we have assembled papers from among the world's leading research institutes, manufacturers and suppliers that will help you achieve your cost-per-watt goals.

Many people speak about opportunities for cost reduction through use of semiconductor processes, and in this issue we go one step further with CH2M HILL, looking at retrofitting aging 200mm fabs for solar manufacturing. This can reduce factory costs by up to 50% over a greenfield approach.

We continue our focus on concentrated photovoltaics (CPV) as a key technology to bring down the installation and production costs of utility-scale PV energy generation. Dr. Pedro Banda and Francisca Rubio of ISFOC, Spain, give us a technical overview of CPV systems that sheds light on this rapidly emerging energy-generating technology.

All eyes have been on the U.S. recently and our man on the scene, Tom Cheyney, has certainly been busy. He catches up with centrotherm, Veeco, and other OEMs in the developing CdTe and CIGS field. He was also one of the few journalists allowed in to the Solyndra facility when it emerged from stealth mode, and we provide a special report on the company's development of its tubular module technology.

EuPD Research offers a timely projection of the U.S. renewables sector following the recent presidential election, discusses the likelihood of Obama being able to deliver on his renewables campaign promises.

A contribution on in-line plasma-chemical etching by Fraunhofer IWS proposes an alternative to the more common wet chemical processing, while SHARP introduces a new wafer technology that claims to reduce wafer cost and silicon feedstock. The National Renewable Energy Laboratory offers an in-depth focus on the design criteria for back- and front-sheet materials.

So here's to a new year of opportunities in the PV industry. I hope you enjoy reading all twenty technical papers in this issue, and if you have not yet subscribed, please feel free to use the subscription form on page 160, or check out www.pv-tech.org for your daily dose of PV industry news!

Sincerely,

David Owen
Photovoltaics International

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Front cover shows visual inspection of c-Si solar cells.
Picture courtesy of Deutsche Solar AG.

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Photovoltaics International

Photovoltaics International's primary focus is on assessing existing and new technologies for "real-world" manufacturing 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 through manufacturing efficiencies. 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.

Photovoltaics International would like to thank all of our advisory board members for their assistance in this issue and we look forward to working with you over the coming years.

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 AG

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 AG, 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).

Rodolfo Archbold,

Vice President of Operations, Evergreen Solar

Rodolfo Archbold joined Evergreen Solar in August 2007 as Vice President of Operations. Prior to joining Evergreen Solar, Mr. Archbold served as an operations consultant at Teradyne, Inc., a $1.1 billion global leader in semiconductor test equipment, and at other leading electronics manufacturing firms. In this role, Archbold developed strategy and execution plans designed to improve global operations and supply chain design, reducing manufacturing costs and increasing responsiveness across global supply chain networks.

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

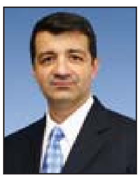
Director of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg

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. pPrior 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.

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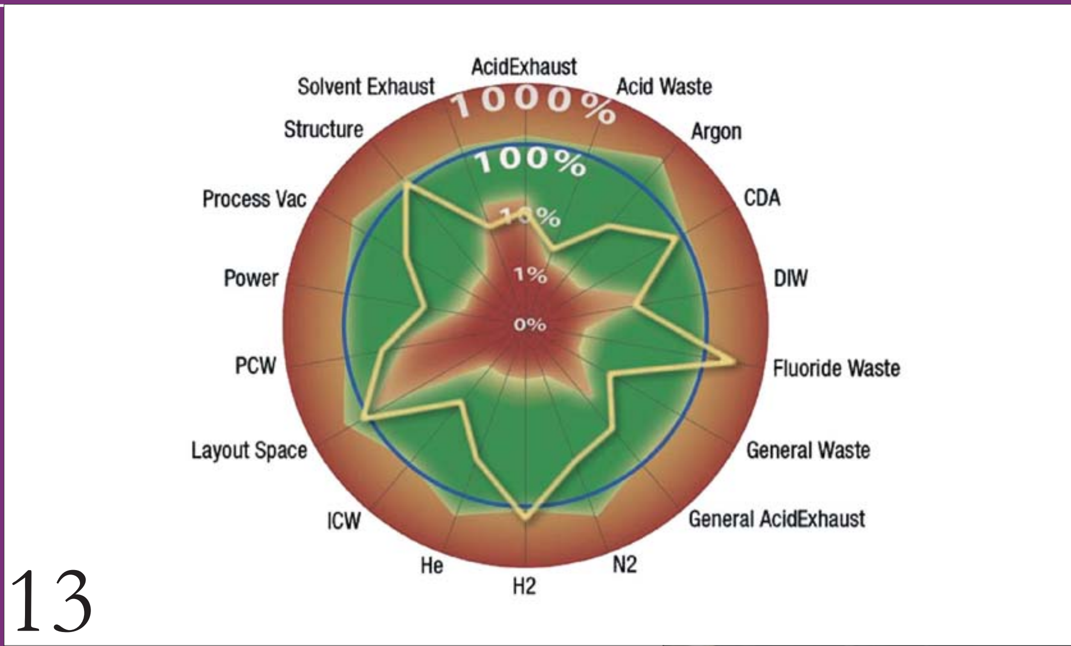

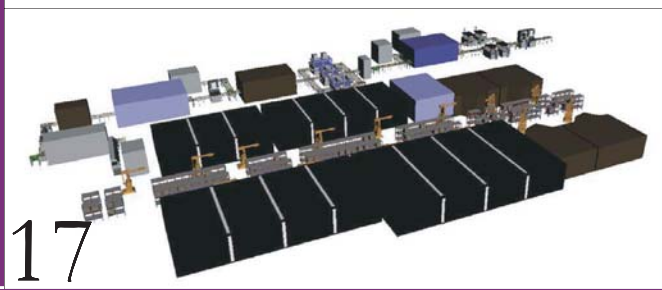

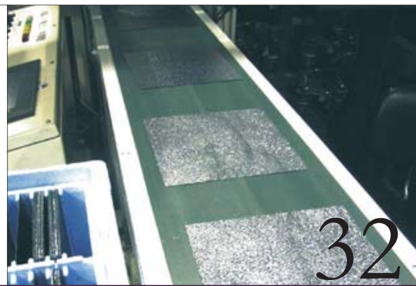

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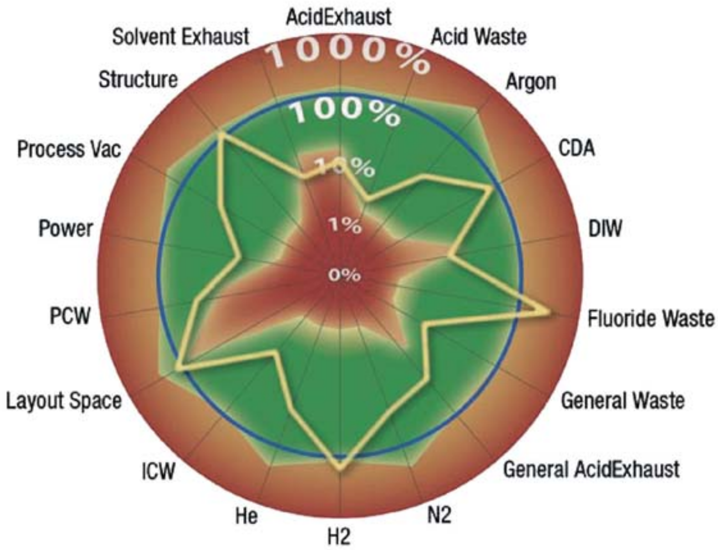

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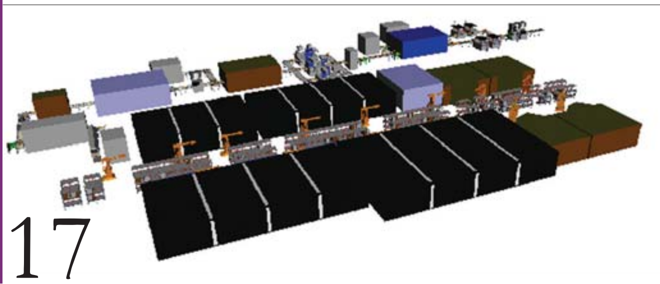

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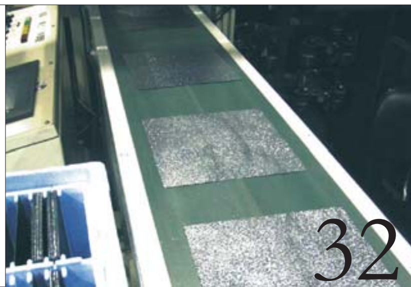

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News

Renewable Energy Corp. plans US$2.5 billion PV manufacturing investment in Singapore

Renewable Energy Corporation ASA (REC) has announced plans to invest NOK 13 billion, approximately US$2.5 billion, in a new manufacturing complex to be built in Singapore that will include an initial capacity of 740MW of multicrystalline solar wafers, 550MW of solar cells and 590MW of solar modules starting in the first quarter of 2010. Full capacity is expected to be reached before 2012, and is being treated as 'Phase 1' of several planned developments, with the decision for the next expansion phase said to be made in 2009, according to REC.

"This investment supports REC's position as a leading provider of highly competitive solar energy solutions, and in achieving our main corporate goals of reducing costs and securing profitable growth", says Erik Thorsen, President and CEO of REC ASA. "Based on this expansion, REC should be producing ~2,400MW of wafers, ~780MW of cells and ~740MW of modules in 2012, and this will secure a significant presence for REC in key solar markets."

The investment will be funded through operating cash flow and existing and new credit facilities, REC said. The company has already established a project team in Singapore and Norway since April, when groundbreaking and engineering work begun.

REC said that 90 percent of the equipment procurement had been secured to ensure they met schedules as well as the polysilicon required due to already announced capacity expansions at its production sites in Moses Lake and Butte.

REC also announced separately that it has approved plans to invest up to NOK 400 million to upgrade its production facility at Herøya to accept thinner wafers and boost wafer production by 100MW. This would see production reach 1.75GW in 2011.

Solar Cell News Focus

Suntech breaks ground on new solar cell production fab

Suntech has broken ground on a new solar photovoltaics cell production facility in Yangzhou, Jiangsu province, China. The company says it plans to finish the factory and bring its 300-MW cell production capacity online by the end of 2009, boosting its total manufacturing capacity to 1.4GW. The new PV cell fab is close to one of Suntech's strategic silicon-wafer supply partners, Shunda Holdings, which the company says will enable it to realize production and operational synergies that are expected to accelerate Suntech's cost-reduction initiatives and path to grid parity.

In May, Suntech announced a 13-year wafer supply agreement with a subsidiary of Shunda, in which the silicon unit will provide Suntech with specified annual volumes of wafers totaling approximately 7GW over the course of the deal (2008-2020).

Over the past few months, Suntech has inked several multiyear supply deals with various polysilicon and wafer producers, including DC Chemical, GCL Silicon, and PV Crystalox, and has also purchased a minority stake in poly manufacturer Nitol.

Photovoltech updates solar cell production expansion plans

Photovoltech is to build a new crystalline solar cell manufacturing plant in Tienen, Belgium, where its current production facility is located. Dutch engineering company DHV is to design and build the 26,500m^2 facility, which will be divided into three floors and will have a 400MW capacity. The new facility will generate 100 new jobs.

The IMEC spin-off is set to double production in the next two years, from 140MW by end-2009 to 260MW by the end of 2010. With the new plant starting production in 2010, Photovoltech expects capacity to be more than 500MW per annum.

Artist's impression of the facility expansion.

Photovoltech has also signed a new wafer supply contract with LDK Solar, which will supply 400MW of silicon wafers over a ten year contract. The company reported revenue of €67 million in 2007, up more than 50% compared to 2006.

SolarWorld opens largest silicon PV wafer, cell factory in North America

SolarWorld cut the ribbon on what is being called the largest silicon solar-cell production facility in North America. The 480,000 square-foot factory, located in Hillsboro, OR, is part of the German company's US$500 million investment in advanced photovoltaics technology in the U.S.

The fab will feature an integrated manufacturing process, producing both solar wafers and cells, and is expected to have an initial annual capacity of 100MW. The plant, a former Komatsu semiconductor manufacturing site bought by SolarWorld in 2007, will grow to an eventual total capacity of 500MW and create 1000 new jobs over the next three years, the company said.

Cells processed at the Hillsboro site will be shipped to SolarWorld's recently expanded 100MW module-assembly line in Camarillo, CA. SolarWorld is also spending an additional €350 million to double the capacity to 1GW at its main solar manufacturing factory in Freiburg, Germany. A solar-module production plant, part of a joint venture in South Korea, is also expected to begin production by year's end.

M+W Zander announces order backlogs over 1GW for 2007

M+W Zander, the Stuttgart, Germany-based design and build engineering company, has announced that it received bookings worth over 1GW peak annual capacity for 2007 in thin-film and wafer-based technologies. The company's worldwide order backlog – up from 410MW in 2006 – comprises 600MW worth of combined design and construction projects, 480MW in pure design projects and 130MW related to services.

REC enlists Fluor to design and build solar panel manufacturing facility in Singapore

Fluor Corporation has been selected by Renewable Energy Corporation (REC) Group to design, build and manage its planned solar panel manufacturing facility in Singapore. The contract, worth approximately US$420 million, will see Fluor oversee all procurement and services and elements such as infrastructure and utilities for the company's venture.

The new facility will produce wafers, cells and modules for the global market.

Groundbreaking took place in July 2008, while production is expected to commence in early 2010. REC plans to produce 740MW of wafers, 550MW of cells and 590MW of modules by 2012. The contract is further to the current work being done by Fluor for REC's polysilicon production facility expansion in Moses Lake, Washington, which will be completed in 2009. REC expects to double polysilicon production at the site.

Spark Solar Australia to build solar cell factory worth US$70 million

Spark Solar Australia, a solar cell manufacturer, has announced that it has completed its first round of funding for the development of a new, US$70 million solar cell manufacturing facility in the Canberra region. The factory, which will produce approximately 19 million solar cells per annum, the majority of which will be exported to Germany, will also see the creation of close to 115 jobs for the region.

Initial cell production is expected in early 2010, while the factory itself is expected to be completed next year.

Yingli Green to stop capacity expansions at 600MW

Yingli Green Energy is to increase production of polysilicon ingots and wafers, PV cells and PV modules to its capacity target of 600MW in 2009.

Yingli Green recently added 200MW of annual manufacturing capacity bringing its total annual manufacturing capacity to 400MW in 2008. The integrated PV manufacturer also noted that its current line of credit and cash flows from operations were sufficient for the its next 200MW expansion phase, negating any need for further funds through 2009.

1366 Technologies celebrates opening of new solar manufacturing facility

1366 Technologies is hosted a grand opening celebration for the unveiling of its new Lexington, Massachusetts, manufacturing facility. The ground breaking of the new facility will enable the company to start manual production of its silicon solar cells in a six-inch industry standard size. 1366 technologies has originated a new photovoltaic manufacturing process and combined it with a uniquely constructed solar silicon cell with the intent of cutting down on cost of solar power, so that it can be comparable to the cost of coal, by 2012.

Professor Emanuel Sachs, Chief Technical Officer and co-founder, (second from left) and Frank vanMierlo, President and co-founder (second from right), celebrate the new facility opening.

Module News Focus

LG Electronics to take a 75% stake in Conergy's solar module plant

A memorandum of understanding has been signed between LG Electronics and Conergy AG that will see LG take a 75% stake in Conergy's advanced solar module plant in Frankfurt (Oder), Germany. The deal could be in place by the end of 2008, Conergy said. LG will also be involved in R&D activities with Conergy, citing its manufacturing experience in the flat panel display industry and its move into being a major PV player in the years to come.

Asola teams on new PV module plant in Morocco

Quantum Fuel Systems Technologies Worldwide and partner, Asola, are to build a solar module manufacturing facility in Casablanca, with an initial capacity of 30MW. The company stated that Asola will hold the controlling stake in this joint venture, while both Asola and its Moroccan partner, Majdaline Holding, will implement the project.

The partners said that they had the potential to generate revenues in excess of US$100 million annually from the venture.

SOLON's new Arizona facility enters first-phase production

SOLON AG's new state-of-the-art module facility in Tucson, Arizona has come on stream. The facility's first phase production will have an annual capacity of 60MWp, producing both crystalline and thin-film solar modules as well as photovoltaic systems. The Tucson site currently employs approximately 100 staff.

Polysilicon & Ingot News Focus

Canadian Solar completes first phase of ingot/wafer plant, sticks by 2009 guidance

Canadian Solar said it has completed and commissioned Phase 1 of its ingot and wafer plant on schedule. The new production capacity gives the company an annualized ingot and wafer capacity of 60MW. CSI expects to complete the second phase of its ingot plant by year-end, ahead of the original schedule, which will bring the company's ingot and wafer capacity to between 150 and 200MW.

The company also said that its 250MW Phase II cell plant will be completed in October, with the next stage set to begin immediately thereafter. CSI's current annualized capacity has reached 220MW and should meet its 400MW target by the end of December, also ahead of schedule.

Both new plants, located in Jiangsu, China, are fully financed and fully supplied with both wafer and feedstock for the fourth quarter, according to the company, which will enable the production of 45-50MW of polysilicon cells and upgraded metallurgical grade (UMG) e-Cells internally. This will be supplemented by solar cells supplied from the company's long-term suppliers at competitive prices.

In light of these recent developments, the CSI has reiterated its 2008 top-line revenue and gross margin guidance of US$850 million-US$970 million and 13-15%, respectively. CSI also said that it believes it has secured approximately 4000 metric tons of UMG for 2009, enabling it to produce between 250 and 300MW of UMG e-cells and e-Modules in 2009. As a result, the company has reiterated its 2009 shipment and gross margin guidance of 500-550MW and 13-15%, respectively.

Sanyo chooses Oregon site for new solar PV ingot, wafer factory

Sanyo North America has received approval from the Salem, OR, city council to build a new solar silicon ingot and wafer factory in the community's Renewable Energy and Technology Park. The company says it plans to begin operations at the plant in October 2009 and be at full operation by April 2010, with a production capacity of approximately 70MW and an employee headcount of 200.

The Salem facility will be constructed and organized by a new entity, Sanyo Solar of Oregon. Once the US$80 million, 861,000-square-foot plant is completed, it will bring the parent company's total U.S. photovoltaic ingot and wafer production capacity – when combined with the output of its existing fab in Carson, CA – to approximately 100MW.

Sanyo has set a goal for an annual global production capacity of at least 600MW by fiscal 2010.

Sanyo plans to expand its Shimane, Japan, solar-cell factory from 50 to 130MW by the fiscal year-end of 2008. The company says it will also add 40MW of module capacity at its new Shiga, Japan, assembly facility this year and is considering expansion plans for its Hungarian and Mexican module plants.

Sanyo expects to have 340MW of both cell and module production capacity online at its various manufacturing sites by the end of fiscal 2008.

LDK Solar raising US$150 million for polysilicon and wafering plants

LDK Solar has filed a preliminary prospectus with the Securities and Exchange Commission for a proposed follow-on public offering of American Depository Shares, expected to generate US$150 million. The funds will be used for the construction, currently ongoing, of its major polysilicon plant as well as expanding its wafer production.

Approximately 60% of the net proceeds will go towards the polysilicon plant, with approximately 30% allocated to the capacity expansion of its wafer production facilities and 10% to fund other general corporate activities.

centrotherm photovoltaics awarded follow-on polysilicon plant contract

centrotherm photovoltaics AG has been awarded a follow-on contract to undertake the complete turnkey contract for the second stage of a polysilicon plant expansion plan. The initial project for 1,000MT facility had been handled by a consortium of suppliers and contractors. However the stage two 4,000MT expansion projected will be controlled by centrotherm photovoltaics exclusively, the company said.

GT Solar expands manufacturing, doubles size of factory

GT Solar has opened a 50,000-square-foot expansion at its manufacturing site, doubling the size of the factory to 106,000 square feet, according to a news story in the Sept. 26 online edition of the New Hampshire Union-Leader. Company CEO Thomas Zarrella also told the paper that the plant is increasing its monthly production output from 40 to 75 furnaces.

Company CEO Thomas Zarrella said the expansion will enable GT Solar to hire 50 more assemblers, engineers, technical, and service workers this year, adding to the plant's existing workforce of 270 employees (including temporary workers). The executive also said it will ramp up output further, if demand is there. GT Solar has US$1.3 billion in backlog orders and is projecting US$600 million-US$650 million in annual revenues.

The CEO also said in the news report that the expanded section of the plant will include a dedicated area for R&D. GT Solar engineers are working on new technology that will make a significant leap to reduce the costs and improve the productivity of solar cells, he noted, including finishing designs and the ordering of materials for a next-generation silicon furnace and 400 ton polysilicon reactor.

LDK Solar in startup and commissioning phase of 1,000MT poly plant

In an update to its polysilicon plant construction project, LDK Solar has said that its smaller 1,000MT plant has been completed and plant process commissioning has commenced. Eight reactors and one converter in the reactor/converter station, and eight distillation/purification columns, heat exchangers and associated piping in the TCS purification station have all been completed.

With regards to its larger 15,000MT polysilicon plant, LDK Solar said that work continues on schedule while reiterating that its plans to produce between 5,000 and 7,000MT of polysilicon in 2009, have not changed.

Aerial view of the LDK plant.

ABB signs US$36 million systems and equipment contract with LDK Solar

ABB has announced that it has entered into a more than US$36 million solar equipment, system and service contract with LDK Solar. The agreement will see ABB, the power and automation technology company, supply electrical systems, equipment and project management services to LDK for its new polysilicon production plant in Xinyu City, China.

As project managers, ABB will provide all services required to get the plant up and running. On completion, the plant will be Asia's largest polysilicon plant, boasting an annual capacity of 15,000 metric tons. The first production line is scheduled to be completed in the fourth quarter of 2008, with an estimated output of 5,000 to 7,000 metric tons of polysilicon for 2009.

Thin-film News

Uni-Solar to build fifth thin-film PV plant in Michigan

United Solar Ovonic (Uni-Solar) has decided on Battle Creek, MI, for the site of its next manufacturing facility, according to a news story in the Oakland (MI) Business Review. The Energy Conversion Devices' subsidiary will begin construction on the US$220 million, 120MW facility within weeks of the expected approval of a long-term state tax incentive package.

Once the fab reaches its full production capacity in the second half of 2010, it would employ 350 workers and become the amorphous-silicon thin-film PV company's fifth production facility in Michigan. The news story says that the "deal also gives the company the option to build an identical twin version" of the 270,000 square-foot factory at the site. The company's new production schedule has it establishing new manufacturing facilities every six months through fiscal 2012, spokesman Mark Trinske told the paper.

The company also looked at sites in Malaysia and New York state, according to the Review. The existing infrastructure and ability to begin construction immediately was one of the key selling points for the site, Trinske said. The company has said it plans to reach an overall production capacity of 1020 megawatts by 2012.

First Solar starts Perrysburg capacity expansion

First Solar has broken ground on its planned production expansion at its facility in Ohio, which will add approximately 192MW of extra module capacity at the Perrysburg plant. The plant construction is expected to be completed in the first half of 2009, with full volume production expected by the second quarter of 2010, the company said.

The new facility will add approximately 500,000 square feet of manufacturing, research and development and office space at Perrysburg. First Solar is also building a separate facility for future development of thin film solar module manufacturing technology.

Moser Baer raises funds for silicon solar and thin-film production expansion

Moser Baer's solar photovoltaic subsidiary has raised approximately US$93 million from an international group of investment houses in its bid to expand production of both crystalline solar wafer and thin film operations. Moser Baer is currently establishing a thin-film PV plant near Chennai with a proposed 500MW annualized capacity, using Applied Materials' 'SunFab' turnkey amorphous silicon production technology.

The Chennai facility was initially established with a single, 40MW capacity line, but with the new funds, Moser Baer plans to expand thin-film production to 120MW. On the crystalline silicon front, the company will invest in expanding capacity to 180MW, up from 80MW, with a target capacity of over 600 MW by 2010 in thin-film production alone. Investors in this round of funding included; Nomura, CDC Group, Credit Suisse, Morgan Stanley, IDFC PE, and IDFC.

Dyesol opens 3rd generation cell manufacturing facility

Dyesol, the Australian owned company that makes Dye Solar Cells (DSC), has officially opened two new manufacturing facilities, one in Queanbeyan, New South Wales, Australia and one in Wales, UK. These facilities will enable Dyesol to fast track its commercialisation strategy.

The Welsh facility will help support the Dyesol/Corus collaboration that has also been awarded an assistance package by the Welsh Assembly Government, to accelerate the commercialisation of DSC technology onto steel sheeting. Corus is the world's fifth largest steel producer.

Dyesol Italia srl recently announced it would partner with ERG Renew and Permasteelisa to develop and commercialise next-generation solar panels for buildings. Similarly, Dyesol has established a joint venture company with Timo Technology in Korea (called Dyesol-Timo) to commercialise DSC products in in Seong Nam city in Gyeonggi province.

PV facilities: opportunities for conversion and re-use of semiconductor fabs

Nate Monosoff, CH2M HILL, Oregon, USA

ABSTRACT

Crystalline wafer and thin-film photovoltaics manufacturing have experienced dramatic expansion in recent years, but future growth requires increasingly effective strategies to reduce costs and increase the competitiveness of PV power. Reducing PV manufacturing costs has been a prime focus of the industry. In the current climate, cost reduction is especially critical given the industry shakeout that many analysts are forecasting. Now more than ever, it is important to bring manufacturing capacity online quickly and cost effectively. The vast majority of commercial-scale PV manufacturing capacity is new construction (greenfield), meaning it is purpose-built on an unused piece of land; however, there are alternatives. This paper will outline opportunities for re-use of existing obsolete semiconductor fabs, and the steps required to convert from one manufacturing strand to another. This is an approach that offers manufacturers the potential advantages of reduced costs, more rapid ramping of plants to produce finished product, and the superior sustainability achieved through the re-use of existing facilities.

Introduction

Siting, design, permitting and construction of a traditional greenfield PV facility is a process that can take 1-2 years and exceed USD$75 million for up to 100MW. This process can vary widely depending upon the specific PV technology, scale, location, and building design involved. While PV manufacturing equipment typically represents the lion's share of capital expense for manufacturing startup, the financial and schedule costs of facilities are also important factors in manufacturing scale-up.

The alternative to greenfield construction is to retrofit existing buildings and sites. Going this route is attractive to cut costs and schedule, but it is not easy to find an existing facility with systems suitable for PV manufacturing already operating and ready to go. One intriguing option is to re-use or retrofit existing semiconductor facilities. PV manufacturing in an old semiconductor building is not an obvious match, but this approach is proving appealing enough that a number of PV and semiconductor firms are conducting in-depth assessments.

The semiconductor industry and aging 200mm fabs

The semiconductor industry has been growing and improving exponentially for decades, lowering costs and increasing the performance of its devices in an increasingly competitive market. This mature industry is subject to significant cost pressure and volatile cyclicality. The very survival of semiconductor manufacturers depends on their ability to achieve regular technological leaps – often of major proportions – to meet the demands of the "Moore's Law" dictum that calls for a doubling of chip capability every 18 months.

Semiconductor process and device improvements drove production wafer sizes from 150mm to 200mm in the mid- to late-1980s, and eventually to the current state-of-the-art, 300mm. Many 200mm fabs, built mostly from the late 1980s until around 2000, are now facing challenges as their capacity is shifting to more cost-competitive 300mm fabs.

Semiconductor fabs are not general use buildings. They are highly customized with complex and elaborate mechanical, electrical, and process (water, chemicals, and gas) production and delivery systems. Many of these systems deal with hazardous

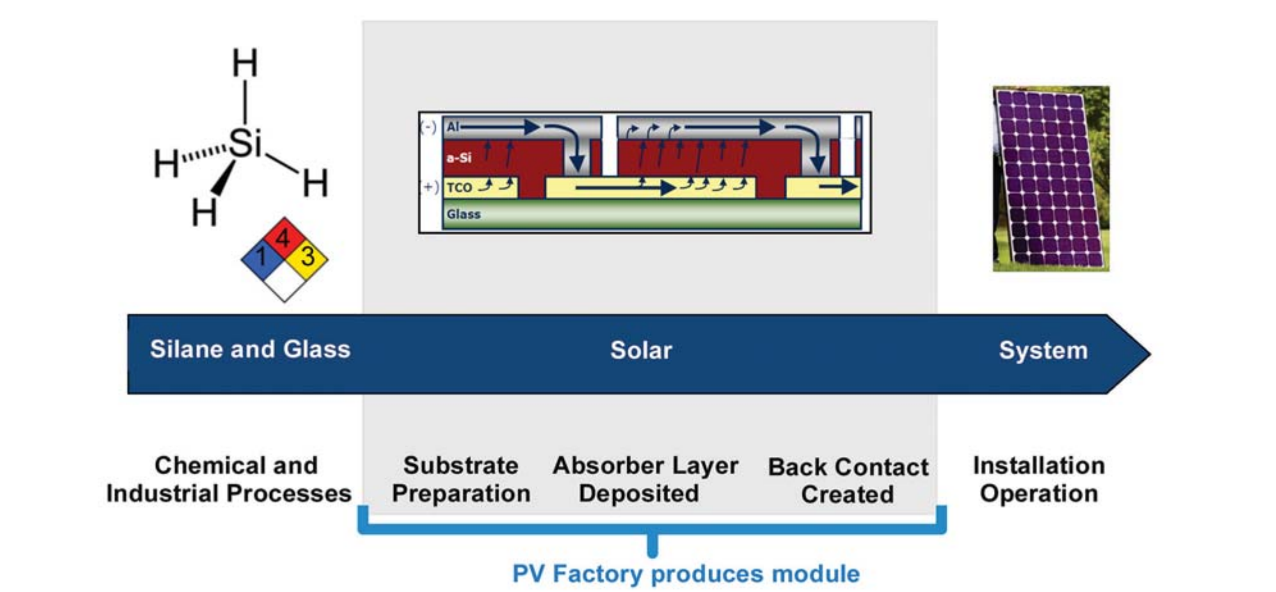

Figure 1. The processes, sequences, and materials related to PV manufacturing shown in this a-Si thin-film process diagram have many similarities to those of semiconductor manufacturing.

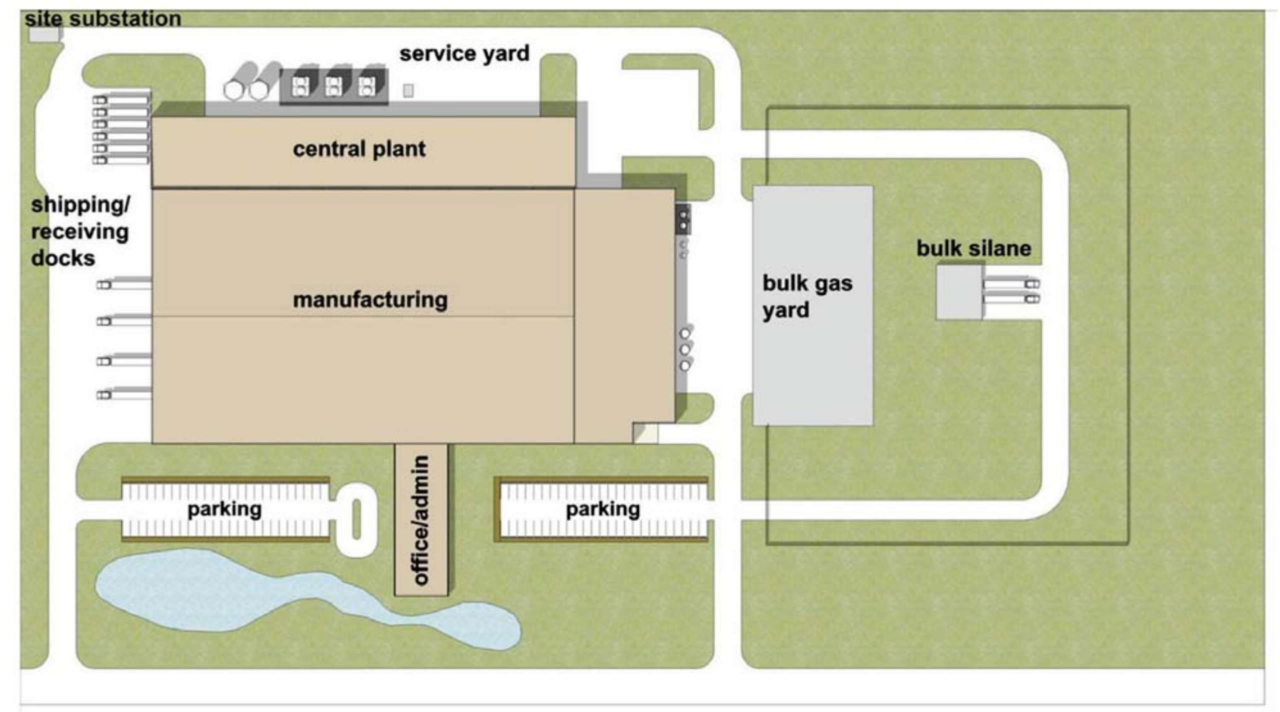

Figure 2. This typical hypothetical site plan for a 50MW PV manufacturing facility bears many similarities to that of a 200mm semiconductor manufacturing site.

and highly regulated materials. While this level of facility customization makes these fabs efficient facilities for producing specific types of semiconductor products, it also makes them very challenging to sell or convert to alternate uses.

Many non-competitive 200mm fabs are facing these challenges now, and many more will face these challenges over the next few years. Of the more than sixty 200mm semiconductor fabs forecast to be candidates for process technology upgrade conversions, CH2M HILL estimates that a quarter will be evaluated for PV. Which of these conversions succeed and which fail to meet expectations depends on how well PV manufacturers match their business strategies and capital improvement budgets to a potential fab conversion property.

The options for aging semiconductor facilities are few: convert the fab or mothball it.

In the past a reasonable option for those who needed the manufacturing capacity and had sufficient capital was to convert a 200mm fab to 300mm processes. Converting to 300mm is an expensive and difficult option that is not always a possibility due to limits of the building and facility support systems. Also, improvements in the efficiency of 300mm process technology have reduced the need for new 300mm facilities.

Mothballing a 200mm semiconductor facility has drawbacks. Moving equipment out and locking the doors creates the prospect of a non-productive and expensive-to-maintain building. To maintain value, the facility cleanroom and many of the facilities support systems must continue to be run even when the semiconductor fab is not in use. Operating these facility systems can cost millions of dollars annually. In addition to annual operating costs, idle or mothballed fabs also continue to incur property taxes and other liabilities. Government regulations may also require the owner to decommission systems containing hazardous material systems that are no longer in regular use.

> "There is the potential opportunity for the PV industry to acquire these assets at a low cost and retrofit them into profitable PV manufacturing facilities."

Because converting to 300mm and mothballing a 200mm fab are difficult and expensive options, there is the potential opportunity for the PV industry to acquire these assets at a low cost and retrofit them into profitable PV manufacturing facilities (see thin-film example in Figure 1). According to analysis by CH2M HILL, there are a number of existing 200mm semiconductor fabs that are potentially good candidates for retrofitting into PV manufacturing.

PV manufacturing in a 200mm fab: a decent fit

At first glance, it may not appear that PV manufacturing is a good fit for such elaborate and complex facilities. No-one would build a new greenfield semiconductor fab-style building for wafer-based or thin-film PV manufacturing because this type of construction would not be cost-effective. However, CH2M HILL has identified a number of advantages and potential benefits of reusing these facilities, and determined that with careful planning and assessment, such a conversion is feasible from both an engineering and cost perspective.

The following is a review of specific issues to be evaluated when considering the viability of converting a semiconductor fab into PV manufacturing.

Business issues

Proximity to critical supply chain materials

PV manufacturing consumables can vary significantly depending on the manufacturing technology required for a particular PV product. The good news is that many materials and consumables required in PV manufacturing processes are also used in the semiconductor industry. Choosing a location with an existing semiconductor plant could be advantageous as there is usually already a supplier infrastructure that can safely and cost-effectively provide the bulk and specialty gases and chemicals required for PV manufacturing.

Access to affordable and skilled labour

A skilled workforce is an important component in justifying the business case of any PV manufacturing operation from both a cost and a quality perspective. Business plans for new manufacturing operations often depend on meeting efficiency, yield, and throughput improvement milestones. The availability of experienced engineers and managers who understand the materials, processes, and equipment

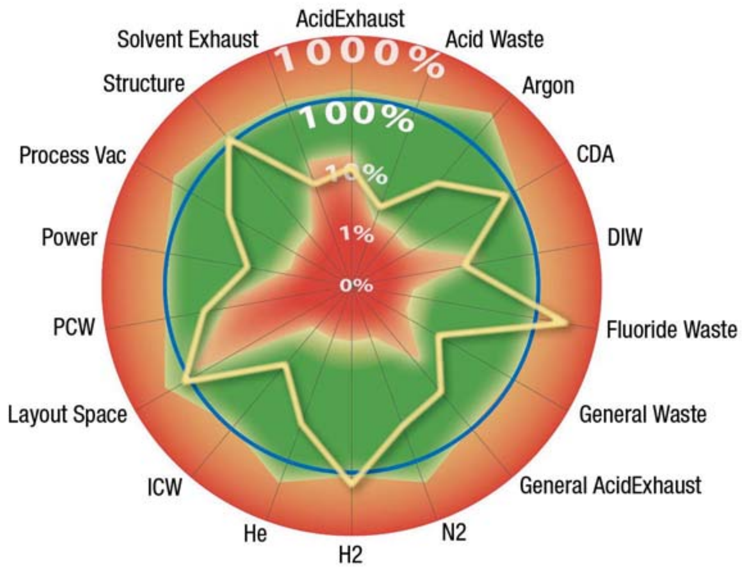

Figure 3. The chart above shows the results of a CH2M HILL study comparing the requirements for a generic 100MW a-Si manufacturing toolset (a composite of major tool vendor requirements) to facility and utilities available in a generic 200mm semiconductor fab. The green regions represent the extents of the "turn-up" and "turn-down" limits per system. Many PV system requirements are shown operating in the green regions, indicating that little effort is required to modify that system to support its new toolset.

common to semiconductor and solar manufacturing is critical to meeting aggressive solar manufacturing ramp plans. The workforce of a semiconductor plant is an excellent pool from which to draw upon in staffing a PV manufacturing plant.

Proximity to customers

Finished PV panels are bulky and heavy products. Freight and logistics costs required to transport them from plant to customer can be a significant factor in total delivered panel costs. Many existing 200mm semiconductor fabs are located in geographic areas that are in close proximity to potentially large PV markets.

Cost and availability of utilities

Semiconductor manufacturing is energy and water intensive. It is likely that existing semiconductor fabs are in locations with access to affordable power, water, and other critical utilities.

Accepting regulatory environments

Many of the gases and chemicals used in PV manufacturing are also used in semiconductor manufacturing. Regulatory agencies near existing 200mm fabs are likely to be more comfortable permitting facilities using these gases and chemicals than locations new to high-tech manufacturing. This built-in familiarity can translate into a smoother and more predictable permitting process.

Building issues

Manufacturing and support space

In general, a 200mm semiconductor fab is a two- to four-storey building with a clean core space on the top floor for clean manufacturing. The core level immediately below is typically a clean support space. The bottom storey and the rooms surrounding the core spaces on all levels are typically less clean support spaces. Separate buildings and areas nearby usually serve as a Central Utility Building (CUB), gas supply and distribution yard, and offices.

In the more modern fabs, 200mm cleanroom floor space (waffle slabs) should generally support 60-200MW of PV production depending on manufacturing technology. According to some recent analysis, this target range of annual solar manufacturing output could represent a potential "sweet spot" for efficient economies of scale. (Again, this is an assumption that is technology-dependant.) Site support areas in a semiconductor fab are typically many times this cleanroom area, and are suitable for reconfiguration into raw and finished goods storage and staging, spare parts storage, consumable storage and distribution, and human resources functions.

Depending on a fab's design, column spacing and other building features in support spaces can make conversion to certain PV requirements such as warehousing challenging, but not prohibitive (see Figure 2).

Structure and interior clear heights

200mm facilities should have sufficient structural strength and interior clear heights in the cleanroom to handle solar wafer or thin film equipment (up to around Generation 5 for typical glass form factors) from the major vendors. Clear heights and structural strength in support spaces can limit warehousing depending on configuration, but with some clever engineering and planning, these challenges shouldn't be prohibitive. PV requirements vary by toolset and technology, and a clear case for physical layout must be made before starting detailed analysis. For certain PV equipment, long clear spans and cranes can be required, and some shoring and structural reinforcement can be required in other retrofit activities. Inter-floor and general material transport issues arising from structural elements such as columns, sheer walls, shafts, and elevators can also be addressed with good planning and renovation design.

Utilities and facility systems

200mm semiconductor fabs have many of the same mechanical, electrical, and process systems required by both wafer and thin-film PV manufacturing. While semiconductor fab systems generally have huge excess capacities and many more points of connection than PV toolsets require, these systems can be "turned-up" or "turned-down" with good design to better meet the demands of the specific PV technology being applied. In most cases, systems must be "turned-down" to accommodate PV manufacturing, but there are exceptions to this norm.

If significant detuning of facility systems is required, the new configurations may operate outside of original equipment's design set-points. These systems may not operate at their highest efficiency, and operating costs will not scale perfectly with use.

Mechanical systems

Most 200mm fabs have huge excesses in air handling capacity, contamination control, and other facility specifications compared to PV requirements for the processing tools and the factory spaces that house them. However, this excess capacity can be "turned down" with relatively little effort by deactivating or removing redundant pumps, air handlers, compressors, sensible cooling coils, chillers, condensers, fans, boilers, and other mechanical equipment. There is also the potential to run the remaining equipment at reduced rates. To offset reconfiguration costs, pre-existing semiconductor-related equipment can be removed and sold on the relatively active global market, or at least be liquidated for its scrap value.

Electrical systems

While total electrical loads in semiconductor facilities are typically more than sufficient to supply PV processing tools, the location of loads must shift significantly from their former semiconductor processing positions. This can involve additional costs associated with removing, re-sizing, and re-installing existing distribution panels, cable trays, and cabling. However, these systems have

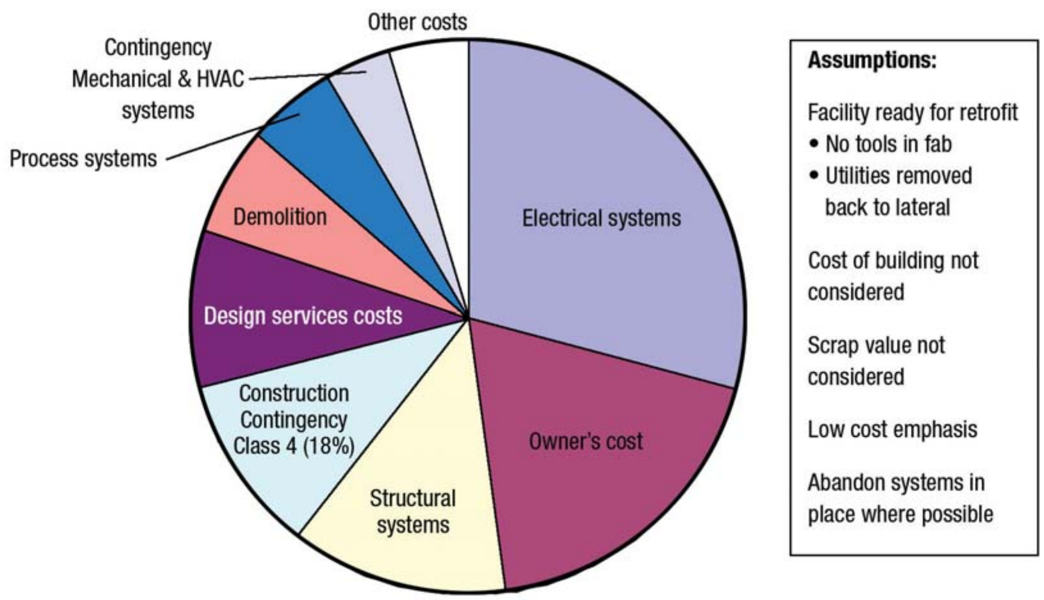

Figure 4. The chart above presents a breakdown of retrofit costs by area. Other costs include life and safety systems retrofit, instrumentation and controls retrofit, architectural systems retrofit, and fire protection retrofit.

a relatively high scrap value, creating the potential to offset the reconfiguration costs of a building's electrical infrastructure. In the CH2M HILL study example below, electrical costs are a significant portion of total direct retrofit costs, but scrap value is not considered. Total retrofit costs are still low compared to greenfield construction.

Water, wastewater, and process chemicals and gasses

Most of the bulk systems required by PV manufacturing exist in a 200mm semiconductor facility. As noted previously, these are among the systems that can often be "turned-down" significantly to align with PV requirements.

The chart in Figure 3 shows some of the results of a CH2M HILL analysis of the utility requirements and other attributes of a 100MW PV a-Si toolset (yellow line) compared to the "turn-up" and "turn-down" limits of a generic 200mm fab (green regions). Many building systems are in appropriate ranges and should entail minimal retrofit efforts.

Permits

Permits can pose significant lead-time constraints when planning greenfield PV manufacturing. Re-using an existing 200mm semiconductor fab and its existing permits can result in significant schedule advantage.

Wastewater permit limits in existing 200mm semiconductor permits should cover most of the waste products related to PV manufacturing, but careful and specific analysis should be conducted because wastewater constituents and volumes can vary widely depending on the manufacturing process, tools, and scale of operation. In the CH2M HILL analysis presented above, fluoride levels in wastewater is one area that should be closely examined to confirm that it will not exceed local discharge limits.

It is likely that existing storm water permits will not need to be modified for most PV re-use scenarios assuming that the project does not involve construction modification outside of the existing building shell. However, in all cases, existing stormwater permits should be reviewed to confirm that no modification will be required.

Air discharge permit conditions are facility-specific and should be considered on a case-by-case basis. However, having existing air discharge permits for a 200mm semiconductor fab may reduce the effort and schedule for permitting any new use.

Accidental release prevention also must be considered on a case-by-case basis, but many programs and protocols carried over from the semiconductor operations can have value in helping establish their equivalents in PV manufacturing. Some hazardous materials common to both types of operations can enable re-use of existing tanks and systems as well as their existing certifications.

Hazardous occupancy codes for 200mm semiconductor fabs vary around the world. PV manufacturing facilities tend to utilize fewer dangerous materials in lower volumes, and are typically classified in a lower hazard category. This has the potential to streamline the new permitting or permit re-classification process.

Summary

Aging semiconductor facilities are facing a dilemma, as they are increasingly being outperformed and displaced by 300mm fabs. The PV manufacturing industry may be able to take advantage of these underutilized facilities and transform them into profitable manufacturing centres. This strategy offers benefits for both the semiconductor fab owners and PV manufacturers; fab owners can extract new value from their outdated fabs, and PV industry manufacturers can significantly reduce project schedule and potentially reduce facility cost. This strategy also offers the satisfaction of knowing that the sustainability of these projects is being enhanced through the re-use of existing facilities.

According to the CH2M HILL study, PV manufacturers may be able to reduce facility costs by up to 50% compared to a greenfield approach, and reduce schedules by between 30-50%. While this scenario looks attractive, especially with a premium on reducing initial capital cost and speed to market, the details of specific fab re-use opportunities require a detailed analysis of retrofit and permitting requirements.

The success of any semiconductor to PV conversion or retrofit will depend on the ability to manage change in complex and fast-moving environments, something both the semiconductor and PV industries understand well. These industries have a shared heritage of ingenuity, adaptability, and reduction of costs per unit of performance that encourages exactly this type of creative solution for manufacturing cost and schedule challenges.

About the Author

Nate Monosoff is a Technologist with CH2M HILL's Industrial Client Group. He has extensive experience in early stage factory planning, industrial engineering, modelling, utility planning, tool layout, and consulting for manufacturing and technology development clients. His expertise spans photovoltaics, nanotechnology, FPD, MEMS and semiconductor manufacturing, and includes cost modelling, business start-up consulting, and strategic planning.

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Evaluating factory performance of photovoltaic manufacturing lines by using log data

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ABSTRACT

Investments in large photovoltaic factories can lead to high capital expenditure. To achieve a fast return on investment, it is essential to ensure a high utilization of process equipment. Optimization of photovoltaic factory performance requires a fundamental understanding of the processes as well as of the material flow and manufacturing equipment. Fraunhofer IPA has developed an approach to gather and analyze the factory data in order to detect and understand the logistic influencing factors. With this factory data, the performance of material flow systems and production equipments can be evaluated, leading to detection and elimination of inefficiencies in the manufacturing lines. The methods of acquiring and analyzing factory performance data as outlined in this article mainly focus on thin-film manufacturing lines, but are also applicable to crystalline technologies.

Introduction

Material flow systems are becoming more and more important in the photovoltaic industry. Factory capacities and their throughput increases, as well as modern factories, have a high degree of automation. An optimized logistics planning and operation of the factories is therefore crucial to the economic success of the factory. Similar to almost all other manufacturing industries, the material flow system has comparably low investment and running costs. A good planning and optimization of the system is mandatory to avoid production losses caused by lack of material. Furthermore, valuable performance data is needed to achieve good planning and further optimization.

Material flow systems

A high degree of automation in material handling and transportation is implemented in current thin-film factories. The different handling systems are controlled by a supervising software system that controls the flow of the material throughout the factory. Due to there being potentially several different hardware suppliers of the material handling systems and the lack of a standardized equipment interface, this task is challenging in terms of data collection and data management. The situation becomes even more complex in the case of a combination of batch and single substrate handling, as tracking of each substrate produces a huge amount of data, if properly implemented. Using appropriate tools, this data can be used to evaluate the performance of logistic systems.

The predominant task of a transport system is the on-time delivery of lots or single substrates within the factory. The importance of the task is especially pertinent for bottleneck processes as unnecessary idle times lead to expensive unused capacity. To evaluate the performance of transport systems, different indicators can be analyzed:

- Utilization, which shows the capability of a transport system to react to different workloads.
- Delivery time – the time needed to accomplish a transport task.
- Waiting time, or the period of time in which material is waiting to be transported after a finished process.

The schematic in Figure 1 exemplarily shows time segments and time stamps that are recorded while substrate handling occurs throughout the batch transportation area of a factory. The time sequences of an automated lot transport task from equipment A to equipment B is clearly portrayed. (We use the term "vehicle", but other transport methods can also be used.)

Time segment 1: A lot is finished at a process and ready to be picked up. The time until a vehicle arrives at the load port (referred to here as t_1).

Time segment 2: The time needed to load the lot onto the vehicle (referred to as t_2).

Time segment 3 & 6: The time taken for the vehicle to arrive at the destination load port (referred to as $t_{3,6}$).

Time segment 7: The time needed to unload the lot, or set-down time (referred to as t_7).

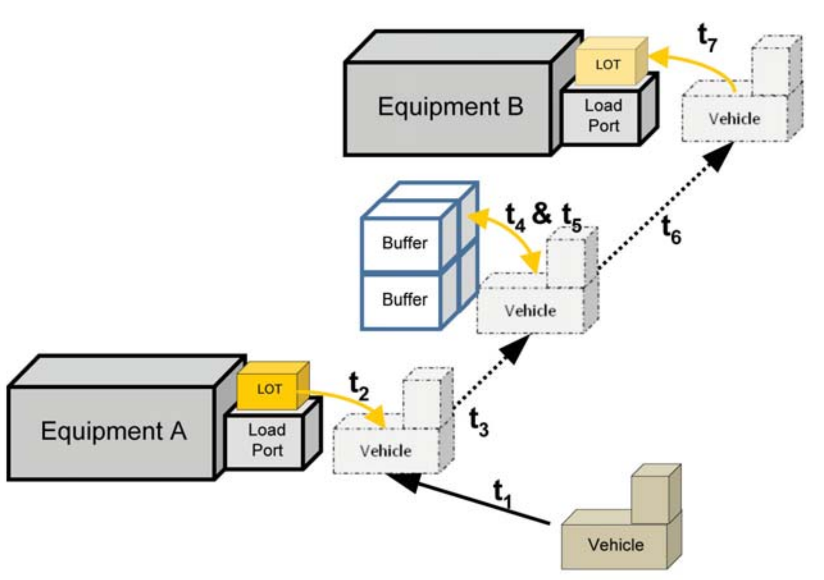


Figure 1. Time segments of an AGV-based lot transport.

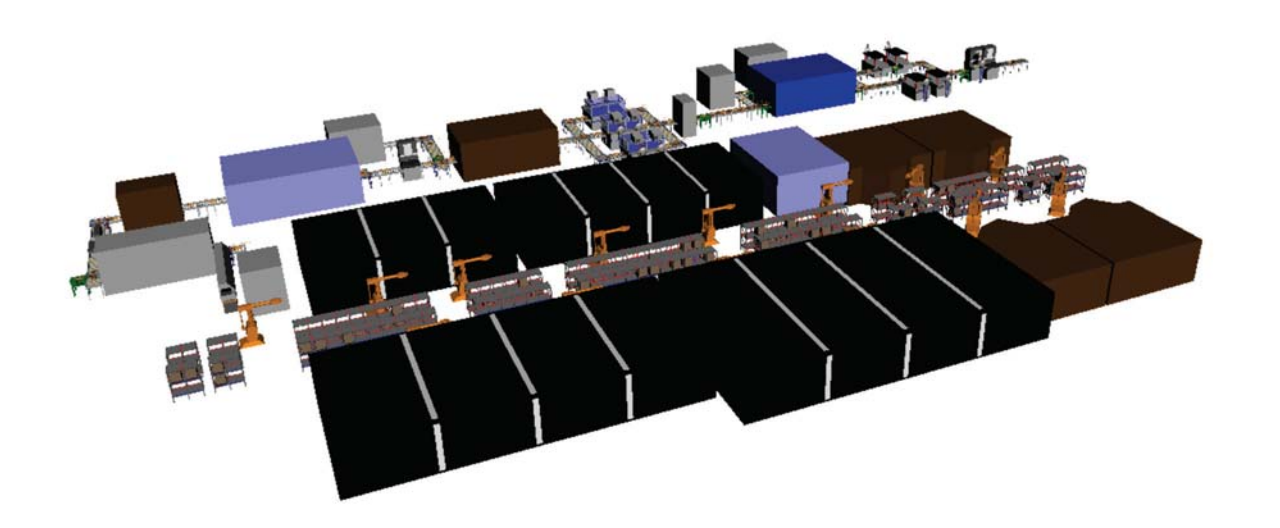


Figure 2. Example layout of a manufacturing line.

Timestamp	Event	EquipSection	LotID	CassetteID
14.02.2007 06:03:59	Substrate Entered	Fab In	1	22
14.02.2007 06:04:20	Location Changed	Rack Out	1	22
14.02.2007 06:04:45	Location Changed	Rack In	1	22
14.02.2007 06:06:02	Substrate Entered	Process In	1	22
14.02.2007 06:07:38	Substrate Entered	Fab In	2	85
14.02.2007 06:08:04	Location Changed	Rack Out	2	85
14.02.2007 06:10:38	Substrate Removed	Process Out	1	22
14.02.2007 06:10:53	Location Changed	Rack Out	1	22
14.02.2007 06:12:14	Location Changed	Rack In	2	85
14.02.2007 06:12:16	Substrate Removed	Fab Out	1	22
14.02.2007 06:13:49	Substrate Entered	Process In	2	85

Table 1. Simplified example of a log file of logistical performance data.

The main indicator delivery time is defined as $t_{delivery} = t_1 + t_2 + t_{3,6} + t_7$

In the case of a lot needing to be buffered before it is transported to its destination process, the overall calculation changes. A transport task would then go from equipment A to a buffer as destination, and the subsequent transport from this buffer to equipment B.

Figure 2 shows a factory layout where the performance of the transport system can be evaluated by using the approach described in the following section.

Acquiring factory performance data

During the last few years, great progress has been made in measuring and improving the performance of cells and modules. The photovoltaic industry was (and to an extent still is) driven by technology aimed at improving the product. This is due to the small time span (relative to mature industries) of production of several photovoltaic products and processes. On the brink of mass manufacturing, this situation is going to change. Already, operators of factories do not only focus on high product quality, but also on achieving a stable and high factory output.

The situation in many factories today is characterized by a fluctuating level of module performance, even for products of the same production batch. This holds especially true for the thin-film branch of photovoltaics. The peak power of the modules often differs by several watts. Factory owners would prefer a stable output rather than the fluctuation of modules with a very high performance and modules with low performance, as it would facilitate a systematic investigation for the reasons of low module performance as well as a reliable volume which can be put on the market.

At the same time, factory owners are focusing more and more on factory output, which, in terms of cells or modules, depends on the following parameters:

- Yield (amount of modules meeting the quality requirements)
- Scheduled maintenance activities of equipment
- Unscheduled repair activities of equipment
- Lack of material and other circumstances causing equipment stand-by time

All these factors have a huge impact on the output of the factory. Therefore, it would be beneficial if there were ways of measuring these parameters in order to carry out reliable analysis. Unfortunately, this data is often not available or the reliability of the data is deemed too low. The main reasons for this are the lack of sophisticated MES (Manufacturing Execution System) in the factories as well as missing standardized interfaces for linking manufacturing equipments to the MES.

Reliable data such as this would be highly beneficial, especially in the operation of large factories. Future factory control systems will not only deliver accurate data from measurements and process parameters, but also data about factory performance in terms of logistical throughput.

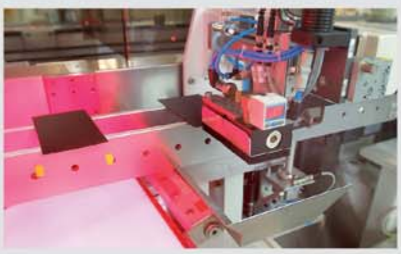
Data for measuring logistical performance is partly available from running factories, and this paper will illustrate the usage of this data in the following sections. The data shown in Table 1 originated from a production process in which substrates are transported in cassettes and also partially processed in batches.

The data is structured in a log-file format. Specific pre-defined events are recorded and stored, typically in a text file. In the case of logistical performance measurement, the events are triggered if a substrate or a carrier (cassette) is moved from one defined location to another (e.g. from a conveyor belt into a process equipment). This procedure requires the tracking of substrates or carriers, which might not be the case in inline wafer manufacturing lines.

Typical data sets usually contain more information, but the reduced complexity shown in Table 1 illustrates the structure of the data more clearly. The main columns of the example are:

Timestamp

Every recorded event is equipped with a timestamp of the occurrence of the event. Timestamps usually include date (day, month and year) and time (hour, minute and second).



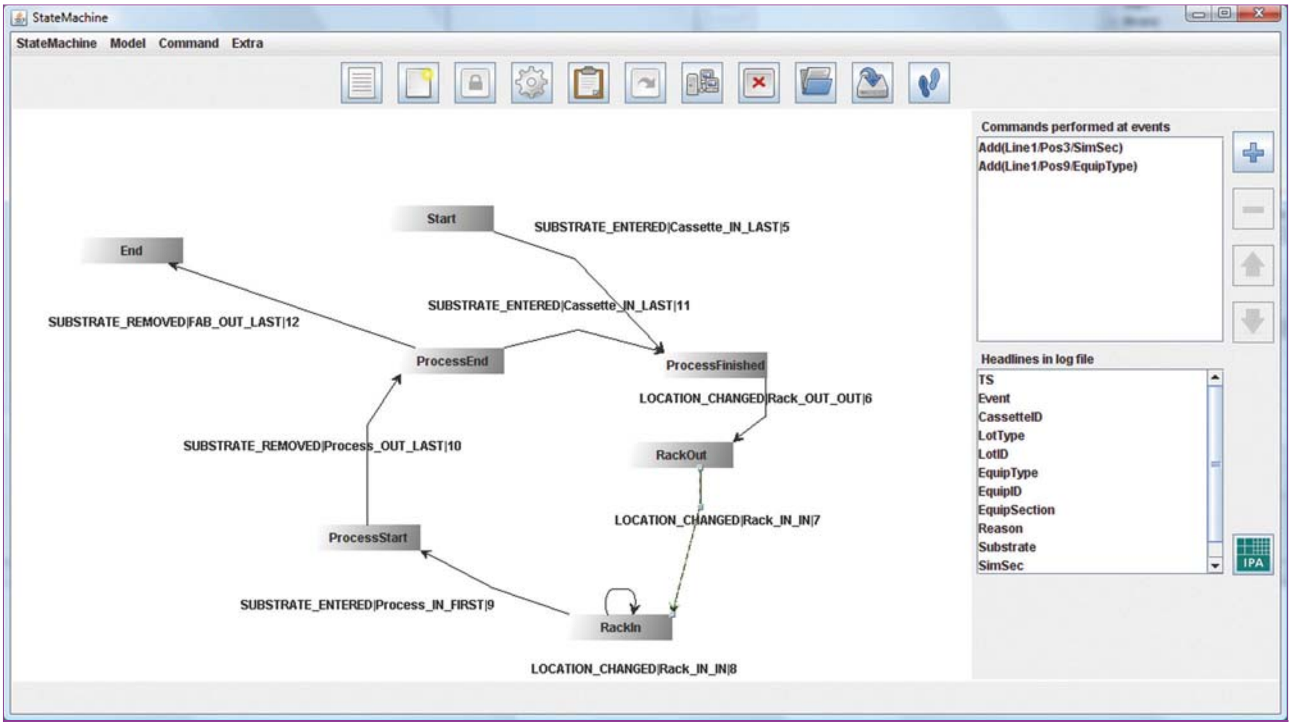


Figure 3. Example state model in Fraunhofer IPA state machine tool.

Event
An event designates the activity that has been carried out with a substrate. An event can also be enhanced with optional sub-events to further specify the activity.

Identification
Identification is effected via identification numbers. Lots have an identification number, as do containers, also called cassettes. Shelves, which serve as racks, often also feature a distinct identification number.

Typical further data fields in the log file are equipment-ID, equipment section, substrate or lot type, cassette-ID and sub-events. Further sources of logistical performance data are simulation models, which are used to plan and optimize photovoltaic manufacturing lines and factories. The described method of acquiring performance data has several advantages. One would be the simplicity of the data as the structure is well defined and can be implemented in almost every type of control system. Although the structure itself is simple, a broad spectrum of different analyses can be obtained from the data. Therefore, almost every needed logistical analysis is based on the same data set.

Using finite automat
The idea behind the analysis is the sequential run through the log file, which is sorted by the timestamp. An object (e.g. a lot) is defined as a tracking item. A separate object is created for each such tracking item to allow each item to be tracked individually. The procedure now foresees that a tracking item can be situated in different states. The state changes if a pre-defined event occurs in the log file. By changing a state, a definable activity can be carried out. In our case, this is usually the creation of a tracking item and the gathering of information out of the log file. The concept behind this approach is called a finite automat.

A finite automat M is specified using a 5-tuple $M = (Z, \Sigma, \delta, z_0, E)$. It consists of five components:

- Z is a finite amount of states
- Σ is the so-called input alphabet
- $\delta: Z \times \Sigma \rightarrow Z$ is the transient function
- $z_0 \in Z$ is the start state
- $E \subseteq Z$ is the amount of end states.

A finite automat is moreover called deterministic if at one state, the following state is clearly defined by a certain character input. Finite automats can be illustrated by means of directive, labelled graphs. The states are mainly demonstrated through use of nodes, whereas the transition from one state to the next is represented by arrows. We refer to such a model as a state machine.

Finite automats are now used to build graph models of different chains of transport moves that can occur in a factory. A simplified example of such a graph is depicted in Figure 3. The model is described by three entities.

States
Material can be situated in different states. For instance, a lot can be in a state of waiting on a load port to be picked up by a vehicle (as shown in Figure 1). For each lot that is created, a start state is defined. The end state is reached as soon as the lot has arrived at the defined terminal stage (e.g., removal from the manufacturing line or reaching a specific process) and is no longer considered part of this analysis.

Events
The events constitute the input alphabet of the finite automat. An event occurs if, for example, a lot is transferred from the load port onto a vehicle.

Transitions
The transient function is defined as the shifting of an entity from one state to another caused by an event.

To evaluate the performance of the transport system, the log files of real MES/MCS factory data or from simulation models have to be analyzed. All valid states of the tracking item have to be defined, as shown in Figure 3. Additionally, all transitions that can occur need to be noted in combination with the events that are triggered by them ("Location changed|Rack_OUT" in the example). Finally, the entity type that is to be tracked can be chosen. Depending on the purpose of the analysis, this could be a number of entities ("LotID"; "ContainerID"; "SubstrateID"), depending on the purpose of the analysis. This information is sufficient to create the finite state model and perform evaluations using the Fraunhofer IPA state machine tool. This tool also provides the possibility of automatically analyzing the log file and listing all of the available discrete events for modeling.

Using this model, the state machine can be configured to parse the log files and extract and process the data according to the needs of the user. Therefore, "commands" can be defined, which allow the customization of the result file generated by the tool. This typically incorporates timestamps, locations or the change of the tracking entity (e.g. from SubstrateID to ContainerID).

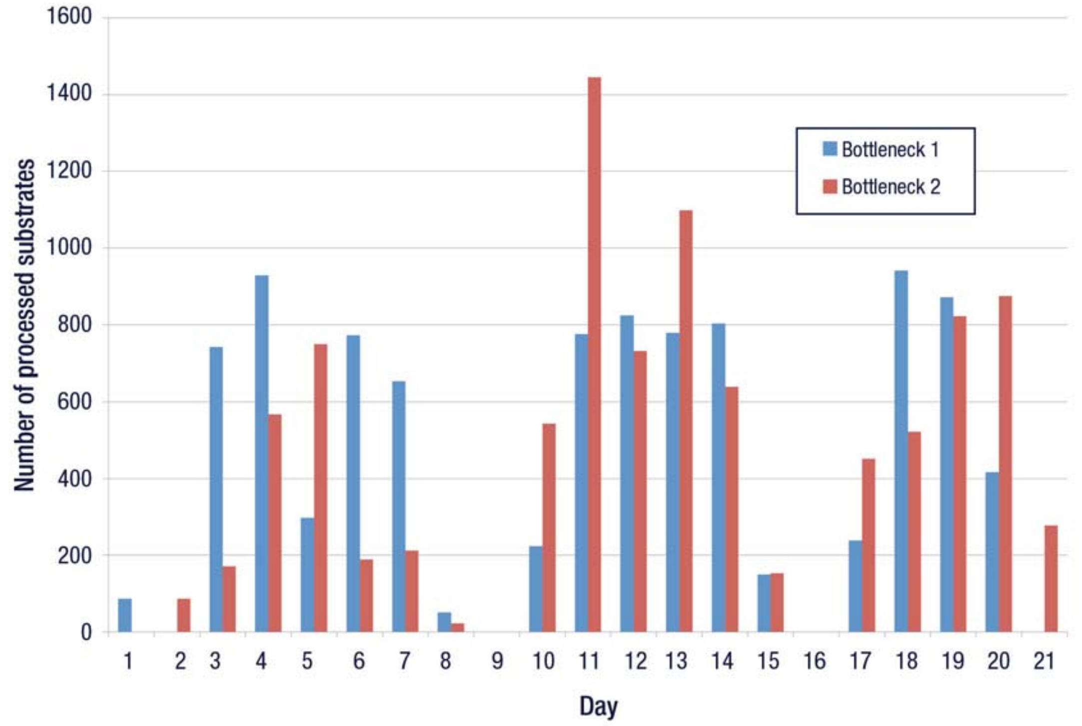


Figure 4. Analysis of the throughput of two bottleneck processes.

Results

The described procedure is currently used to benchmark results from simulation models as well as to analyze the factory behaviour.

An example log file has been used to analyze factory behaviour during ramp-up. The timeframe of the analysis was set to three weeks, whereas longer or shorter periods are also possible. The factory produces thin-film modules in a factory that is based on a job-shop principle. The challenge of the used technology and the factory are twofold. As with other factories, the available tool-set is characterized by a considerable amount of non-redundant process equipment. The other challenge is technology-related. In order to ensure a high throughput, the work-in-progress (WIP) in the line has to be high in order to avoid stand-by times. Contrary to this, the interval between some processes should not exceed a specific time-span, while other processes also require a minimum interval. This conflict of objectives requires further analysis.

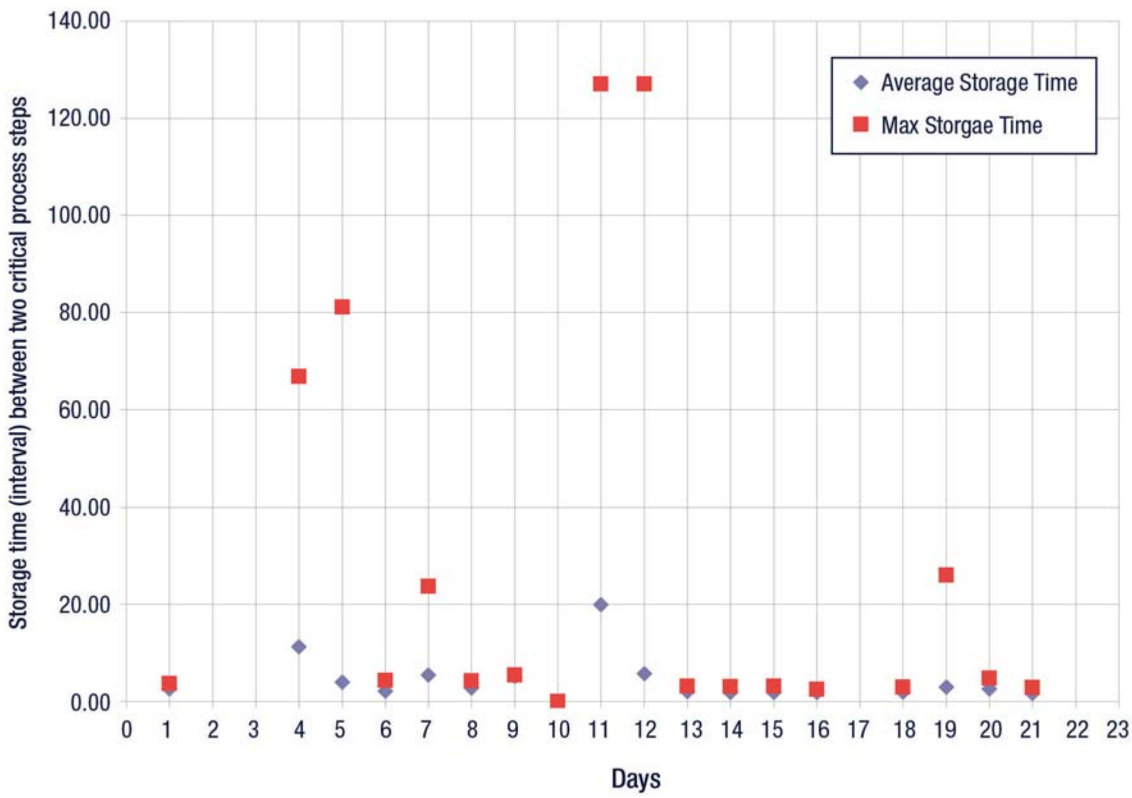


Figure 5. Storage time (interval) between two critical process steps.

The factory operates two major bottleneck processes as shown in Figure 4. During the ramp-up phase, the factory had lulls in operation of 1-2 days to allow for technological and logistical adjustments. Because of the bottleneck processes, the throughput is not stable and it is clear that the succeeding process frequently has to work off the surplus from the preceding process. The preceding process therefore needs to be stopped to allow reduction of the stored substrates.

The balancing of the WIP is difficult to achieve, at least during the ramp-up phase. Therefore, the intervals between the processes cannot be maintained. Figure 5 shows the storage time (interval) between two critical process steps. The substrate should not exceed a time-span of a few hours. However, this time-span is frequently exceeded; some days the substrates have to wait several days before the next process starts. This can be accepted during the ramp-up of the factory, but it has to be managed for constant operations.

Summary

In the future, we will have a much better comprehension of production processes and influences on module performance. Dependencies and influences of the processes will play a larger role in achieving a high and constant level of module performance. Alongside these technological advantages, factories will also grow in capacity, requiring a detailed planning and evaluation of material flow systems. With the proposed methods and tools, the planning and optimization of a factory can be carried out efficiently. This will not only support the factory in question, but will hold great benefit for future factories in the precision of their planning and configuration.

About the Authors

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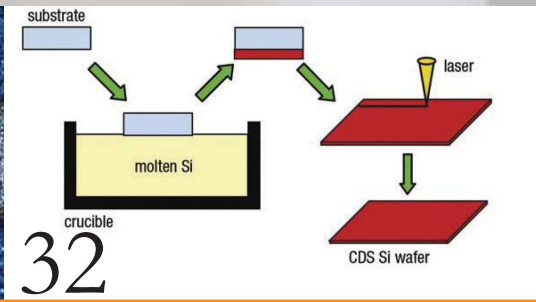

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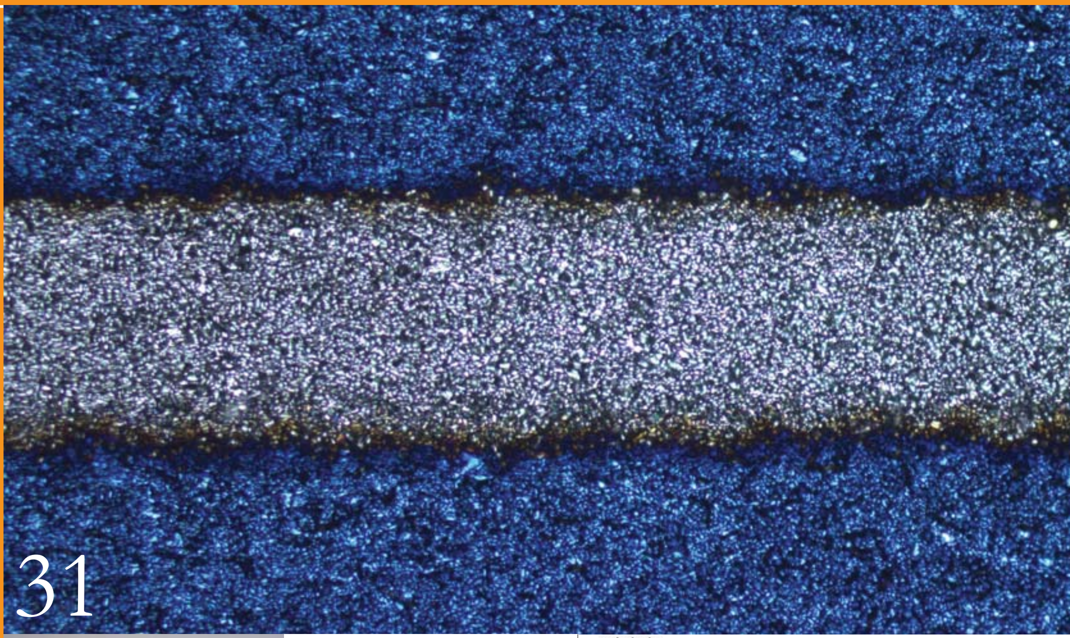
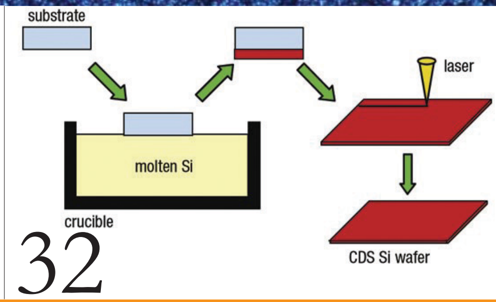




News

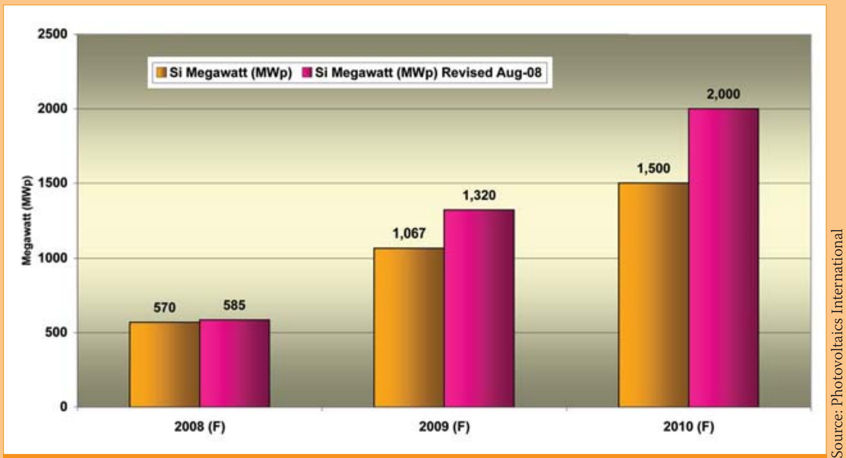
Q-Cells taps LDK solar for 20,000MT of UMG-Si wafers

Q-Cells AG has signed a significant supply deal with LDK Solar for upgraded metallurgical silicon (UMG-Si) based wafers. The signed MOU (Memorandum of Understanding) will see LDK Solar process approximately 20,000MT (metric tones) of upgraded metallurgical silicon into wafers for Q-Cells, until 2018, with an option for an additional 21,000MT. Supply of the UMG-Si wafers is to start this year, the companies said.

Earlier this year, Q-Cells signed a umg-Si supply deal with Becancour Silicon, Inc. (BSI), a division of Timminco. The initial deal was later increased to 6,000 metric tons per year in the years 2010 to 2013.

Q-Cells had also recently said that it would use UMG-Si wafers exclusively at its new 300MW solar cell facility, Line VII in Malaysia. The Malaysian facility is expected to start production early in 2009. The company is also using UMG-Si at its production facility in Thalheim, Germany which initially has a 20MW capacity but is being expanded to 80MW later this year.

Q-Cells also announced that LDK Solar will provide up to 5GW of silicon solar wafers that are additional to the original contract signed in December 2007. The company reiterated production forecasts of more than 1GW in 2009 and over 2GW in 2010. Total production capacity that includes thin film is expected to reach 2.5GW in 2010.



Q-Cells AG: Si MW production forecast (September '08).

Polysilicon and UMG News Focus

Timminco updates solar-grade silicon operations, sees production of 1200-1500 metric tons in 2008

PV silicon manufacturer Timminco has updated its solar-grade production and operations numbers for the third quarter, saying it manufactured 342 metric tons and shipped 300 metric tons during the period. The totals bring the year-to-date shipments to more than 600 metric tons, according to the Toronto-based company.

The company said production and shipments increased sequentially each month during the quarter, with September production reaching a record monthly volume.

Timminco also reiterated its guidance for shipments in 2008 in the range of 1200-1500 metric tons of metallurgical-grade solar silicon.

The company has been expanding its manufacturing capacity this year with a stated nominal annual goal of 14,400 metric tons. It also recently announced long-term solar-grade silicon supply deals, totaling 7150 metric tons, with Q-Cells and an unnamed major wafer producer.

A crisis of credit for Solarvalue's metallurgical silicon ramp

In an announcement, Solarvalue has recognised that the schedule to ramp it's Slovenia silicon facility has met financing and R+D set backs. Solarvalue is now unlikely to ramp this facility to produce metallurgical grade silicon until 2009. Recent studies on the pilot production line in the U.S. by Evans Analytical Group and Balazs have found some issues with the crucibles being used.

Dr. Julio Bragagnolo, Chief Technology Officer of Solarvalue AG: "It made sense to us to start building the industrial scale production equipment in Slovenia only after having final specifications from the laboratory scale production facility in the U.S. However, we had several unexpected issues in developing the laboratory size production. Today, we are well on our way to completing this development. A severe problem was crucible breakage, which turned out to be a supplier issue, but took us several months to evaluate. To make sure that future industrial scale production will work efficiently and at moderate production cost we decided to build a test furnace that will give us the possibility to provide some hundred-kilogram samples to potential customers. We expect the furnace to be built in the near future."

GT Solar enters Taiwan market in US$46.8 million contract with Top Green Energy Technologies

GT Solar International, Inc. has secured its first contract with a Taiwanese company in its recent announcement of a US$46.8 million contract with Top Green Energy Technologies, Inc., a Taiwan-based solar cell producer. The agreement will see GT Solar supply the company with CVD reactors, STC converters and an integrated support module, as well as instrumentation, piping and controls for all gases and water entering and exiting the reactors.

Suntech signs new US$750 million polysilicon supply agreement with DC Chemical

Suntech Power has signed a new seven-year polysilicon supply agreement with DC Chemical Co. Ltd., worth approximately US$750 million from 2010 to 2016. In March, 2008, DC Chemical entered into its first polysilicon supply deal with Suntech, worth approximately US$631 million with supply running from 2009 to 2016.

MEMC remains cautious on polysilicon production ramp

MEMC Electronic Materials has said that it continues to add polysilicon capacity at its Pasadena, Texas facility after several unscheduled disruptions in recent months. The company said in a mid-quarter update that it expects revenues of US$560 to US$620 million for the quarter, which is in the upper half of its previous guidance.

MEMC also noted that it has received full deposits from both Conergy and Tainergy for 2008, with wafer deliveries now begun.

LDK Solar selects DWT's Filament Saws for 15,000MT poly plant

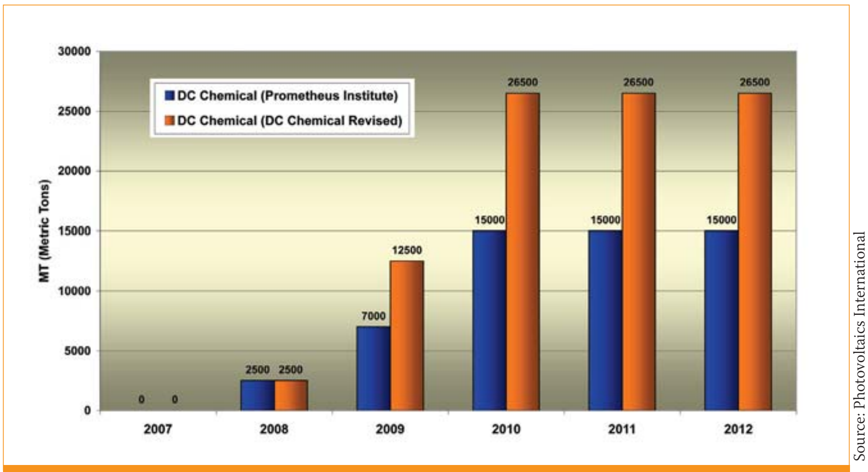
LDK Solar has selected Diamond Wire Technology's SR200 Filament Saws to be used in LDK Solar's new 15,000MT polysilicon production plant currently under construction in Xinyu City, China. The custom filament saws are claimed to cut up to 100 percent more filaments, with lower kerf, resulting in more material for use in the production of polysilicon rods.

DWT claims that its SR200 Filament Saw can produce more than 360 filaments per day on 120mm rods and cut filaments up to 150 microns in diameter and 2500mm long into 7mm x 7mm rods in one cycle.

DC Chemical places US$173 million polysilicon CVD reactor order with GT Solar

DC Chemical has placed an order with GT Solar worth US$173 million with GT Solar for polysilicon CVD reactors as part of DC Chemical's aggressive production ramp to meet long-term supply contracts. This is the third contract signed between the two companies.

Shipments of the CVD reactors signed in this latest contract are expected to begin in April 2009.



DC Chemical Korea polysilicon production ramp (2008-2012).

Wacker Chemie aims to be largest polysilicon producer with new capacity expansion plans

Wacker Chemie AG has announced new polysilicon expansion plans that would see the company become the largest producer in the world, when the new round of capacity comes on stream in 2011.

Wacker said it would increase the capacity under its current 'Phase 8' expansion from 7,000MT to 10,000MT as well as starting 'Phase 9,' a further 10,000MT expansion that will see capacity reach 35,000MT by the end of 2011. The expansions are expected to cost €760 million.

The new 10,000MT polysilicon plant will be built at Nünchritz, Saxony, Germany, which has already seen the company invest over €550 million. Approximately 450 new jobs will be created.

"We expect crystalline solar technology to show continued strong growth and customer demand for polysilicon to remain high," said Dr. Rudolf Staudigl, CEO of Wacker Chemie AG. "Already the world's second-largest polysilicon producer, we intend to reinforce and extend our market position by intensifying capacity expansion."

Hemlock is currently completing a US$1 billion expansion in production and has been reported to be looking for a new plant location to begin the next phase of growth.

GT Solar wins new US$32 million CVD reactor order from LDK Solar

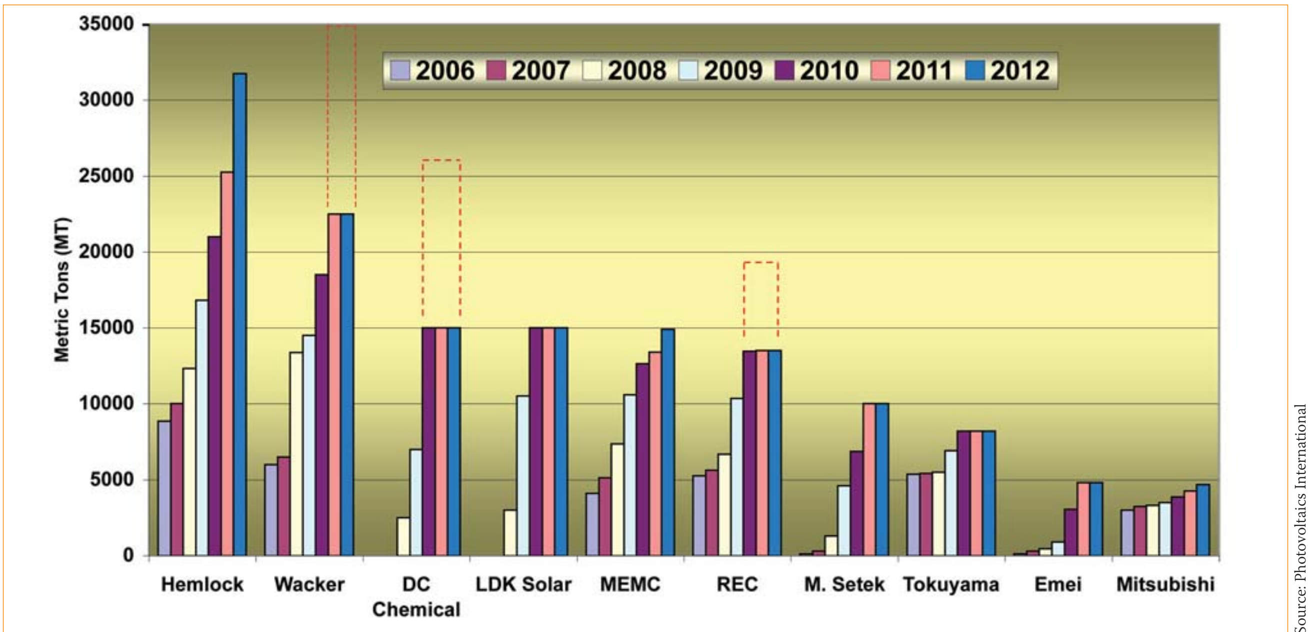
LDK Solar has placed a new order with long-term CVD reactor supplier GT Solar, worth US$32 million. The reactors will be used in LDK Solar's manufacturing facilities in Xinyu City, China as it continues to add new capacity to meet market demand. LDK doubled wafer production in 2007, reaching nominal capacity of 400MW. At the beginning of the year, LDK Solar expected to reach a capacity of 800MW in 2008. However, this has been revised upwards at least twice since then and is now expected to reach 1.2GW by the end of 2008. The company has also recently said that it was sold out through 2009.

PV silicon start-up Confluence Solar lands US$12.7 million in Series A financing

Confluence Solar has raised US$12.7 million in a Series A financing round led by Convexa Capital. The high-quality photovoltaic silicon manufacturer will use the money to help finance the opening of its new facility in Hazelwood, MO, where the company will develop its HiCz single-crystal product, which it says produces greater watt output than that found in traditional multicrystalline silicon platforms.

Oslo, Norway-based Convexa was joined by Korean materials company DC Chemical, Norwegian concern Scatec Adventure, California venture capitalists Oceanshore Ventures and other investors in the funding round.

Confluence, which was founded in 2007, says it has developed strategic relationships with key suppliers for all critical raw materials, supplies and equipment – including polysilicon.



Prometheus Institute: polysilicon production ramp 2006-2012 (revised October '08)

Hoku shuffles customers and polysilicon capacities

In a major effort to realign financial requirements for the construction and development of its first polysilicon plant, currently being built in Pocatello, Idaho, Hoku Materials, Inc., a wholly owned subsidiary of Hoku Scientific, Inc. has cancelled certain future supply contracts in favour of others that provide up-front multi-million dollar deposits, reducing the burden of raising further cash for the project.

Hoku Materials has cancelled polysilicon supply deals with Sanyo and Global Expertise Wafer Division, Ltd. (GEWD), a wholly owned subsidiary of Solar Fabrik AG, which were not conditional on significant cash deposits. The company said that each company had only made US$2 million each in pre-payments with those amounts being returned to them.

Hoku also said that the expected capacity at its Pocatello plant of 3,500MT had been oversubscribed, so the cancellation of earlier signed contracts would also free capacity for further deals based on deposits. The plant is estimated to cost approximately US$390 million.

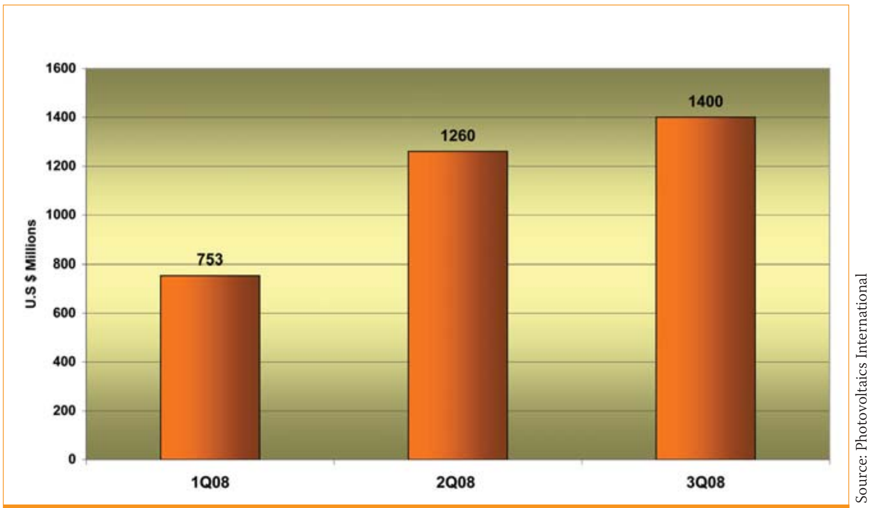
Hoku now retains prepayment commitments totaling US$270 million. With the signing of its three most recent contracts, with Kinko Energy, Tianwei New Energy, and Wealthy Rise International, Ltd. (Solargiga), worth more than US$1 billion in future revenues, Hoku now has US$30 million more in committed prepayments than from the contracts signed in 2007.

Recently, the company finalized and obtained the necessary air permits to operate its plant at 4,000 metric tons of capacity. Hoku reiterated that it was on schedule for first commercial shipments to take place in the first half of 2009, with full plant capacity reached in the first half of 2010.

Yingli Green Energy signs fifth polysilicon contract with Wacker Chemie

Wacker Chemie AG has signed a new 380MW equivalent polysilicon supply contract with Yingli Green Energy, making it the fifth long-term deal the two companies have secured since 2006. The new deal starts in 2010 and runs through the end of 2017.

Liansheng Miao, Chairman and CEO of Yingli, said that Yingli has five polysilicon supply deals starting at the beginning of 2009 that will enable the company to produce more than 230MW of PV modules next year. The company has a total planned capacity of 600MW of module production for 2009.



GT Solar order backlog (US$millions).

GT Solar's order backlog exceeds US$1.4 billion

GT Solar's order backlog second quarter financial results topped US$292 million, resulting in its total order backlog exceeding US$1.4 billion, up from US$1.26 billion at the end of the first quarter. GT Solar also shipped more than 200 DSS furnaces to the solar market with many orders shipped ahead of schedule due to customer demand, the company said.

GT Solar noted its sixth agreement for DSS furnaces with Sino American Silicon (SAS), of Taiwan and an agreement with China-based KMYY.

The company also said that it was developing a 400 metric ton polysilicon reactor, which would produce silicon faster with up to a 30 percent reduction in energy usage, significantly reducing polysilicon production costs.

Silfab secures funding and major supply contract with Sino-American Silicon

Italian high-grade (9N) polysilicon start-up, Silfab S.p.A., has secured a €30 million investment in the company from Sino-American Silicon Product, Inc. (SAS), a Taiwanese manufacturer of polysilicon wafers for use in both photovoltaic and semiconductor industries. Silfab has also entered into a 500MT per annum polysilicon supply deal with SAS that will start in 2010 and last six years.

"With this investment, we have met our initial capital-raising goals, and are squarely on track to meet our original project schedule." said Franco Traverso, Silfab Chairman and CEO.

Pan Asia Solar had invested the initial €54 million in Silfab, which in addition to the €30 million invested by SAS, brings the total equity capital raised to €84 million. Production of up to 5,000 metric tons per year is the target, starting in late 2009.

Wafer News Focus

'Black Silicon' to see the light of day

Harvard University spin-off SiOnyx, founded by Professor Eric Mazur and Dr. James Carey in 2006, has exclusively licensed Harvard's portfolio of 'Black Silicon' patents. The 'Black Silicon' relate to a highly light-absorbent material that absorbs nearly twice the visible light of regular silicon and detects infrared light that silicon based devices cannot utilize. SiOnyx claims it is able to produce silicon detectors and photovoltaic devices that respond from 400nm to 2500nm.

Fabrication of black silicon uses femtosecond laser processing of the target material resulting in a 300nm photoconduction layer applicable to both biased (detection) and photovoltaic (power generation) applications.

Harvard has received an equity position in SiOnyx which recently raised US$11 million in funding from Harris & Harris, Polaris Venture Partners and RedShift Ventures.

REC ASA enters long-term wafer supply contract worth NOK 2.6 billion

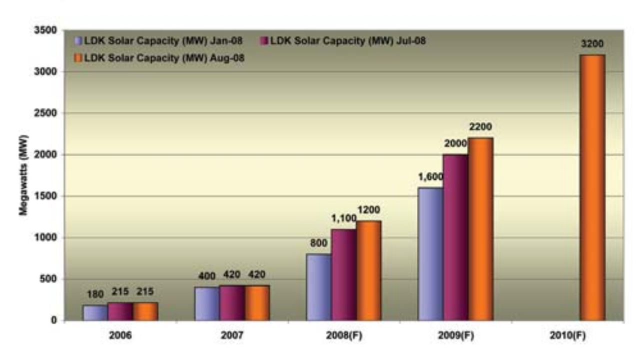
Norwegian wafer supplier REC ASA has entered into a new long-term agreement for supply of multicrystalline silicon wafers to Taiwanese company Neo Solar Power. The contract will see REC supply the wafers, worth over US$452 million (NOK 2.6 billion), to Neo Solar Power until 2015.

The pre-determined price structure agreed under the terms of this agreement will see deliveries of the fixed volume of wafers begin in the second half of 2009. This new contract accounts for most of REC's wafer production output for 2010, according to the company.

LDK Solar ahead of MW capacity ramp schedules

LDK Solar has said that it has reached 1.2GW in annualized wafer production

Source: Photovoltaics International



LDK Solar wafer (MW) capacity expansion projections in 2008.

capacity in the third quarter of 2008, exceeding its previously announced target to reach that level by the end of the year. The company also raised its revenue guidance to be in the range of US$530 to US$540 million, compared to US$486 to US$496 million for the quarter. LDK Solar also raised its quarterly wafer shipment guidance from 210 to 220MW to between 230 and 240MW.

Solar-Fabrik secures new long-term wafer supply deal

In its bid to meet targeted capacity expansion plans, Solar-Fabrik has secured a new long-term 156mm monocrystalline wafer supply deal from Korean based Smart Applications Co., Ltd. The US$120.7 million worth deal starts in January 2009 and runs for six years.

Solar-Fabrik is currently ramping to 80MW by the end of 2008 and plans to reach 150MW in 2010. The company intimated that it would be running at full capacity in 2009 to meet demand.

LDK Solar signs three year wafer supply contract with U.S. energy provider

In an agreement with an as-yet-unnamed U.S. energy solutions supplier, LDK Solar Co., Ltd. will deliver approximately 90MW of multicrystalline silicon solar wafers for a three-year period commencing in 2009. The 'take-or-pay' contract will see the customer supply at least 300MT of polysilicon to LDK in the form of a down payment for part of the contract value, which was also undisclosed.

REC sold out of wafers for 2010 with US$450 million order from Neo Solar Power

Neo Solar Power (NSP) has placed a US$450 million multi-crystalline silicon wafer supply contract with REC ASA. The contract will start in the second half of 2009 and run through 2015. The agreement is structured as a take-or-pay contract with pre-determined prices and volumes for the entire contract period, REC said. "Including this latest contract, most of our wafer production for 2010 has now been sold. This should give us a relatively good visibility on revenues and earnings going forward", says Erik Thorsen, President and CEO.

Taiwan-based NSP added four additional production lines in mid-August 2008, adding 120MW to its capacity base. Total capacity will now be 210MW for 2008. The company plans to add an additional 300MW of capacity in 2009.

NSP has secured several major long-term wafer supply deals this year to match its aggressive capacity ramp goals, including a supply deal with LDK Solar, which was a 500MW, 10 year multi-crystalline contract starting in 2009.

SC GaAs bulk substrates demand from the PV industry has potential growth rate of 79% by 2013

Demand for SC GaAs bulk substrates from the photovoltaic industry has the potential to grow at a rate of 79 percent by 2013, representing over 20 percent of demand, according to the latest analysis from Strategy Analytics. LEDs currently represent the largest section of the market, with 39 percent of demand. Overall market demand will grow at a rate of 7 percent in the same period.

News

"Mitsubishi Chemical, Sumitomo Electric Industries and Hitachi Cable are the market leaders," noted Asif Anwar, Director of Strategy Analytics' GaAs service. "Collectively, the Japanese leaders accounted for over 64 percent of the total market. Other significant suppliers in 2007 in rank order included AXT, Dowa, Freiberger Compound Materials and Neosemitech."

LDK Solar to supply 750MW of multicrystalline wafers to Sumitomo

Sumitomo Corporation has signed a long-term wafer supply deal with LDK Solar. Under terms of the agreement, LDK Solar will deliver approximately 750MW of multicrystalline silicon wafers to Sumitomo over an eight-year period. The deal starts in 2009 and extends through 2016.

Sumitomo will make an advanced payment representing a portion of the contract value to LDK Solar.

DuPont to double 'Tedlar' backsheet material production

Due to the continued rapid growth of the photovoltaics industry, DuPont has said that it will more than double the production of its 'Tedlar' films, which are used in backsheet applications. DuPont anticipates that the PV market will grow by more than 50 percent per annum over the next few years and expects its sales in the sector could exceed US$1 billion within the next five years.

Actual production sites and timescales have yet to be revealed, but are expected later this year, the company said.

DuPont Tedlar polyvinyl film.

Meyer Burger nabs PV wafer wire-saw deal with Konca Solar

Meyer Burger has signed a follow-up contract worth more than CHF 30 million (US$26.5 million) with Konca Solar (Wixi) to deliver advanced wire-saw equipment used in the manufacturing of high-quality solar wafers. The Swiss company says it will deliver the tools in stages, with the first shipment scheduled for the first half of 2009 and the remaining equipment to arrive at the Chinese wafer manufacturer in the second half of the year.

With plans to expand its production capacity from its current level of 135MW to 300MW in 2009, Konca has also agreed to an option for Meyer Burger wire saws worth another CHF 30 million. Konca and Meyer Burger's relationship goes back to June 2005, when the two companies inked their first wire-saw deal. The tool company has supplied numerous wafer-cutting systems to the Chinese firm over the course of their relationship.

In July, Meyer Burger announced that another Chinese silicon-wafer manufacturer, ReneSola, had signed a follow-on order for advanced thin-wafer wire-saws worth CHF 60 million (US$53 million), with deliveries scheduled starting in mid-2008 and running throughout 2009. The Swiss company says its slurry-fed DS 264 tool can cut wafers down to a thickness of 180µm.

Canadian Solar, GCL ink long-term polysilicon, wafer supply deals

Canadian Solar (CSI) and GCL Silicon Technology have signed new long-term supply agreements, in which GCL will provide 510 metric tons of high-purity polysilicon feedstock over the next two years and approximately 1.8GW of solar wafers from 2010-2015.

The wafer part of the deal marks the second major supply agreement inked by CSI in the past few months. The company also signed a contract with LDK Solar to provide 800MW of wafers to CSI over the next 10 years, as part of an extension of the two firms' original deal. In its most recent quarterly report, CSI said it should have 620MW of module capacity and 400MW of internal solar-cell manufacturing online by the end of this year. The vertically integrated PV company also said that it expects to have 180MW of in-house ingot and wafer production capacity in place by early 2009.

Solartech secures 110MW per annum multicrystalline wafer supply deal with LDK Solar

To meet its previously stated capacity ramp, Taiwan-based Solartech Energy Corp has secured a five-year contract with LDK Solar for multicrystalline wafers that equates to 110MW supply per annum. The deal starts in 2009 and extends through 2013.

Chemicals and Gases News Focus

REC boosts silane production at expense of polysilicon

Due to the current and future demand of silane gas for thin-film and flat panel display manufacturing, REC ASA has amended its 'Plant IV' polysilicon expansion plans. REC is to expand silane gas production by a further 2,300MT per annum, while reducing polysilicon production from a planned 6,000MT to approximately 4,000MT per annum. REC has seen sales of silane grow 44 percent in a year and has secured US$1 billion in long-term supply contracts in this year alone.

REC will now invest a further US$200 million on expanding silane production, which includes additional silane loading bays, intermediate storage tanks for liquid silane and the expansion of general utilities.

The 2,000MT polysilicon reduction was said to also reflect the final scope of the Singapore Phase I expansion announced in June 2008.

Air Liquide announces increase in industrial gas prices

Air Liquide Industrial U.S. LP, a subsidiary of American Air Liquide Holdings, Inc., revealed its plans to increase the prices for industrial gas customers. Prices for bulk oxygen, nitrogen, hydrogen and helium will increase by 15 percent, carbon dioxide and dry ice prices are due to rise by 10 percent while argon will have a price increase of 20 percent. The new prices came into effect on October 15.

Image of photoactive polymer.

Konarka gains exclusive license on photoactive polymers from CERSIM

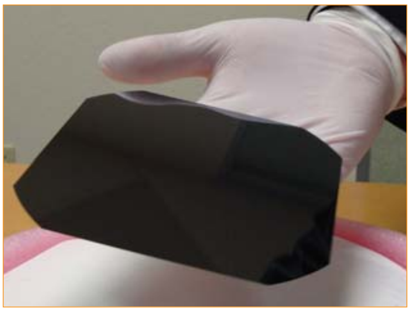
A new group of photoactive polymers (polycarbazoles – PCZ) developed by Professor Mario Leclerc, Director of the Macromolecular Science and Engineering Research Center of Universite Laval (CERSIM) and the Quebec Center on Functional Materials (CQMF) have been exclusively licensed to Konarka Technologies. Konarka aims to use the polymers to boost the conversion efficiencies of its PV modules.

Air Products wins bulk gases contract at SCHOTT Solar's New Mexico plant

SCHOTT Solar's new PV module and receiver production facility in Albuquerque, NM, is to have bulk gases supplied by Air Products. The new 200,000 square foot facility was announced at the beginning of 2008, with production expected to start in the spring of 2009. Air Products is to supply liquid nitrogen, oxygen, argon and hydrogen to the facility under a long-term supply deal.

Product Briefings

Silicon Genesis



Silicon Genesis produces 150µm 'kerf-free' PV wafers

Product Briefing Outline: Silicon Genesis has successfully produced solar substrates for the PV industry using its 'kerf-free' wafering process technology called 'PolyMax.' The company has started production of the first ever kerf-free 150µm solar-cell substrates at its new solar development and pilot production facility. In addition to saving poly, the wafers are claimed to be significantly more resistant to breakage than conventional wafers using its proprietary equipment.

Problem: Today, there are two primary types of solar cells: thin film and thick film. The thin film cells have excellent silicon utilization, but suffer from poor conversion efficiency. The thick films have typically high conversion efficiencies, but require excessive amounts of precious silicon.

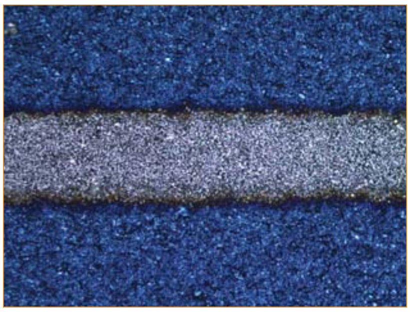
Solution: By eliminating sawing losses, the PolyMax equipment set can substantially reduce the amount of polysilicon used within the ingot to wafer manufacturing steps and also eliminate some of the costly consumables in today's wafer manufacturing. The kerf-free nature of the PolyMax system is claimed to halve the silicon feedstock material required to manufacture the same amount of MW capacity per year. The company has produced 50µm thick, full-size 125mm wafer samples utilizing engineering equipment with excellent mechanical and electrical characteristics. SiGen plans to start pilot line operations by spring 2009 that demonstrate kerf-free processing of silicon ingots into wafers ranging from 150µm to 50µm in thickness.

Applications: First targeted to process monocrystalline silicon to produce high-efficiency silicon solar cells, the equipment is expected to help the PV industry reach grid parity while simultaneously relaxing the shortage of polysilicon feedstock.

Platform: Monocrystalline wafers ranging from 150µm to 50µm in thickness.

Availability: Contact the company for more information.

Rohm and Haas Company



Rohm and Haas' 'Enlight' materials are designed for improved cell efficiencies

Product Briefing Outline: Rohm and Haas Company has launched its new line of 'Enlight' materials suite of products for crystalline silicon cell photovoltaic manufacturing. The Enlight product suite is designed to improve traditional solar cell processing by increasing cell efficiency and increasing manufacturing yields.

Problem: The need for higher cell efficiencies while controlling costs and improving yields is a core focus towards reducing the cost-per-watt of traditional solar cell products. Improved material performance is a key focus for achieving these goals in high-volume cell and wafer production environments.

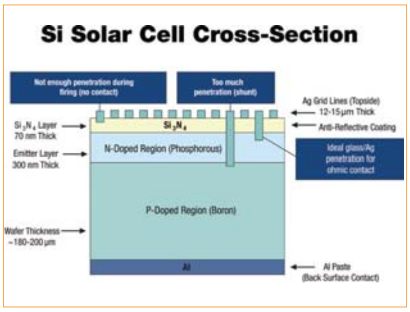
Solution: The Enlight SilverPlate 620 is used for PV metallization offering an improved Light Induced Plating (LIP) solution over the company's first generation product. This new technology, claims the company, can increase cell efficiencies by as much as 0.6% compared to standard paste processes. Enlight JetResist 1310 is for PV imaging and is a hot melt ink that is compatible with most drop-on-demand inkjet systems. The product has resolution capability down to 60µm and is compatible with most etches, including BOE, HF and cupric chloride. Enlight JetStrip 1210 Stripper is optimized to remove JetResist 1310 with fast stripping speeds. It can be used in either spray or immersion equipment configurations and will not attack underlying emitter layers. Enlight Wafer Clean 320 Series is designed for PV cleaning that has been optimized to allow for customized cleaning and etching performance while being compatible with mono-crystalline and multi-crystalline substrates.

Applications: Crystalline silicon solar cell processing applications.

Platform: Enlight photovoltaic materials offer a broad range of products for various photovoltaic applications, including: Enlight Caustic Texturizer 100 Series, Acidic Texturizer 200 Series, Electroless Nickel 700 Series, Electroless Copper 900 Series, Electrolytic Copper 400 Series, Electrolytic Tin 500 Series.

Availability: September 2008 onwards.

Five Star Technologies



New solar inks from Five Star Technologies offer 80-100 micron grid lines

Product Briefing Outline: Five Star Technologies has introduced the 'ElectroSperse' S-series solar inks for use in crystalline silicon photovoltaic cells. Five Star's S-500 series, silver-based conductive inks, will allow solar cell makers to lay out front side grid lines as narrow as 80-100 microns-much thinner than the 120-175-micron width of conventional contacts.

Problem: Current commercial pastes have a narrow process window, and cell manufacturers quite often have to modify the firing profile for different lots of material due to inconsistent dispersion in traditional pastes. The need for consistent contact could improve manufacturing yields significantly and boost overall cell efficiency by as much as one full percentage point, according to Five Star.

Solution: Patented hydrodynamic cavitation process enables Five Star to produce inks and pastes with silver and glass particle uniformity and particle sizes in the low to sub-micron range. That, in turn, gives users the ability to screen print much finer lines and to achieve more consistent emitter contact. According to recent tests conducted by the Georgia Institute of Technology, monocrystalline cells produced with S-540 demonstrated cell efficiencies of 17.4% and fill factors approaching 78%. The company claims that there was virtually no variation in performance at firing profiles differing by as much as 20°C.

Applications: Initial grades of the inks are intended for screen-printing applications, but Five Star says it can control rheology to match a variety of printing processes, including non-contact dispensing approaches.

Platform: Five Star produces the ElectroSperse series of inks and pastes as well as a wide range of precision dispersions. ElectroSperse thick film conductor pastes are rheologically stable, easy-to-process materials, ideally suited for direct printing of fine features.

Availability: October 2008 onwards.

Crystallization on dipped substrate wafer technology for crystalline silicon solar cells reduces wafer costs

H. Yamatsugu, H. Mitsuyasu, T. Takakura, S. Goma, S. Kidoguchi, R. Oishi, Y. Okamoto, K. Yoshida, K. Yano & **H. Taniguchi**, Solar Systems Group; **M. Kamitaka** & **C. Yamawaki**, Production Technology Development Group; **M. Futagawa**, Electronic Components and Devices Development Group, SHARP Corporation, Toyama, Japan

ABSTRACT

A new wafer technology, named CDS (Crystallization on Dipped Substrate), is under development and has been found to be effective in the reduction of wafer cost and silicon feedstock. CDS technology was applied to 156mm × 156mm-sized wafers, obtained via the throughput of 1825cm²/min, and the resulting cell efficiency of 14.8% was confirmed. This paper outlines the principle behind the technology and outlines the procedure

Introduction

The silicon wafer-based solar cell plays a main role in the present photovoltaic market. As a result, the development of wafer technology is very important in realizing the mass supply of inexpensive solar cells. Conventional multi-crystalline silicon wafers are produced by ingot casting technology; however, the reduction of wafer cost and silicon feedstock is difficult because of the unavoidable sawing process. On the other hand, ribbon technologies hold hope, due to the lack of kerf losses. However, these technologies have the problem of low throughput, or small wafer size. Therefore, a new ribbon technology has been developed that has demonstrated high throughput and large wafer size.

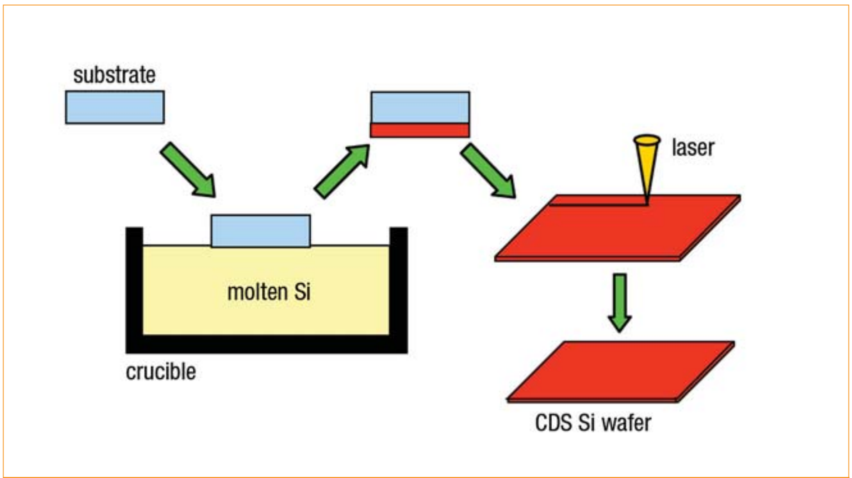


Figure 1. Principle of the CDS Si wafer production technique.

CDS technology

CDS enables the formation of multicrystalline silicon sheets directly from molten silicon, with no kerf loss.

Basic principle

Figure 1 illustrates the basic principle behind CDS technology. Firstly, a substrate is dipped into molten silicon. The silicon crystallizes uniformly at the surface due to the extraction of the latent heat. Secondly, the substrate is pulled out from the molten silicon. Next, a multicrystalline silicon sheet is detached from the substrate. Finally, it is cut to an appropriate size by a laser cutter [1].

Development of CDS technology

The development of CDS technology began in 1997 and in the intervening 11 years, the technology development achieved practical-sized wafers (156mm × 156mm) – a figure that is compatible with high throughput (1825cm²/min). The progression to this point is shown in Figure 2.

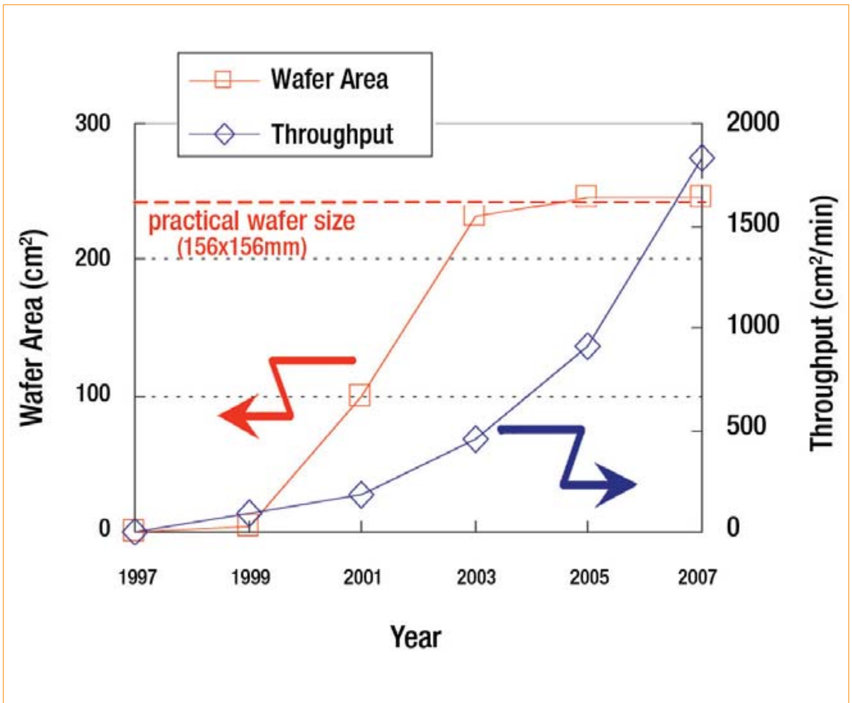


Figure 2. Development of CDS technology.

Comparison with other ribbon methods

There are many other kinds of silicon ribbon technologies, such as Edge-defined

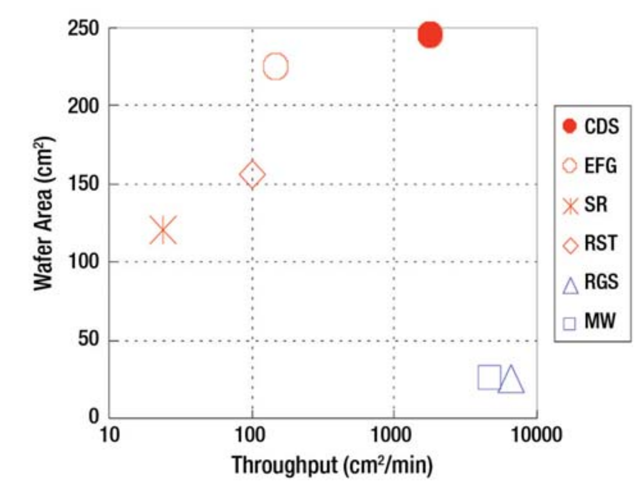


Figure 3. Wafer size and throughput of ribbon methods [2-7].

Figure 4. CDS Si wafer (156mm × 156mm).

Film-fed Growth (EFG), String Ribbon (SR) Ribbon Growth on Substrate (RGS), among others. From a practical point of view, both wafer size and throughput are hugely important. Figure 3 shows wafer size and throughput of these technologies. EFG technology boasts excellent wafer sizes, while both RGS and Molded Wafer (MW) technologies present excellent throughput. CDS technology has achieved both practical-sized wafer and high throughput, and is a ribbon method much suited to mass-production.

CDS wafer and facilities

Figure 4 shows a 156mm × 156mm-sized wafer obtained via CDS technology. Figure 5 shows a general view of the CDS process, an inline wafer process that enables the production of 10,000 wafers in one day (one wafer every 8 seconds). Therefore, a wafer cost of approximately 50% of cast-process wafer was achieved in our estimation.

> "CDS technology has achieved both practical-sized wafer and high throughput, and is a ribbon method much suited to mass-production."

Characteristics of CDS silicon wafers

CDS technology is significantly different from other ribbon technologies. Therefore, we have evaluated the properties of the new wafer by surface photovoltage analysis (SPV), and electron backscatter patterns analysis (EBSP) [8]. Surface photovoltage (SPV) measurements are used to determine the minority carrier diffusion length of a silicon wafer. The minority carrier diffusion length of CDS Si wafer turned out to be longer than 100μm.

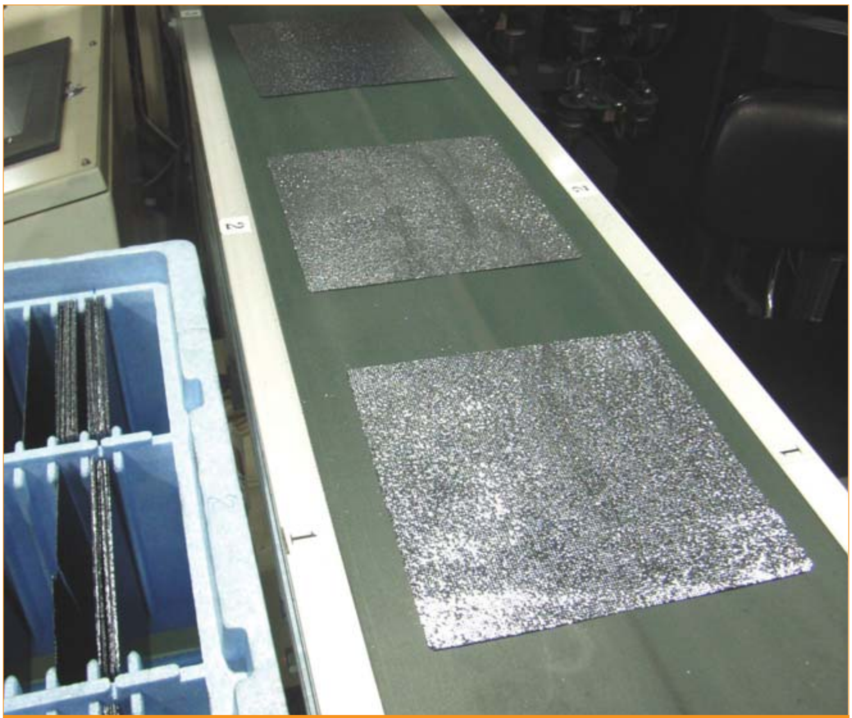


Figure 5. General view of the CDS process.

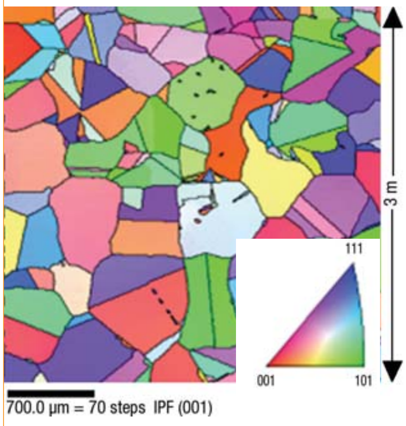


Figure 6. Planar IPF map of a CDS Si wafer.

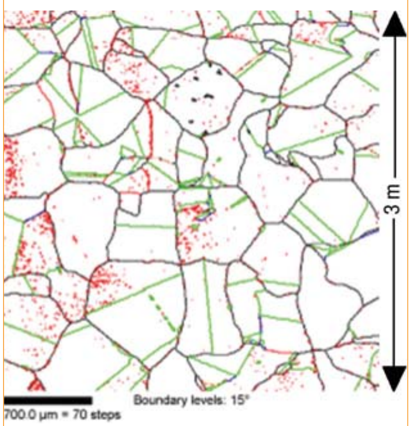


Figure 7. Coincident site lattice map of a CDS Si wafer (black: random; green: Σ3; red: other CSL GB and errors).

The evaluation of the multicrystalline silicon grain boundary that uses the Electron Backscatter Patterns (EBSP) method was reported in recent years. Figure 6 shows the planar Inverse Pole Figure (IPF) map of the CDS Si wafer. Judging from the result of the IPF map within our observed range, there can be no specific silicon growth directions in any CDS Si wafers, with grain sizes of 1mm or less, similar to externals.

Elements such as grain size and crystal direction, as well as silicon grain boundaries, have a huge impact on the cell's efficiency. The straight grain boundary, known as twin, or the Σ3 coincident site lattice (CSL) grain boundary, signifies good quality and electric inactivity. Figure 7 shows the CSL map of the CDS Si wafer, clearly showing remarkable Σ3 CSL grain boundaries.

A cross-sectional map of the crystalline orientations showing confirmed columnar grain structures is presented in Figure 8. While there are relatively few grain boundaries in the up-and-down direction, through which current flows in the solar cells, it is expected that these columnar structures will induce an excellent result in the cells.

Cell processing and cell development results

Solar cell process

A quite simple screen-printing-based cell process was applied to CDS as shown in Figure 9. However, since the crystalline property of CDS is quite different from cast Si, each process has been optimized to CDS taking its character into consideration.

An example of process optimization is the firing of the aluminum back electrode by rapid thermal processing (RTP). The firing time of RTP is much shorter than conventional firing and we have succeeded in an increase of about 1.0 in absolute efficiency by RTP compared to conventional firing [9]. It is presumed that such an eminent improvement by use of RTP is caused by hydrogen passivation or aluminum gettering. Since CDS Si wafers have many grain boundaries, there must be a significant amount of space for such an improvement by such an effect.

Development of CDS cell efficiencies

Figure 10 shows the development of CDS cell efficiencies. 14.8% cell efficiency of CDS cell was obtained in 2006 by a quite simple process of in-house measurement. This is the result of step-by-step refinement of each process, such as the RTP technique application.

CDS modules

A practical-sized module (1165mm × 990mm) made up of 42 solar cells (156mm × 156mm) was also fabricated in this process, and a maximum output power of

Figure 8. Cross-sectional map of crystalline orientations (black: blank). CDS Si wafers had a quite small grain size, but contained columnar grain structures and good grain boundaries, elements that are suitable for solar cells.

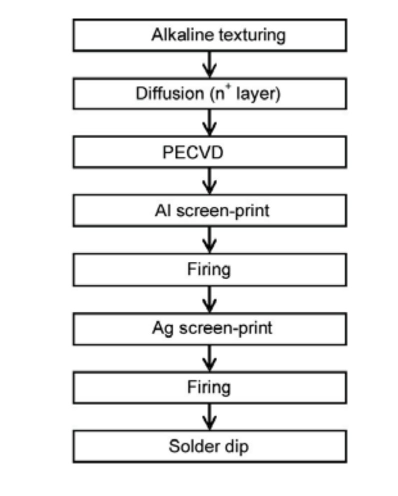


Figure 9. Flowchart showing stages of the cell process.

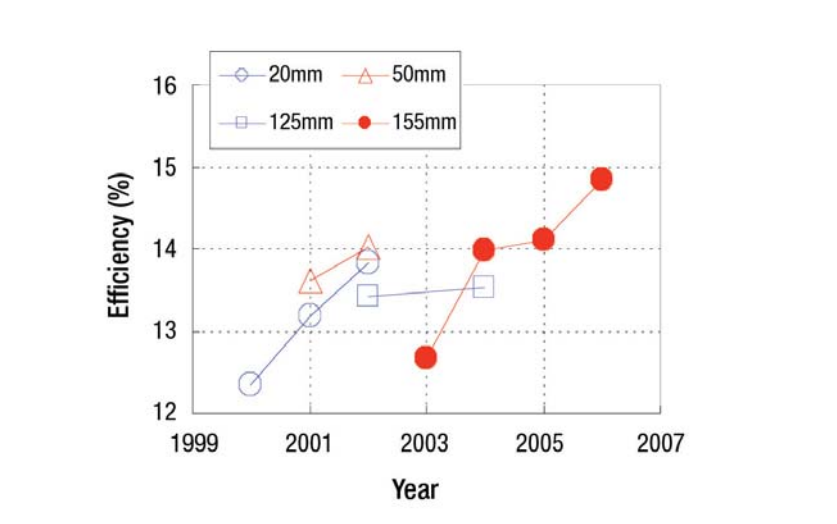


Figure 10. Development of the CDS cell efficiencies.


Figure 11. The appearance of the practical-sized module (1165mm × 990mm) made up of 42 screen-printed CDS solar cells.

144W($\eta_{AV.}$=14.2%) was confirmed through in-house measurement. The resulting module is shown in Figure 11.

"Characterizations of wafers showed that CDS Si wafers have columnar grain structures, containing a significant amount of high-quality grain boundaries."

Conclusions

A new technology, CDS, which is effective in the reduction of wafer cost and silicon feedstock, has been developed. Through use of this technology, practical-sized wafers (156mm × 156mm) featuring high throughput (1825cm^2/min; 10,000 wafers production in one day) were demonstrated, and a low wafer cost (approximately 50% of cast wafer) was estimated. Characterizations of wafers showed that CDS Si wafers have columnar grain structures, containing a significant amount of high-quality grain boundaries. Using these wafers, solar cells and solar cell modules were fabricated using a conventional low-cost process. Cell efficiency of 14.8% and module maximum output power of 144W were confirmed.

Acknowledgements

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About the Author

Hokuto Yamatsugu studied chemical system engineering at The University of Tokyo, Japan, and received his B.S. and M.S. degrees in 1997 and 1999, respectively. From 1999, he worked for SHARP Corporation and has since been engaged in research and development of New Wafer Technologies. He is Junior Manager of the technology development department, material business promotion center, Solar Systems Group. His research interests include crystal growth, facilities, and solar cells and their materials.

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Market Watch

Solar cells' silver lining

Carl Firman, VM Group, London, UK

ABSTRACT

In the perpetual struggle to reduce the costs associated with PV energy generation, one aspect of the manufacturing process has potential to shine. To date, the PV sector is dominated by crystalline silicon wafers (90%), which largely use silver as the conducting medium for the front side grid, and to a lesser extent the backside contact. The conducting media are crucial to the overall efficiency of the cell by providing the means for current to flow when sunlight strikes the doped silicon wafer. This paper presents silver as a vital factor in the PV process, and discusses the future industry requirements as well as a projection for the overall silver market for the next eight years.

As the PV efficiency measure is probably the most important consideration when purchasing a solar system, it is difficult to see a substitution for silver since its superior conductivity and ease of use betters that of all other potential materials that are currently available.

New regulations, technological innovation and a paradigm shift in consumer behaviour will likely propel the renewable energy sector to record levels of growth over the coming years. As a direct consequence, growth in the photovoltaic sector is tipped to increase rapidly and with it a marked rise in the demand for silver metal.

The application of silver metal onto the silicon wafer typically comes in the form of a paste, which is screen-printed on the front surface in a grid-like pattern consisting of fine fingers and thicker busbars. In addition, but to a lesser extent, silver is also screen-printed as a paste on the backside contact, which generally covers the entire underside of the silicon wafer. For the paste to aid current flow, it is fired at several hundred degrees Celsius to form metal electrodes in ohmic contact with the silicon. After the metal contacts are made, the solar cells are interconnected in series (and/or parallel) by flat wires or metal ribbons, and assembled into modules.

"Growth in the photovoltaic sector is tipped to increase rapidly and with it a marked rise in the demand for silver metal."

One consideration to silver's dominance in the PV cell industry is the rapidly growing thin-film PV market, which uses little of the metal in its makeup. Thin-film technology currently holds a 10% share in the total PV market, and despite significantly lower efficiencies than crystalline silicon-type cells, its lower cost of production should see it expand its market share to 25% by 2012.

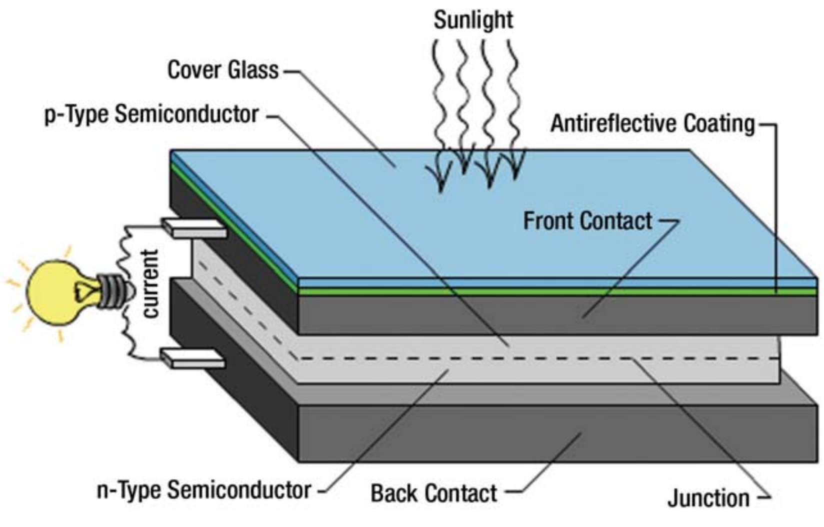

Figure 1. Schematic showing typical crystalline silicon solar cell composition.

Year	Silver consumed (metric tonnes)	Total PV Cell production (GW)
1999	43	0.4
2000	58	0.5
2001	78	0.7
2002	105	0.9
2003	140	1.2
2004	187	1.6
2005	250	2.2
2006	327	3.0
2007	432	4.0
2008	516	5.2
2009	647	6.8
2010	811	8.8
2011	1016	11.4
2012	1270	14.9
2013	1651	19.3
2014	1997	23.4
2015	2417	28.3
2016	2924	34.2

Table 1. Silver consumption report and forecast vs. PV cell production to 2016.

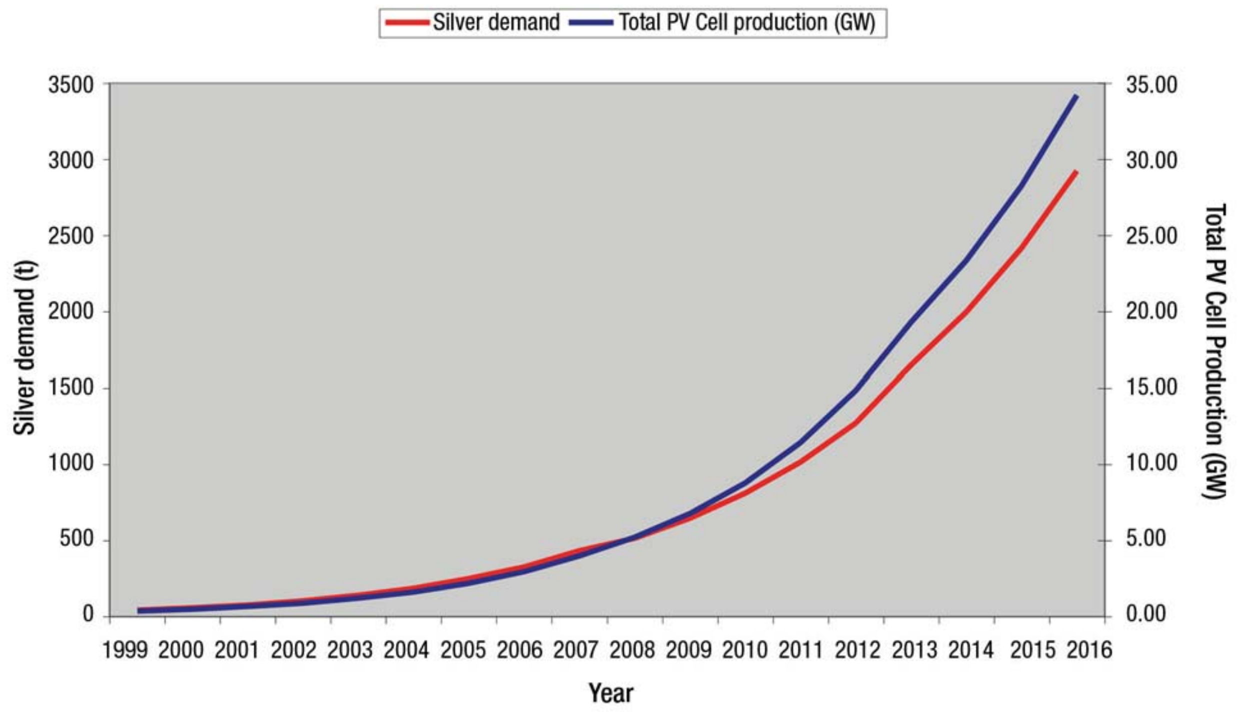

Figure 2. Global silver demand forecast.

So how does this affect the silver market? Assuming maximum silver loadings of 0.12g/W, 4GW production (2007), and taking into account a 10% market share of non-silver containing thin-film PV units, only 432t of silver metals was required in 2007. This equates to 13.9M/oz at a total value of US$170m, using the average Comex settlement price of US$13.38/oz in 2007. But by 2012, some 1,270t of silver could be consumed – a threefold increase compared with 2007. This assumes that the PV market grows at a compound annual growth rate of 30% to 2012, a 5% annual decrease in silver loading per watt as efficiencies improve and a ramp-up in market share of thin-film technology to 25%.

A conservative industry outlook for PV sector growth predicts 13GW of PV cell production in 2012, which brings the estimate for that year down to 1,111t, but the most aggressive forecast is 52GW, which would imply 4,446t of silver. Like any high and low forecast, the truth will probably lie somewhere in between; nevertheless, the PV industry is going to represent a robust and growing item in the future silver supply/demand balance.

So does the supply of silver represent a potential bottleneck to future crystalline silicon PV cell growth? In 2007, the PV market consumed just 432t of silver out of a total global silver supply of 34,450t. By 2012, the PV market will still only consume a small fraction of total supply; however, by 2016, almost 3,000t of silver may be consumed (see Figure 2). This could put pressure on the crystalline silicon PV sector depending on the then levels of mine supply and total recycling, and hence silver price. In addition, there should be little relief from the direct supply of secondary silver from the recycling of PV systems due to the relative youth of the industry, long life of the PV units (typically 20-25 years), and the huge cost and logistical effort needed for the collection of these panels.

"Despite improved efficiencies and increased thrifting, silver consumption could potentially increase seven-fold by 2016."

Therefore, as things stand, the PV market looks likely to be dominated for many years by crystalline silicon cell technology, and despite improved efficiencies and increased thrifting, silver consumption could potentially increase seven-fold by 2016. This implies a cost of almost US$1bn using an average price of US$10/oz in 2016. The question is whether the industry will be large enough to be able to absorb this cost.

About the Author

Carl Firman joined VM Group as a Metals Analyst in 2008. He holds a degree in geology from the University of London and has worked as a petroleum geologist and later as a geotechnical engineer in the Far East. He also has experience in the Information Technology sector having spent several years at IBM during the dotcom boom era. Carl joined *Mining Journal* in 2002 and later became editor for the Production and Markets section of the weekly newspaper. In 2007, he launched the highly successful mining and energy focused *Global Capital* magazine at Pro Publications.

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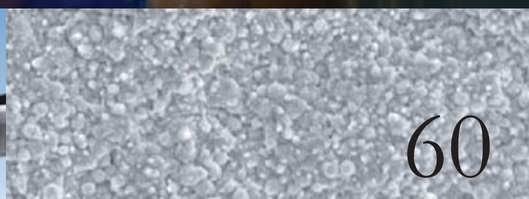
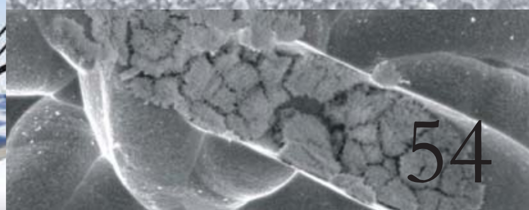




News

NREL confirms that Suniva pushes R&D solar-cell efficiencies past 20%

Solar-cell manufacturer Suniva says that the U.S. National Renewable Energy Laboratory (NREL) has verified 20+% conversion efficiencies on several screen-printed silicon cells developed by the company's R&D team in its lab.

"This demonstrates that Suniva's advanced technologies in diffusion, surface passivation, and contacts can increase conversion efficiency, while reducing processing time and maintaining low cell cost," says Ajeet Rohatgi, company founder/CTO and head of the Georgia Institute of Technology's University Center of Excellence in Photovoltaics. Applying the company's patented technology to reduce the number of steps in the production process and generate a series of cells with efficiencies over 20%, Suniva says its cells represent a world record for screen-printed cells and incorporate advanced design features that boost power output from the cell.

Suniva claims that it can create a higher sheet resistance emitter as well as enhanced surface passivation dielectrics in one high-temperature step. It fabricates narrow screen-printed contacts on the front of the cell and a high-quality surface reflector on the back. These components, combined with improved texturing methodologies, allow the cells to trap light and achieve high efficiencies, while keeping production costs low.

The company also has three new patents pending – in the areas of structural design, fabrication process, module integration, and the efficient use of low-cost heterojunction cells – which brings its intellectual property portfolio to 32 patents and patent applications worldwide.

The company says that its current ARTisun cell technology has produced a verified efficiency of 18.5% in the lab. In recent months, Suniva has signed a wafer supply deal with REC and solar-module agreements with Solon and Titan Energy, and opened its first manufacturing line near Atlanta.

Research and Development News Focus

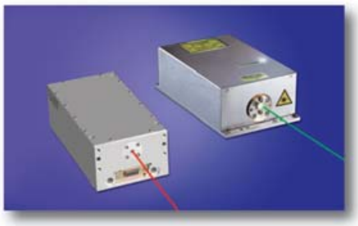
CIP Technologies reveals InP-based thermo-photovoltaic cells with 12% efficiency

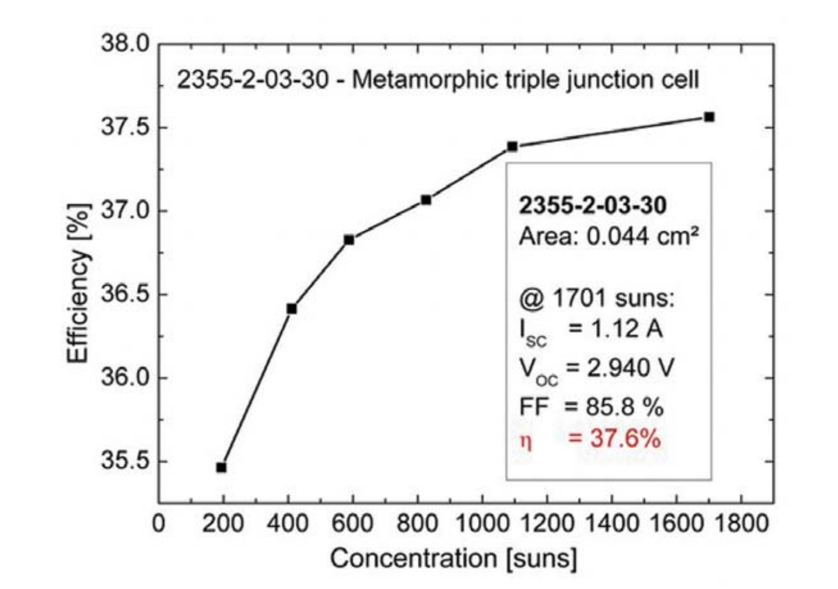
UK based photonics specialist CIP Technologies (CIP) has revealed details regarding indium phosphide (InP), based single-junction thermo-photovoltaic (TPV) cells with 12% efficiency levels, in collaboration with Wafer Technology and the University of Oxford. The company states that the research has taken three years and surpasses previous commercially available cells that registered 9% conversion efficiencies.

The consortium said that a second-generation cell design with a more complex multi layer construction was being developed to reach efficiency levels of 15%. The team is now seeking partners and customers to aid in the commercialization of the technology.

IMEC to develop organic multi-junction solar cells for Plextronics

IMEC and Plextronics, Inc. are to partner on the further development of Plextronics





Concentrated cell efficiency of a metamorphic triple junction cell structure.

'Plexcore' branded materials and inks to boost the efficiency levels of its solar cells. IMEC aims to develop organic multi-junction solar cells with efficiency of 10% by 2012 with an average efficiency of 7% (+/- 0.5%) and solar cell lifetime of five years. Plextronics' Andy Hannah, CEO, said that this collaboration with IMEC is an important one for the company.

In the first phase, IMEC will investigate 'Plexcore OS,' materials, which is a regioregular poly-3-hexylthiophene (P3HT) polymer with a high absorption coefficient close to the maximum photon flux in the solar spectrum and high mobility. These materials will be processed using spin coating and validated on film morphology, carrier mobility and reproducibility. Solar cells will be processed on different substrates using spin-coated films of the material, IMEC said.

Plextronics has already demonstrated world-record efficiencies as high as 5.9%, in recent testing at the National Renewable Energy Laboratory (NREL).

Manz Automation and Basler team on fully automated cell tester

Collaboration between Manz Automation AG and Basler AG has led to Manz claiming that it has developed the fastest cell testers for crystalline silicon solar cells at more than 2,400 solar cells per hour. In an exclusive deal Manz has integrated Basler's electroluminescence measurement technology into its testing platform, which is fully automated.

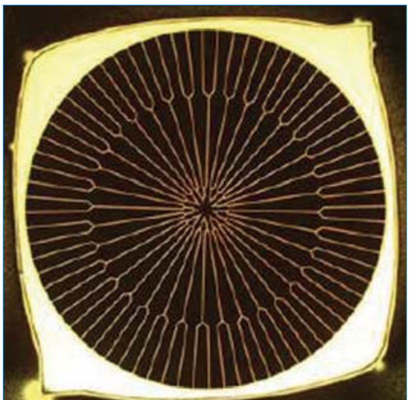
"Integrating this solution allows microscopic cracks in solar cells to be reliably detected, thus reducing breakage rates," commented Volker Biemann, Basler AG's Product Manager for solar inspection solutions. "Experiments to date have shown that in addition to the microscopic cracks, which are relevant for breakages, other defects can also by easily recognized with the help of the images."

Basler said that it had been able to optimize the measurement process so that it can be used for the inline production of crystalline silicon solar cells. This method applies an electrical current to the solar cell. As a result of the thereby generated current, the solar cell emits a weak luminescence. This 'light' can be recorded and evaluated by using ultra-sensitive optical measuring systems.

Fraunhofer ISE ups III-V cell efficiency to 39.7%

The Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg has surpassed its own European multi-junction III-V solar cell efficiency record, recently reaching 37.6%. The new record of 39.7% was achieved using a front-side network of thin metal wires that transport large currents but with low resistance.

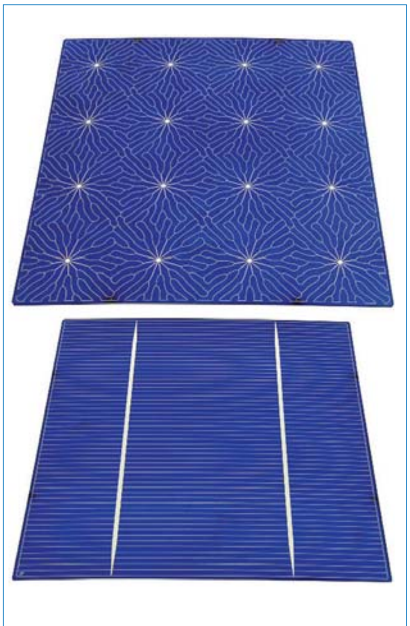
"We have improved the contact structures of our solar cells," commented Frank Dimroth, Head of the III-V – Epitaxy and Solar Cells Group at Fraunhofer ISE. "As a result, using the same semiconductor structures, we now achieve the higher efficiency when converting sunlight into electricity."



GaInP/GaInAs/Ge concentrator solar cell.

Fraunhofer ISE has been working on a new program for the theoretical calculation of optimal contact structures. Based on this work sponsored by the EU Project Fullspectrum (SES6-CT-2003-502620), the new cells are especially suitable for situations of inhomogeneous radiation, as occurs in the case of concentrated sunlight between 300 and 600 suns.

The solar cell structures consist of more than 30 single layers, which are deposited on a germanium substrate by means of metal-organic vapour-phase epitaxy (MOVPE).



Solland Solar develops back contact cell using 'Metal Wrap Through' method.

Solland Solar develops back contact cell using 'Metal Wrap Through' method

Dutch solar cell producer, Solland Solar has announced the development of a new photovoltaic solar cell design using the 'Metal Wrap Through' (MWT) method. The technique enables the removal of the traditional 'bus bars' from the cells front-side, increase the usable area and reduce shading, boosting cell efficiencies. The research was carried out in collaboration with ECN (Energy research Centre of the Netherlands).

Solland Solar said that the MWT technique boosts conventional cell efficiencies by 2%. Using its 'Sunweb' front-side design, the output of a solar module with a traditional cell is around 13.5%, the Sunweb cell increases this efficiency to nearly 15%. Solland is currently working with third parties on the development of a special back-sheet foil to connect the Sunweb cells at the back. This will enable further automation of the production process, reducing manufacturing costs, the company said.

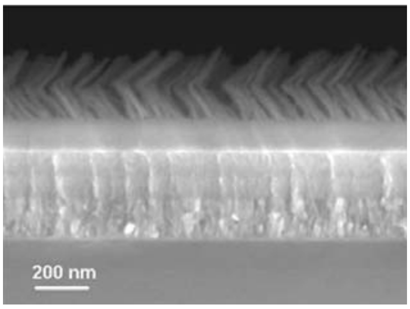
Soaking in the sun: Rensselaer Polytechnic Institute develops advanced sunlight absorption coating

Professor Shawn-Yu Lin of Rensselaer's physics department published findings, after a year-long project, that can potentially help the solar industry overcome some of the major hurdles involving the percentage of solar absorption. Working with his team, Lin has produced a new antireflective coating that increases the amount of sunlight captured by solar panels, while also allowing the panels to take in sun from almost every angle.

Published in his paper "Realization of a Near Perfect Antireflection Coating for Silicon Solar Energy", Lin demonstrated that a current untreated silicon solar cell absorbs about 67.4 percent of sunlight. But after the silicon surface is treated with Lin's reflective coating, the panel absorbs 96.21 percent of the sunlight shone on it, allowing only 3.79 percent of the sunlight to be reflected. The large percentage of solar absorption was constant throughout the entire spectrum of sunlight including UV, visible light and infrared.

Along with absorbing over 28 percent more sunlight, the coating helped the panels absorb light from several different angles. Lin's antireflective coating absorbs the light from all angles, equally and evenly, thereby potentially eliminating the need for mechanized systems that keep the solar panels directly in line with the sun.

Lin's coating stacks seven layers on top of one another in a way that each layer increases the antireflective properties of the layer below it and curves the sunlight being captured to angles that enhance the coating's antireflective properties and therefore allows each layer to transit and capture light that may have previously been reflected off. Each of the seven layers has a height between 50 to 100 nanometers and is made from silicon dioxide and titanium dioxide nanorods, which were affixed to a silicon substrate via chemical vapor disposition. Lin claims that the his new coating can be joined to almost any photovoltaic materials for use in solar cells, including III-V multi-junction and cadmium telluride.



Suniva to sell over US$500 million worth of solar cells to Solon

Suniva is to supply monocrystalline silicon solar cells to Solon, Europe's largest solar photovoltaic module manufacturer, in a contract worth in excess of US$500 million through 2012. Suniva is expanding the number of production lines to meet demand.

Suniva's manufacturing plant in Alanta, currently has a capacity of 32MW. Plans are for capacity to be expanded by at least another 130MW over the next two years.

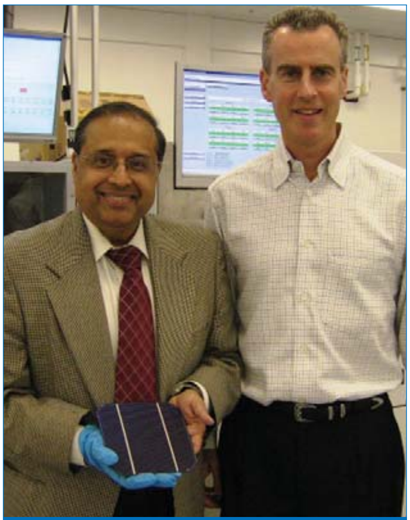
Blue Square Energy produces 14.6 percent efficient solar cell

Blue Square Energy (BSE) announced its production of a 14.6 percent efficiency solar cell using its Bright Point technology. The result is the highest on upgraded metallurgical grade (UMG) silicon and was verified independently by the National Renewable Energy Laboratory (NREL).

BSE's Bright Point uses a two-part structure: a fine layer of high-grade silicon placed on top of 4N UMG silicon.

Suniva begins production, announces plans for second solar-cell line

Suniva confirmed that it has successfully begun production on its 32MW



John Baumstark, Suniva CEO (right), alongside company founder/CTO Ajeet Rohatgi with the first cell off the production line.

monocrystalline solar-cell production line in Norcross, GA. The company also said that it plans to install a second fab line next year with double the manufacturing capacity of the first line and will continue its turnkey partnership with centrotherm photovoltaics.

Once the new line is completed in mid-2009, the company will have a total cell-production capacity of 96 MW-peak, with both of the initial lines combining centrotherm integrated equipment and Suniva's proprietary fabrication techniques. The cell manufacturer said it plans to push the capacity in its first factory to about 175MWp by early 2010.

The newly completed 32MWp line (ramped less than 12 months after initial planning) produces Suniva's ARTisun solar cells, which are sent to module manufacturers to be assembled into high-efficiency solar modules. The company sells PV cells produced at the Norcross facility under existing customer contracts totaling more than US$1 billion, with companies including Solon and Titan Energy Systems.

Suniva's manufacturing technique, which was developed at the Georgia Institute of Technology's University Center of Excellence for Photovoltaics, includes several optimized process steps that enhance the devices' light-trapping capabilities, producing what the company calls one of the industry's most efficient solar cells.

Earlier this year, Suniva produced cells in the lab with better than 20% conversion efficiency, verified by the National Renewable Energy Laboratory, a world record for low-cost, screen-printed solar cells.

As part of efforts to ensure its materials supply chain, Suniva signed a five-year monocrystalline wafer supply deal with REC in July.

Order Win News Focus

Roth & Rau saw €45 million in new orders from Valencia PV SEC event

Roth & Rau has said that during the 23rd European Photovoltaic Solar Energy Conference and Exhibition which took place in Valencia, Spain in September, it generated new contracts and declarations of intent worth approximately €45 million. A major deal was declared for a 60MW turnkey manufacturing line to a new customer in India as well as AIS, for its Manufacturing Execution Systems (MES) projects. The company also said that the Group booked orders worth €206.1 million during the first eight months of 2008, up 84.5% on €111.7 million, in 2007.

Komax wins major order from Algatec Solar AG

On the back of the 23rd European Photovoltaic Solar Energy Conference and Exhibition held in Valencia, Spain, Komax Holding AG has received orders worth over CHF 30 million, which includes a significant order from Algatec Solar AG for Komax's crystalline solar module automation systems for a new 160MW module plant. The Algatec Solar order includes stringer and layup systems. Komax also said that it had received orders leading up to the show in Valencia that included its new bussing system for thin-film modules.

The company showcased new product introductions at the show, including its new cell tester with integrated electroluminescence measurements which it developed in a strategic alliance with Basler. Manz said that it received an initial order for this line while at the conference.

Tool Order: Spire sells multiple tools for Tianwei's solar cell production expansion

ChengDu Tianwei New Energy PV Module Co. Ltd. (Tianwei) has selected stringing and tabbing systems from Spire as well as multiple 'Spi-Assembler' 6000 systems to fully automate the soldering of individual solar cells into strings ready for busing. Tianwei is automating these production steps as part of its plans to increase capacity of its solar cell products.

Tianwei is expected to have 100MW of cell capacity and 60MW of installed PV module capacity by the end of 2008. In 2009, the company is planning to increase total cell and module capacity to 300MW.

Tool Order: Amtech receives US$9.0 million in follow-on deals

Two existing customers based in Asia have placed follow-on orders worth US$9 million with Amtech Systems, Inc. The orders are for its subsidiary, Tempress Systems, diffusion processing tools.

Amteh subsidiary, Tempress Systems, receives European order for solar diffusion system

Tempress Systems, Inc., the subsidiary company of Amtech Systems, Inc., has received a US$3 million order from a new European-based customer that supplies solar turnkey systems. The new order comes after two existing customers in Asia placed follow up orders in September 2008 for Tempress Systems diffusion tools and a separate follow-on solar order for its diffusion processing system in August from another existing customer in Asia.

Spire to supply 30MW cell manufacturing line to Hanwha Chemical Corporation

Spire Corporation recently announced its new contract with Hanwha Chemical Corporation, located in Seoul, Korea, to provide a Spi-Line 30C complete turnkey factory to produce up to 30MW per year. The agreement marks Hanwha's entrance into the solar market with hopes to make it one of the most modern cell factories in Korea.

The 'Spi-Assembler' 6000.

Product Briefings

Adept Technology

Adept Technology's new robot streamlines solar cell production

Product Briefing Outline: Adept Technology has launched its 'Adept Quattro' s650 robot that comes with a Bernoulli gripper. The new system integrates high-resolution inspection with high-speed solar cell handling. The Quattro robot is claimed to be the world's fastest robot with over 200 systems sold worldwide. The Bernoulli gripper combined with the Quattro robot creates an effective method for manipulating solar cells without the potential for product damage.

Problem: Automating solar cell inspection has proven to be an effective way to increase yields and reduce in-process scrap. Integrating inspection with automated handling is the next step in improving production efficiencies and continuing the trend towards lower cost solar cells.

Solution: The Adept Quattro s650 parallel robot is specifically designed for high-speed manufacturing, packaging, material handling and assembly. It is the only robot in the world that features a unique four-arm rotational platform designed for maximum speed, maximum acceleration and exceptional performance across the entire work envelope, according to the company. Additionally, the powerful embedded amplifiers and compact controls make installation easy and enable saved workspace.

Applications: High-speed manufacturing, packaging, material handling and assembly.

Platform: 4 parallel arms with a rotational platform design for high speeds; 2kg rated payload; high-efficiency motors deliver high performance with more torque per amp.

Embedded 'SmartServo' controls. Large 1300 mm work envelope. Maximum of 500mm Z stroke. High-resolution encoders provide high precision and superior slow-speed following.

Availability: July 2008 onwards.

DuPont Performance Elastomers

DuPont targets 'Kalrez' perfluoroelastomer parts to wafer & thin-film equipment

Product Briefing Outline: DuPont Performance Elastomers (DPE) has introduced 'Kalrez' perfluoroelastomer parts specifically designed for the photovoltaic market for both wafer-based and thin-film PV processes, demonstrating broad chemical compatibility and excellent thermal stability. Kalrez parts are used to improve sealing reliability in critical PV wafer processing equipment that uses plasma, high heat and aggressive chemicals.

Problem: As PV manufacturers use more aggressive and efficient chemicals and higher temperatures to increase uptime and improve output, more strain is placed on the manufacturing process. Unplanned maintenance due to incompatible sealing materials can interfere with production schedules, causing downtime.

Solution: Kalrez seals resist over 1800 chemicals including reactive gases and plasmas, alkalis, acids and solvents. Even in contact with these corrosive chemicals, the seals retain their elastomer properties to temperatures as high as 325°C. These products produce improved results with less downtime due to a reduction in the need for preventative maintenance (PM).

Applications: Kalrez PV8030 is used for surface texturing, polysilicate removal and 'wet' scrubber/abatement applications. Kalrez PV8050 is used for edge isolation, ARC coating, CIS/CIGS and cadmium telluride cell layer and TCO deposition processes. Kalrez PV8070 is used for doping, metallization and CIS/CIGS cell layer deposition processes. Kalrez 9100 is designed for amorphous/microcrystalline silicon cell layer deposition processes.

Platform: DuPont Performance Elastomers also has integrated manufacturing back to the polymer, enhancing quality control and product development.

Availability: August 2008 onwards.

AMB

AMB's WWS 3000+ wafer handler reduces wafer breakage in high-throughput water bath applications

Product Briefing Outline: AMB Apparate + Maschinenbau GmbH is launching the Wet Wafer Separator 3000+, a new high throughput wafer handling system designed for the thinnest 150 micron wafers in production through to 300 micron thick wafers. The WWS 3000+ is focused on water bath system integration requirements where emphasis is placed on wafers being handled safely and reliably by gentle separation of the wafers from the stack in the water bath with reduced breakage rates without an impact on high-throughput.

Problem: The continued high cost of solar grade wafers due to demand from the PV industry has led to wafer cost reductions focused on reducing the thickness of wafers to current leading-edge thicknesses of 150 microns. These ultra-thin wafers are prone to breakage without correctly selected wafer handling systems specifically designed to limit wastage while enabling high-throughput in volume production applications.

Solution: The loaded carriers are lowered into a water bath. A feeder system brings the stack of wafers automatically to the pickup point. A newly developed pickup system separates the foremost wafer from the stack without any mechanical stress which results in reduced breakage rates. After separation, the wafers are moved out of the water bath to the transfer station along a special conveyer belt with a non-slip surface. The belt creates a large surface contact with the wafers which guarantees a gentle transport.

Applications: Wafer type: Multi- and Mono-crystalline silicon. Wafer geometry: Square and pseudo-square. Wafer thickness: 150 - 300µm.

Platform: With the technology used in the system, wafer damage and breakage is reduced to a minimum. High efficiency separating unit, combined with wafer control units and buffer systems, guarantee high production and yield.

Availability: End of 2008.

Product Briefings

Mallinckrodt Baker

Mallinckrodt Baker's wet chemical cleaning solution improves conversion efficiencies

Product Briefing Outline: Mallinckrodt Baker has launched its BakerClean PV-160 solar cell surface cleaner, a wet chemical cleaning solution incorporated in the Energy research Centre of the Netherlands' (ECN) 'ECN-CLEAN' process for manufacturing multi-crystalline silicon solar cells. The BakerClean PV-160 solar cell surface cleaner in the ECN-CLEAN process is already being used by several companies to manufacture solar cells in production quantities.

Problem: A key requirement for the reduction in the cost per watt of c-Si solar cells is the need to improve cell conversion efficiencies. This means that specific performance chemistries and changes to process steps are required to improve surface passivation.

Solution: Solar cells produced utilizing BakerClean PV-160 solar cell surface cleaner in the ECN-CLEAN process convert more incident light energy into electrical energy, generating more electricity than cells made without the benefit of the ECN-CLEAN process and BakerClean PV-160 solar cell surface cleaner. Therefore, solar panels made from these more efficient, higher output solar cells generate more electricity per square metre than traditional solar arrays. Mallinckrodt Baker says that solar cells manufactured with BakerClean PV-160 solar cell surface cleaner in the ECN-CLEAN process exhibit relative energy conversion efficiency gains of two percent, providing more electricity output per unit of incident solar radiation.

Applications: Solar cell surface cleaning.

Platform: The BakerClean PV-160 solar cell surface cleaner in the ECN-CLEAN process is already being used by several companies to manufacture solar cells in production quantities. Additionally, equipment to apply BakerClean PV-160 solar cell surface cleaner in the ECN-CLEAN process is commercially available from multiple suppliers.

Availability: Currently available.

Newport Corporation

Newport's PV 'IsoStation' vibration isolation workstation designed to reduce reflected light impact

Product Briefing Outline: Newport Corporation has introduced the latest addition to its industry-leading portfolio of photovoltaic development solutions – the PV 'IsoStation' Series Workstations. Newport's PV IsoStation Workstation is a 36"x 60" ergonomic workstation specifically designed for PV test and development applications. It features integrated storage and shelving for instruments, solar simulators and other devices and a specially treated worksurface that reduces light reflectivity by a factor of six compared to typical optical table surfaces. The PV IsoStation workstation is ideal for a wide range of photovoltaic applications.

Problem: Newport's PV IsoStation Workstation provides a 6x less reflective work surface than standard workstations to minimize the effects of reflected and scattered light.

Solution: The RG series 3' x 5' breadboard is a lightweight honeycomb structure that is superior to granite or steel plate platforms and much easier to assemble and move. The breadboard surface has a durable black matte finish on the surface and has a 1⁄4-20 hole pattern on 1" centers. The instrument rack is a standard 19" rack mount integrated into the workstation frame. The rack is constructed of welded heavy gauge steel for stability and ruggedness.

Applications: Including I-V testing, quantum efficiency (QE) testing of solar cells, light-biased QE testing, photoluminescence lifetime measurements and pump probe and 2D IR study of charge transfer in organic solar cells.

Platform: Newport's PV IsoStation Workstation features a black shelving system for supporting instruments, a low reflectivity, black RG series breadboard, a rigid black support structure with built in cabinets, 19" standard instrument rack and casters for easy mobility.

Availability: November 2008 onwards.

KIC

KIC's new thermal profiler handles thermal process window accuracy

Product Briefing Outline: KIC has introduced a thermal profiler that is specifically designed for the unique needs and challenges of the PV industry. The SunKIC benefits from several hardware and software innovations that help solar cell manufacturers better manage their thermal processes.

Problem: Profiling involves measuring the time versus temperature relationship as the product travels through the process. The data typically includes statistics such as peak temperature, soak, time above liquidous and more. The product's profile is crucial to understanding the "success" of the thermal process relative to the factors that limit the process (i.e. the process window).

Solution: The compact form factor (19 millimeter/0.75" tall thermal shield) enables the SunKIC to pass through the tight furnace tunnel clearance, and the easy-to-use software makes for quick and convenient profiling. The analytical software helps users study and improve upon all the important aspects of the time-temperature profile. Unique to SunKIC is the 'area under the curve' measurement, enabling the study of the energy transmitted onto the solar cell during the thermal process, position pointers on the profile graph and examine the slope between each pointer. Additionally, you can inspect the thermal process information at strategic locations along the profile.

Applications: c-Si solar cell thermal processes.

Platform: Using standard, type K thermocouples, it incorporates KIC's patented 'Air-TC' technology and introduces automation to the time consuming task of profiling. The 'Spectrum' option, an automatic prediction feature, is also available for the SunKIC. Spectrum automatically simulates millions of alternative setpoints and selects the single best furnace recipe relative to the process window-within seconds.

Availability: August 2008 onwards.

Product Briefings

Oerlikon Leybold Vacuum

Oerlikon Leybold's TURBOVAC SL pumps made for harsh environments

Product Briefing Outline: Oerlikon Leybold Vacuum has introduced TURBOVAC SL, a line of high-reliability mechanical turbomolecular vacuum pumps for use in solar manufacturing, analytical instrumentation, R&D, semiconductor manufacturing and other demanding applications. The pumps feature extreme durability, ease of use and several innovations that simplify and improve incorporation into customer equipment.

Problem: OEM equipment designers are seeking smaller footprints and more flexibility in pump placement and orientation, as well as tight integration into control systems.

Solution: TURBOVAC SL pumps feature new compact space-saving housing. Ceramic ball bearings provide extreme durability under a wide range of operating conditions, with lubrication technology that enables installation vertically, sideways, upside down or in virtually any orientation. A wide variety of data interfaces (RS232, 485, Ethernet, profibus or 24V type) simplifies networking and digital control.

Applications: The most demanding requirements in manufacturing and R&D, including: analytical instruments, Flat panel display production, DVD production, leak detectors, mass spectrometers, electron microscopes, gas and liquid chromatography, Inductively coupled plasma mass spectrometry and coating technologies.

Platform: The entire TURBOVAC family utilizes Oerlikon Leybold Vacuum's unique rotor design, which the company claims incorporates the industry's most precise and robust blade configuration for ultra-reliable operation at speeds of up to 70,000 rpm. The SL series pumps also include a novel sealing system that offers the highest resistance to mechanical and thermal shock, ensuring reliable operation under a wide range of conditions. Pumps are available in 80-, 300-, and 700-litre/second sizes.

Availability: Summer 2008.

DEK

1,200wph solar cell metallization platform from DEK

Product Briefing Outline: DEK has introduced the PVP1200 screen printer capable of 1,200 wafers-per-hour (WPH) throughput and offering advanced automated features for high speed and repeatability. The PVP1200 is built using expertise gained from DEK's established high-accuracy screen printing platforms, proven in surface-mount assembly and chip-scale semiconductor packaging.

Problem: Six-sigma repeatability at ±12.5 micron resolution of the PVP1200 demonstrates its capability in advance of current requirements for solar cell front-side and back-side metallization. DEK also claims that it can deliver the PVP1200 within shorter lead-times than the current industry norm.

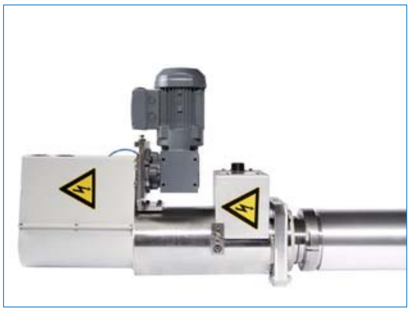
Solution: Specially optimized for solar cell metallization, the PVP1200 is compatible with wafer sizes up to 125mm x 125mm or 156mm x 156mm in Square or Pseudo Square formats. The handling and support mechanisms are suitable for wafer thicknesses from 1mm down to 120 micron, which allows all stock wafer gauges to be used including the latest ultra-thin and lightweight wafers. For maximum accuracy and repeatability when depositing features ranging from sub-100-micron current collectors to low-resistivity bus bars, the PVP1200 printer is directly compatible with emulsion screens designed and produced in-house by DEK's screen manufacturing facility. Special features of the PVP1200 for solar cell applications include dedicated handling for thin wafers, ensuring low breakage rates for maximum yield, as well as high-speed machine vision capabilities.

Applications: Standard wafer sizes for front-side and back-side metallization.

Platform: The PVP1200 is easy to set-up and use, with menu-driven software enabling intuitive control of complex processes via a full-colour TFT-LCD touchscreen. Other management and communication facilities include on-board Statistical Process Control (SPC) software, integrated 10/100 LAN connectivity and a USB 2.0 interface.

Availability: June 2008 onwards.

Bekaert Advanced Coatings



Bekaert offers turnkey solution for rotating cylindrical magnetron applications

Product Briefing Outline: Bekaert Advanced Coatings has developed a series of flexible and high performing sputter hardware components for rotating cylindrical magnetron applications. With these key components a customized and complete sputter solution can be worked out in close collaboration with the customer..

Problem: Within the large area coating business, the rotating cylindrical magnetron concept has proven to offer superior properties relative to the planar concept and to satisfy most of the industrial requirements. Especially in architectural and automotive industry, this technology is commonly accepted as state-of-the-art. In display and PV applications however, the use of rotatable technology is more recently introduced and not yet well known.

Solution: With Bekaert's critical key components, a customized solution can be worked out in close collaboration with the customer. Features include: advantages of this rotatable technology, e.g. a larger useful target material inventory and increased target material utilization, leading to reduced machine down-time; an increased process stability for reactive depositions (drastically reduced arc sensitivity); an enhanced target cooling; a more focused ejection of particles and an enhanced anode functionality during AC sputtering.

Applications: Sputtering of transparent conductive oxides (such as doped oxides of In, Zn, Sn and Cd), reflective layers (thin film), anti-reflective layers (c-Si) and absorbers, necessary in the production of PV cells.

Platform: The Bekaert sputter module solutions consist of the magnetron (end blocks, compact end block or Bekaert Axial Magnetron and adjustable magnet bars), electronics (which can be DC or AC), gas control (which can consist of gas manifold, pumps, plenum and process control), integration of the solution (PLC control, safety interlocks, custom designed automation etc.) and rotatable targets.

Availability: Currently available.

In-line plasma-chemical etching of crystalline silicon wafers at atmospheric pressure using FT-IR spectroscopic process control

Dorit Linaschke, **Mattias Leistner**, **Gerrit Mäder**, **Wulf Grählert**, **Ines Dani** & **Stefan Kaskel**, Fraunhofer IWS, Dresden, Germany

ABSTRACT

The etching technology currently used in the solar industry is mostly based on wet chemical processing. Plasma-enhanced dry chemical etching at atmospheric pressure is an alternative to the existing technology, especially when combined with similar process technologies, for example plasma-enhanced deposition techniques at atmospheric pressure, to provide a continuous in-line processing of crystalline silicon solar cells. This paper presents the use of plasma chemical etching using Fourier Transform infrared (FT-IR) spectroscopy to monitor different silicon wafer processing steps as an alternative to the widely used wet chemical processing approach.

Introduction

Silicon etching processes are essential steps in crystalline silicon solar cell manufacturing. Currently, industrial production of silicon solar wafers is mostly based on wet chemical processing. Etching steps like saw damage removal, surface texturing, edge isolation, and phosphorous silicate-glass removal are often done in acidic or alkaline solutions at elevated temperatures. The drawbacks of this process are the needs for large volumes of distilled water, the chemical waste disposal requirements, as well as the high mechanical impact on the wafer [1].

Etching of crystalline silicon can also be carried out by plasma technology. Plasma-chemical etching has attracted recent interest for economic and technological reasons [2], especially when realised at atmospheric pressure. Advantages can be seen in:

- High throughput for in-line solar wafer processing
- Cost efficiency due to decreased breakage rate of thin solar wafers by soft processing and reduced handling due to in-line processing
- One side treatment for texturing
- Adaptive for different etching steps
- Reduced chemical waste.

Based on a linearly extended DC arc with a working width of 150mm for plasma activation, an innovative atmospheric pressure plasma etching technology has been developed. The remote injection of the etching gas prevents plasma source damage due to chemical attack of etching radicals. Fluorine radicals generated from NF_3 and SF_6 by an argon-nitrogen remote

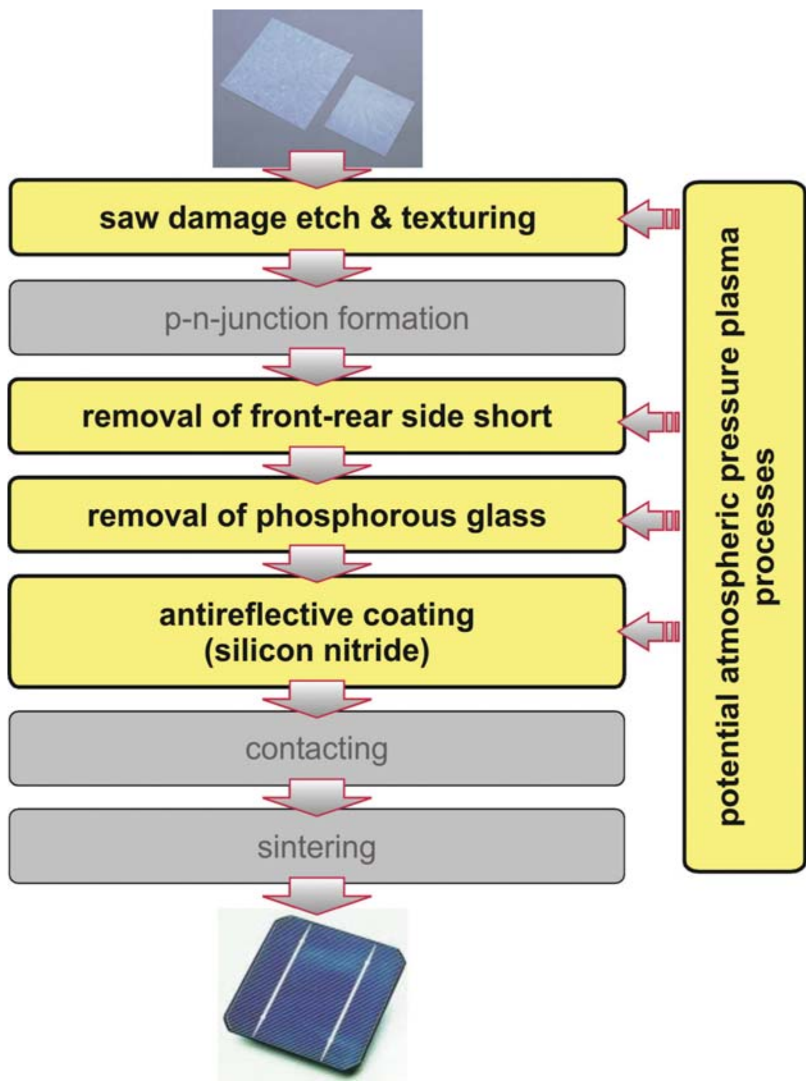


Figure 1. Wafer processing schematic. Potential atmospheric pressure plasma processes are highlighted in yellow.

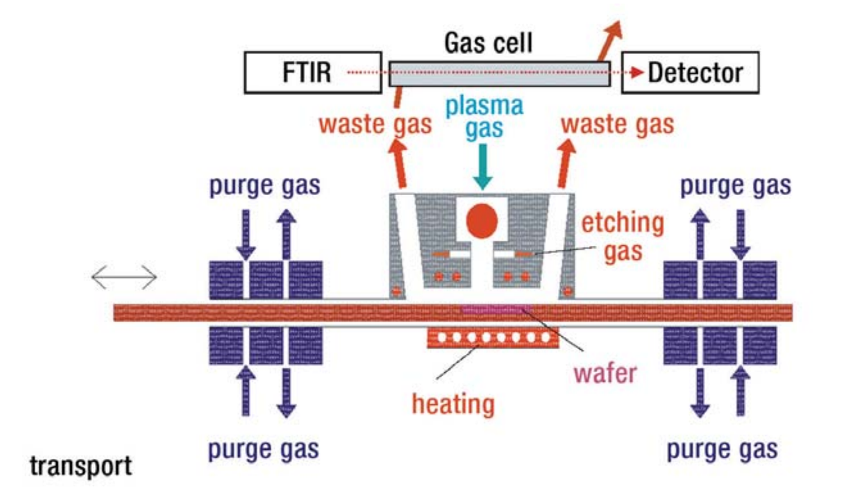


Figure 2. Principle of atmospheric pressure plasma etching equipment and FT-IR measurement device.

plasma have been successfully utilized to etch (100) monocrystalline-Si wafers.

Fourier Transform infrared (FT-IR) spectroscopy was applied to monitor different silicon wafer processing steps. Instantaneous determination of the current etching rates is achieved by the analysis of the waste gas during wafer treatment. This non-destructive measurement device has the potential to be inserted into a plasma-chemical silicon wafer processing line to monitor processes such as saw damage etching, edge isolation and phosphorous silicate-glass removal.

Plasma technology developed at Fraunhofer IWS works at atmospheric pressure and is able to cover not only plasma etching but also plasma-enhanced chemical vapour deposition (AP-PECVD). The deposition technique was successfully applied to coat crystalline silicon solar wafers with SiN_x as the antireflective and passivation layer [3]. Figure 1 shows the processing sequence of crystalline silicon wafers. Saw damage etching, surface structuring, front-rear side short removal and etching of the phosphorous silicate-glass are demonstrated with atmospheric pressure arc plasma technology. The feasibility of edge isolation was proved several times by industrial tests [4].

Launching a new technology based on atmospheric pressure plasma etching processes leads to the important question of process control during wafer processing, especially when aimed at industrialisation. The method of choice should be non-destructive, fast, and easy to handle, so that the wafers do not have to undergo an extra handling step. Time-resolved FT-IR spectroscopy is able to detect volatile silicon species occurring during plasma-chemical etching of silicon wafers, which provide instantaneous information about the current etching rate and the etched depth of the wafer; this data in turn plays an important role when a certain thickness of the saw damaged layer has to be removed at the beginning of the processing chain. Monitoring of phosphorous gas species can be used for controlling the process of phosphorous silicate-glass etching in terms of front-side or back surface etching after p-n junction formation. In-line FT-IR spectroscopy analyses the exhaust gas to obtain relevant information about the etching progress and thus is a promising non-destructive measurement method.

Etching and monitoring equipment

Etching of crystalline silicon solar wafers is carried out by an innovative atmospheric pressure plasma process. This technology is based on a linearly extended arc discharge with a working width of 150mm; as well as the 150mm DC arc, a plasma source with an arc length of 250mm has been established at Fraunhofer IWS, rendering the processing of 6-inch wafers possible. The plasma is generated in the DC arc while argon and nitrogen, which act as plasma gases, flow in a perpendicular direction through the arc axis (see Figure 2), resulting in a remote plasma. Detailed information about the plasma source assembly can be found elsewhere [5, 6, 7].

The etching reactor design and the FT-IR measurement device are also depicted in Figure 2. Since the technology works at atmospheric pressure, simple purge gas curtains on the entrance and on the end of the reactor prevent the leakage of the etching gases, also providing a controlled atmosphere inside the reactor. A careful design of the reactor based on fluid dynamic modelling is necessary to this process.

The core piece of the reactor is the plasma source with a specially designed plasma gas distributor, a remote precursor injection system and double-sided waste gas extraction channels, which direct the waste gas to an abatement system for treatment. Leaving a small distance between the plasma source and the etch gas injection system leads to better utilization of the etching gas. Since the ions in the plasma recombine early, no ion bombardment of the wafer takes place and hence no wafer damage occurs. Etching gases are not supplied directly through the plasma source to prevent the possibility of damage due to chemical attack.

During etching, the silicon wafers are placed on a carbon substrate holder, allowing the wafers to be heated up to 400°C. The wafer itself is fixed on the substrate holder by a suction system and passes dynamically under the plasma source with velocities up to 100mm/s.

Typical experimental parameters for plasma enhanced chemical etching are summarized in Table 1. In this case, the etching gases used were SF_6 and NF_3.

Plasma etching processes carried out in the described atmospheric pressure plasma etching equipment were monitored by Fourier Transform Infrared absorption spectroscopy using a Bruker Matrix FT-IR spectrometer. Table 2 summarizes the acquisition parameters utilized for this example.

Parameter	Parameter range
Plasma/Carrier gas	Ar / N_2
Voltage (V)	190 – 240
Current (A)	80 – 100
Power input (kW)	15 – 24
Plasma gas flow (slm)	45 – 65
Etching gases	NF_3, SF_6
Amount of etch gases (slm)	0.3 – 2
Temperature of wafer (°C)	300 – 400

Table 1. Typical parameter range for the 150mm DC arc plasma source and for the plasma etching process.

Parameter	Range
Detector	N_2-MCT (mercury-cadmium-telluride)
Measurement range (cm^{-1})	500 - 4500
Spectral resolution (cm^{-1})	4
Time resolution (s)	1
Optical path length (m)	0,2

Table 2. Acquisition parameters of waste gas measurement.

The measurement was performed in the waste gas line (see Figure 2) to determine the chemical composition of the waste gas. Initially, measurements of pure etching gases without plasma were performed and compared to the spectra of the etching gases with plasma impact to estimate their decomposition rates. Measurements during the plasma etching of 5-inch (125 × 125mm^2) alkaline (KOH) textured monocrystalline silicon wafers and 5-inch alkaline textured monocrystalline silicon wafers after $POCl_3$ diffusion (P-doped) were carried out.

Results of in-line FT-IR spectroscopy

Figures 3 and 4 show the spectra of the precursors SF_6 and NF_3 as well as their decomposition in the plasma. The comparison of the spectra in Figure 3

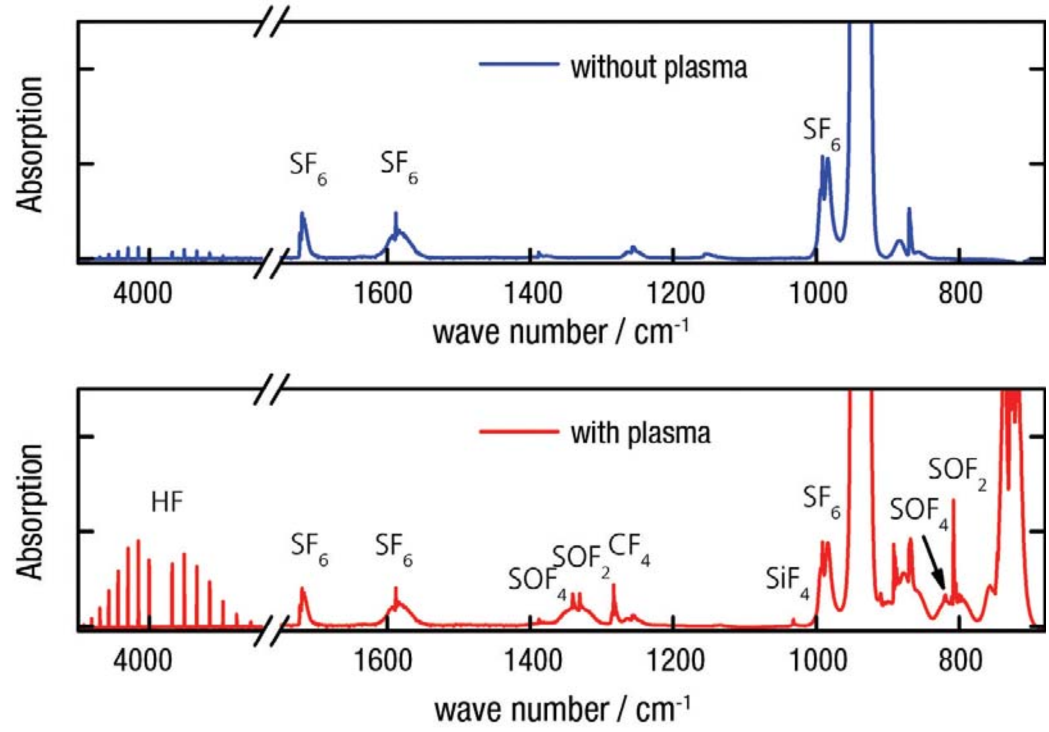


Figure 3. IR spectra of pure SF_6 (top) and during SF_6 plasma decomposition (bottom).

(SF_6) and Figure 4 (NF_3) indicates that the plasma plays a crucial role for an effective etching gas decomposition. According to the spectra, a decomposition rate of 15% for SF_6 and 90% for NF_3 can be calculated; the reason for this difference can be found in the different average energies for S-F (368 kJ/mol, 298 K) and N-F (278 kJ/mol, 298 K) bonds. In both cases the formation of active fluorine species due to the plasma impact can be assumed, leading to the components HF (3960cm^{-1}), SOF_2 (810cm^{-1}, 1335cm^{-1}) and SOF_4 (820cm^{-1}, 1890cm^{-1}) when a low concentration of water vapour is present in the reaction chamber and CF_4 (1280cm^{-1}) due to a slight etching of the graphite substrate holder.

Probably, silicon deposits of preceding etching cycles at the reactor walls and in the waste gas line lead to the appearance of SiF_4 traces at 1030 cm^{-1}.

During the plasma etching of the silicon wafer, SiF_4 was identified as the volatile key species. Figure 5 shows the SiF_4 IR-absorption band at 1030cm^{-1} during SF_6 and NF_3 etching.

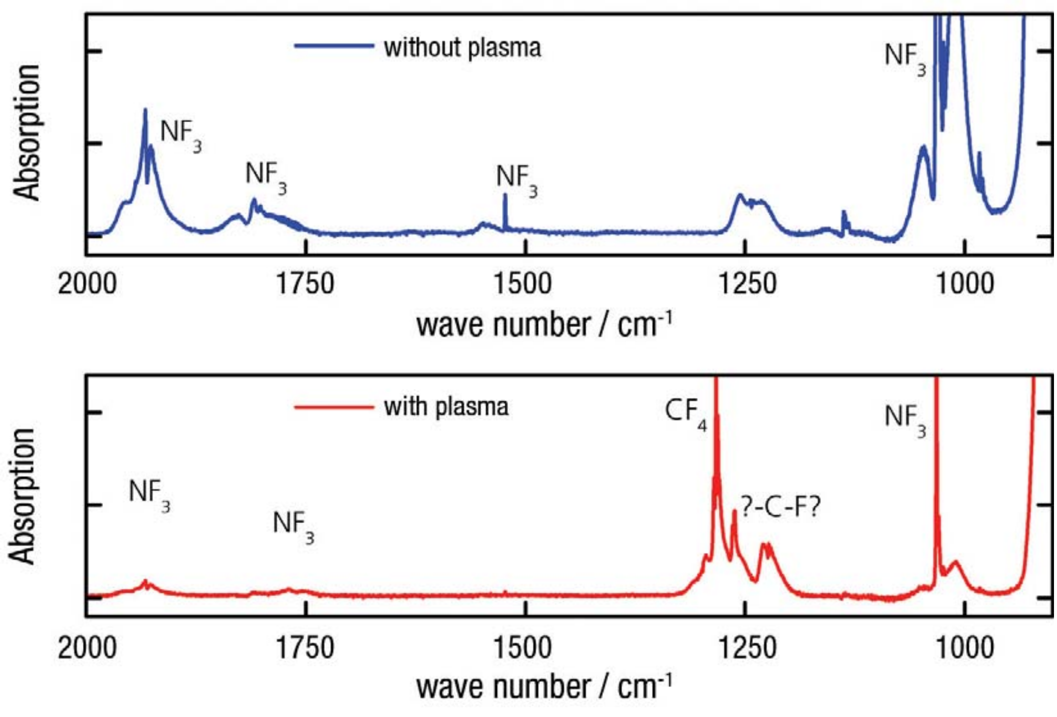


Figure 4. IR spectra of pure NF_3 (top) and during NF_3 decomposition in plasma (bottom).

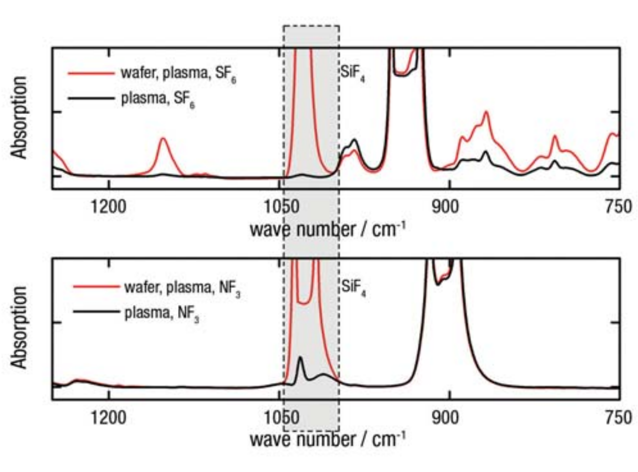


Figure 5. IR spectra during plasma-enhanced chemical etching of silicon wafers with SF_6 (top) and NF_3 (bottom) (reference measurement without wafer depicted in black).

As the high concentration of SiF_4 leads to too high absorbance values at 1030cm^{-1} and also completely overlaps with the NF_3 absorption (Figure 5, bottom image), the quantitative evaluation of SiF_4 concentration was carried out at 1191cm^{-1} (not shown in Figure 5 due to the y-axis scale). It was found that the measured SiF_4 IR-absorption could be directly related to the weight loss of the wafer, which was determined by gravimetric measurements.

Based on the calculated weight loss from SiF_4 IR-absorption or gravimetry after etching, the dynamic etching rate in [µm · m/min] can be determined by the following equation:

- dynamic etching rate = Δm / wafer factor (f(A, ρ)) * R,

while the etched thickness in [µm] can be determined by:

- etched thickness = Δm / wafer factor (f(A, ρ)

where Δm is the weight loss of the wafer, A the wafer area, ρ the density of the silicon wafer, and R the reactor residence time of the wafer.

Both the etched thickness (Figure 6) and the etching rate can therefore be calculated in real-time using in-line FT-IR spectroscopy.

In-line FT-IR measurements can be applied to determine the weight loss of the wafer, but can also monitor the edge isolation process step on the rear side or the phosphorous silicate glass (PSG) etching step on the front side after $POCl_3$ diffusion. In this case the key species is POF_3, which can be found at 1416cm^{-1}. Figure 7 points out the time-dependent concentration of SiF_4 and POF_3 during dynamic PSG removal (the wafer passed through the reactor several times). POF_3 is present only during the first wafer run due to the thin PSG layer on the front side of the wafer, whereas SiF_4 is detectable during the whole six runs. Furthermore, the progress of the process can be monitored. The course of SiF_4 concentration shows the movement of the wafer into and out of the etching zone.

Given that all measurements are carried out at the waste gas line, the infrared spectroscopy provides an efficient and non-destructive tool for direct in-line process monitoring and process control. It allows precise control of the removal of silicon and PSG layers from the wafer.

Conclusion

In-line plasma-chemical etching of crystalline silicon solar wafers at atmospheric pressure and FT-IR spectroscopic measurements for quantitative analysis of the decomposition products of the etching gas NF_3 and SF_6 in the plasma were demonstrated as alternatives to the wet chemical processing method. NF_3 shows the highest decomposition rate in the plasma due to its lower binding energy compared to SF_6, while the same method was used to monitor the waste gas during plasma chemical etching of crystalline silicon wafers.

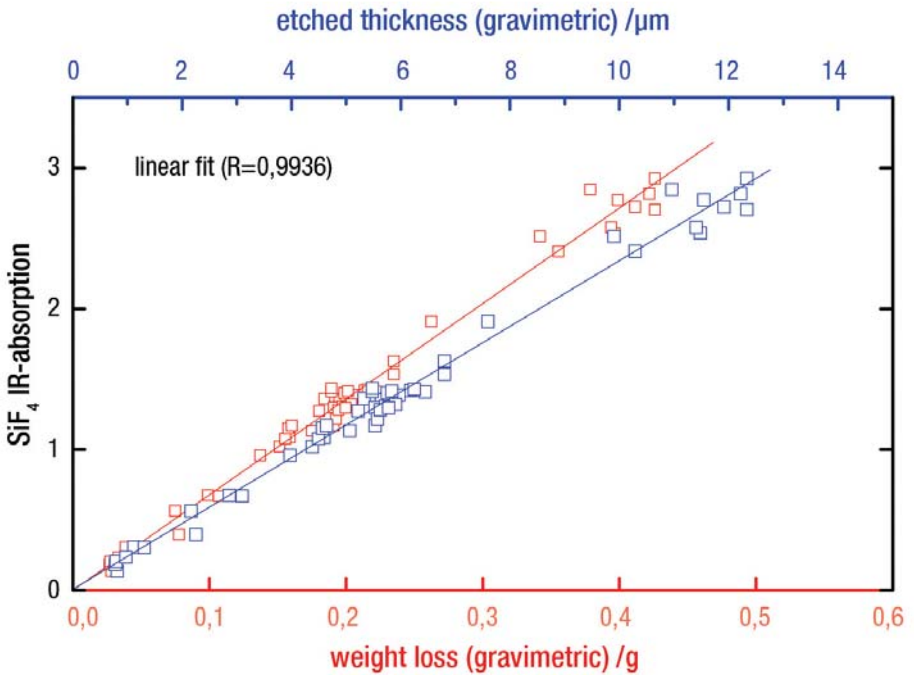


Figure 6. Relationship of SiF_4 IR absorption during wafer etching showing weight loss (x-axis 1) and etched thickness (x-axis 2). Etched thickness is determined by gravimetric measurements after wafer etching with SF_6 and NF_3.

The study identified SiF_4 as the main reaction product during etching, the IR-absorption of which is linearly related to the weight loss of the etched wafer. Thus, SiF_4 monitoring by FT-IR spectroscopy allows the determination of the etched thickness and the dynamic etching rates of the wafers. A FT-IR spectroscopic process analysis for phosphorous silicate glass (PSG) etching was demonstrated by monitoring POF_3. Since the concentrations of the etching products can be mapped, the progress of the etching process can be recorded precisely.

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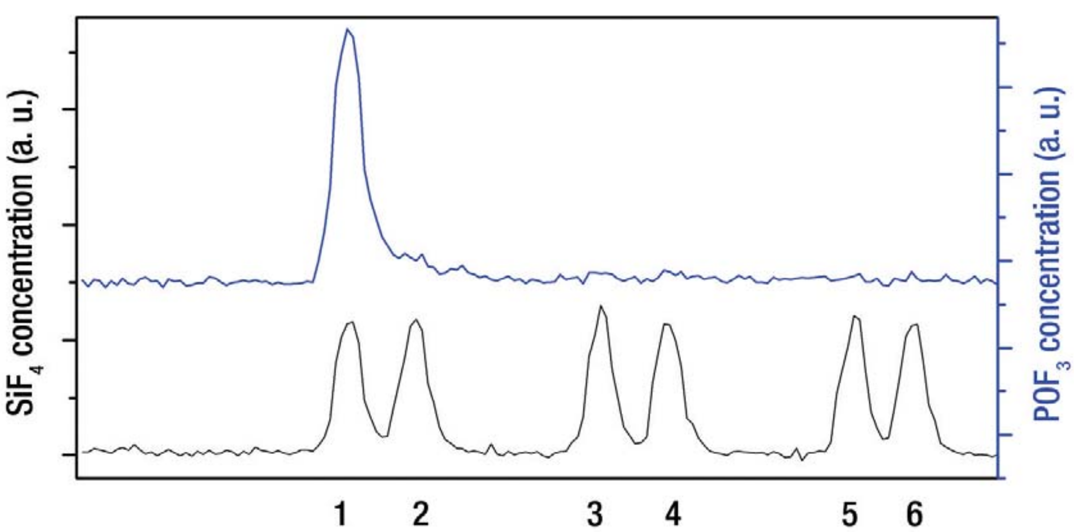

Figure 7. Time-dependent concentration of SiF_4 and POF_3 during phosphorous silicate glass etching (etching gas NF_3).

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Dorit Linaschke has held the role of researcher and project manager in the CVD thin-film technology group at Fraunhofer Institute for Material and Beam Technology since 2005. She graduated with a Dipl.-Ing. in material science in 2002 from the Technical University Bergakademie in Freiberg and in 2004 she received an M.Sc. degree in molecular bioengineering from the Technical University, Dresden.

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Surface modification for efficiency improvement of inline solar cell manufacture

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ABSTRACT

Inline processing, one of the fastest-growing production processes for crystalline silicon solar cells, uses continuously operated belt furnaces to achieve higher overall throughput compared with traditional batch processing. A second, major advantage of inline processing is improved manufacturing yields through reduced breakage of today's thinner, increasingly delicate wafers. This is accomplished by eliminating several handling steps unique to batch processing techniques. This paper describes the influence of ECN-Clean, as developed by Mallinckrodt Baker and ECN in 2006, whose application increases the efficiency of solar cells produced using inline processing by approximately 0.3 percent absolute, compared with standard inline processing. The increase is achieved by using a wet chemical surface modifier after emitter formation. Additionally, experimental data is presented on establishing a stable process on an industrial scale, prior to optimization of the line for cell efficiency.

Introduction

One of the main challenges facing the photovoltaic industry in the coming years will be the reduction of the cost/Wp. One of the most effective methods available to reduce cost/Wp is to use thinner crystalline wafers. Currently, in batch systems, such as $POCl_3$ diffusion, wafers are placed vertically in a boat, entering and exiting the furnace through the same opening. This entails a great deal of handling of very fragile material, significantly raising the risk of breakage and lowering overall manufacturing yields. Current equipment is capable of handling wafers with thicknesses down to 150 micrometers. If the thickness of the wafers is reduced further, as industry roadmaps predict, increased breakage due to handling, as well as effects due to fast cooling, will become serious problems.

Inline diffusion offers a definite advantage over batch systems, in that wafer handling is minimal, and overall throughput is considerably higher than for similar batch processes. As such, the inline process is considered to be one of the most promising alternatives for high-yield cell manufacturing. Instead of using a gas-phase process to deposit the emitter source, the phosphorous is deposited onto the wafer using an ultrasonic spray or spin tool. Phosphoric acid, either in pure form

	J_{SC} (mA/cm²)	V_{OC} (mV)	FF (%)	Eff. (%)	J x V (mAV/cm²)
ECN-Clean	33.3	608	77.1	15.63	20.26
No Clean	32.9	603	77.3	15.37	19.88
Diff. Abs.	0.4	5	-0.2	0.26	0.38
Diff %	1.1 %	0.80 %	-0.25 %	1.7 %	1.89 %

Table 1. Cell-level results of ECN-Clean-processed wafers. Experiments were performed on 19 neighboring wafers per group.

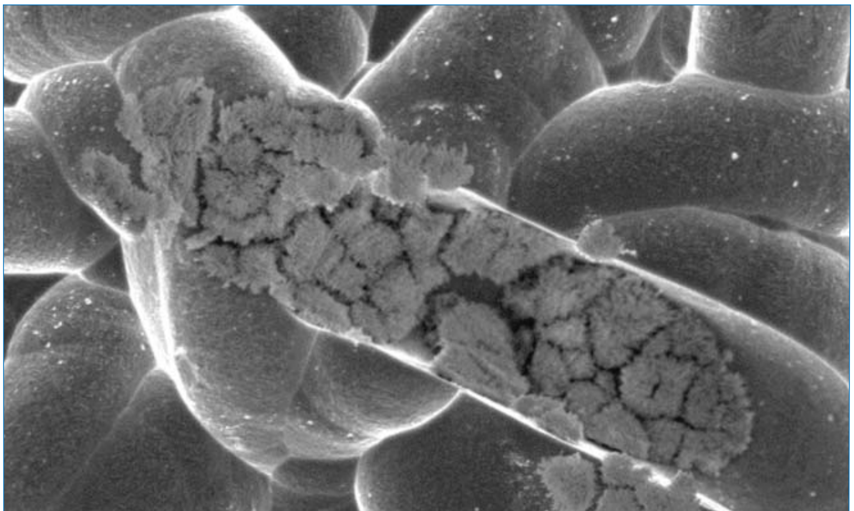

Figure 1. SEM of PSG on a textured multicrystalline wafer. PSG is visible as crystalline material. Image is 10 x 7μm.

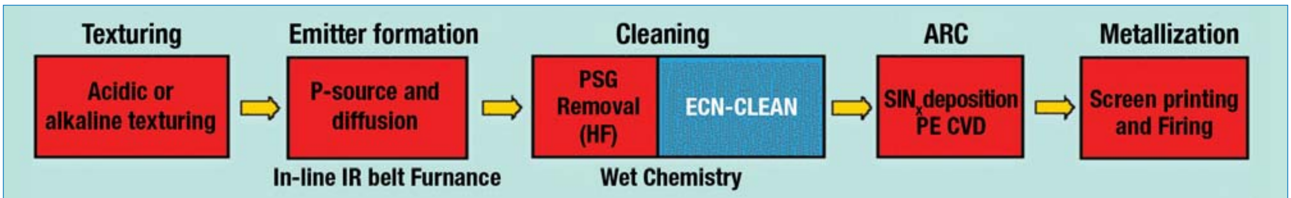

Figure 2. Schematic overview of a cell manufacturing process, including ECN-Clean.

or mixed with water, is typically used as the phosphor source for the emitter. In some cases, additives can be used to facilitate wetting of the phosphor source and to improve emitter homogeneity. The ECN-Clean is capable of increasing the efficiency of inline-produced wafers by 0.3% absolute [1,2]. Process conditions can be easily stabilized in an industrial production line prior to efficiency optimization.

ECN-Clean

In the standard cell manufacturing process, emitter formation is followed by an HF dip to remove phosphosilicate glass (PSG, or phosglass, see Figure 1), after which the passivation layer (usually silicon nitride: SiN_x:H or silicon oxide) is applied. This crucial step reduces the amount of surface recombination of charge carriers, substantially increasing short-circuit current and thereby the efficiency of the cell. To further improve surface passivation in solar cell processing, a cleaning step can be employed immediately following the PSG removal.

Traditionally, cleans like RCA1 and RCA2 are used for surface cleaning. These cleans, consisting of an etching alkaline bath and an acidic dip, have been used in the IC industry for decades. Unfortunately, these cleans involve a two-step process (excluding rinsing) at very high temperatures. ECN-

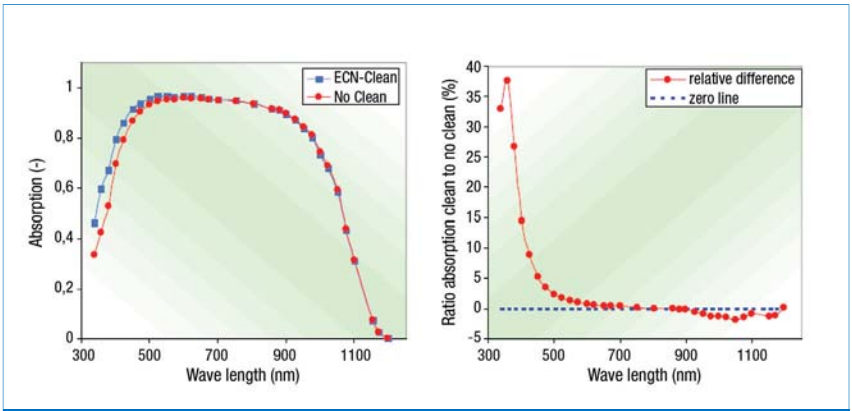

Figure 3. Plot of the absorption of incident light for ECN-Clean versus no clean, and the ratio of the two respective measurements.

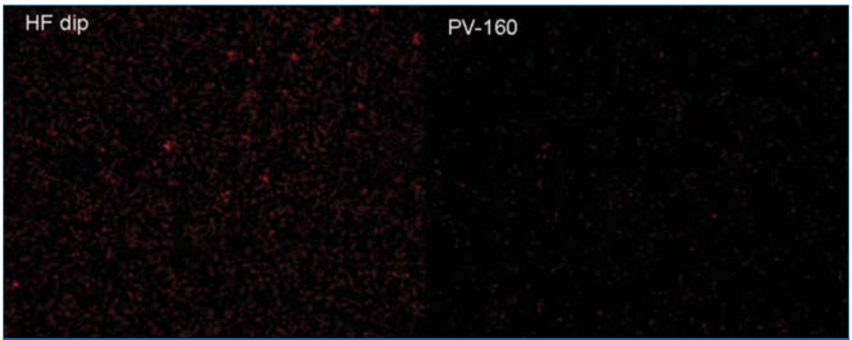

Figure 4. SEM/EDX micrographs of identical spots on a multicrystalline wafer before and after application of the BakerClean Surface Cleaner. Presence of phosphorous is indicated in red. Images are 50 x 30µm.

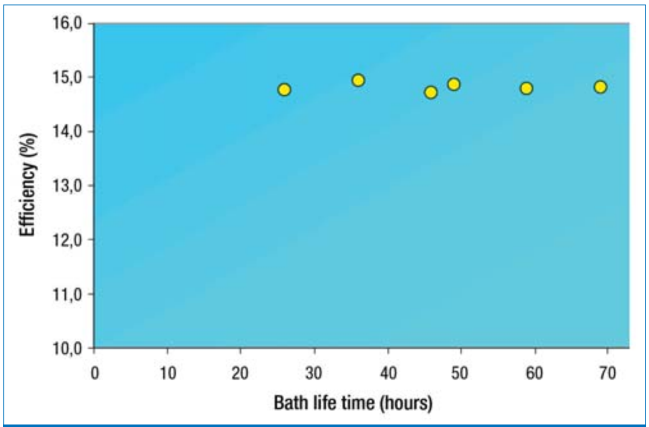

Figure 5. Cell efficiency as a function of run time for industrial production involving ECN-Clean. The purpose of the experiment was to achieve a stable line, not to optimize cell efficiency.

Clean involves applying a simple wet bench single cleaning step after standard glass removal with HF but before SiN_x:H deposition (Figure 2) [1,2].

Laboratory experiments have shown that improvements in efficiency resulting from the cleaning step were due to an increase in voltage and current, while the loss in fill factor was small (Table 1). This increase was found to be irrespective of wafer position in the ingot [1,2]. In contrast, applying a standard RCA clean resulted in a dramatic loss of fill factor of several percent, drastically reducing final cell efficiency [3].

The application of Mallinckrodt Baker and ECN's BakerClean PV-160 Solar Cell Surface Cleaner resulted in an increased blue response from the cell, as shown by IQE measurements (Figure 3).

The increased blue response is generally seen as an indication of the removal of phosphorous from the n^{++} region of the wafer [4]. In this region, the phosphorous concentration easily exceeds its solubility limit in silicon, resulting in additional charge carrier recombination near the surface. Using SEM/EDX, which is capable of determining the surface concentration of various elements, we were able to show that the application of the cleaner selectively reduces the surface concentration of phosphorous on the wafer surface (Figure 4). This results in less recombination, and leads to an increase of over 1 percent in the current. Additionally, the open-circuit voltage was found to increase by almost 1 percent, which can be attributed to the partial removal of the dead layer.

Industrial application

Translating an etching step from a simple wet bench under laboratory conditions to a fully ramped production site can be a time-consuming and costly undertaking, as it entails executing start-up protocols, on-site training of engineers and possibly down-time of the production facility.

By using a tailor-made start-up protocol, the cleaning process was implemented on an industrial production line of crystalline wafers with a spray-on phosphorous emitter. The purpose of this ramp-up procedure was to achieve stable production. At this point, the fabrication line was not yet optimized for cell efficiency.

In a 70-hour production run time, consisting of 85,000 wafers, cell efficiency and other cell parameters were monitored as a function of time. The data clearly show that all cell parameters are stable within this interval (see both Figure 5 and Table 2).

The bath conditions can be monitored both inline and offline. For this production run, several parameters were monitored in time; total bath volume and pH are shown in Figures 6 and 7. Figure 6 shows the total bath volume as a function of time. Using a tailored spiking protocol, calculated from specific equipment properties and factory conditions, the bath volume was kept within 5 percent of its initial capacity. When the spiking protocol was stopped at 58 hours, a rapid decrease in bath volume was observed due to the evaporation of water.

Time	JSC (mA/cm2)	VOC (V)	FF	Eff. (%)
26 hrs	33.00	0.601	0.744	14.8
36 hrs	33.07	0.600	0.751	14.9
46 hrs	33.03	0.599	0.743	14.7
49 hrs	33.03	0.601	0.752	14.9
59 hrs	33.02	0.600	0.747	14.8
69 hrs	32.99	0.599	0.748	14.8

Table 2. Selected cell parameters as a function of time for an industrial production run involving ECN-Clean.

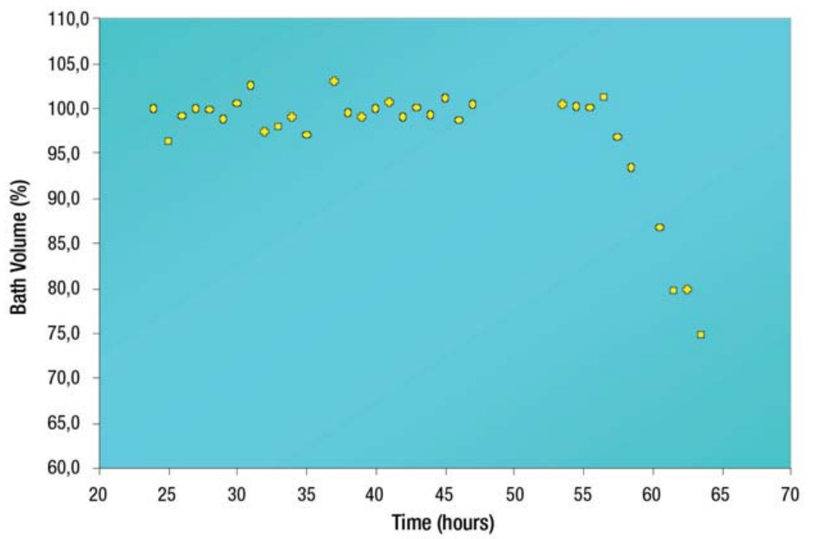

Figure 6. Plot of total bath volume as a function of time. A tailor-made spiking protocol was used to keep production conditions constant. Spiking was discontinued at 58 hours.

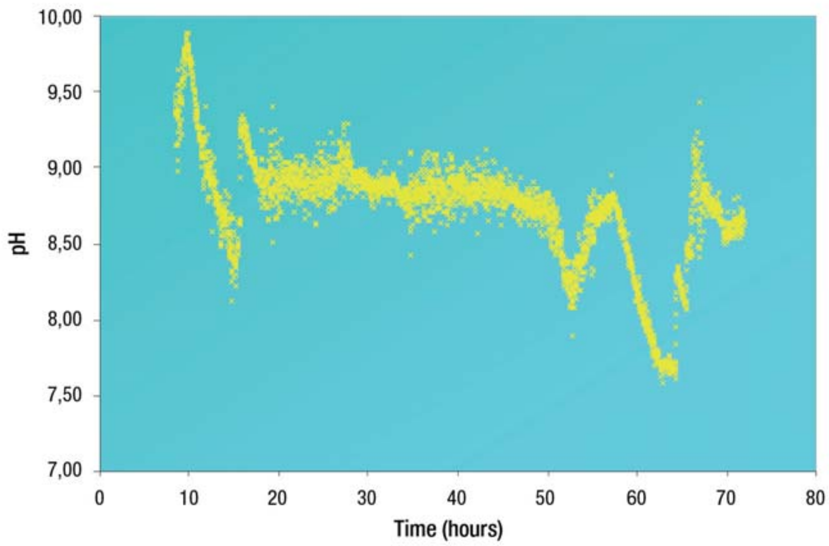

Figure 7. Plot of pH of the ECN-Clean bath during the production run. The stable regime was achieved with a tailor-made spiking protocol.

Other parameters, such as the concentrations of the individual components of the ECN-Clean, were also monitored. These components were stable up to the discontinuation of spiking, similar behaviour to that displayed by the total bath volume.

The pH was measured inline at normal operating temperatures. By tailoring the spiking protocol, we were able to keep the pH stable during the production time, up to discontinuation of spiking (Figure 7). The initial fluctuations in the pH value were attributed to discontinuation of temperature control and the cessation of spiking, after having heated the bath to its operating temperature, to observe what effect this would have on the properties of the bath. As expected, bath volume decreased during this time and the concentration of the individual components fluctuated (not shown), as did the pH. Once temperature and spiking control were reinstated, at 15 hours, the pH returned to stable values up until spiking was stopped. At 65 hours, the spiking protocol was reinstated, which once again resulted in a stable pH of the bath (Figure 7).

These experiments show the importance of tailored spiking in achieving a stable, running production line.

Conclusion

This paper presents data on the ECN-Clean process, which was designed to selectively etch excess phosphorous from inline emitters, thereby increasing the blue response of the cells. This controlled post-emitter etch increases the current and voltage of the solar cells by about 1 percent, resulting in an efficiency increase of 0.3 percent absolute, independent of wafer quality. Additionally, an industrial example of the application of this process is shown, resulting in a stable production line before efficiency optimization. The data show that by using a tailor-made start-up protocol, a stable production run of 70 hours and 85,000 wafers was achieved.

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About the Authors

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Dr. Jan H. Bultman has been one of the group leaders of Energy research Centre of the Netherlands' (ECN) Crystalline Silicon PV technology group since 2003. He is responsible for industry projects, technology transfer and finances. In 2002, Bultman was responsible for the acquisition of the Integrated Project Crystal Clear together with Paul Wyers. In 1998, he started the development of the Pin-Up Module, now one of the main areas of PV research at ECN. Since 2000, Bultman has been involved in knowledge transfer between ECN and industry, acquiring and negotiating license agreements with numerous industrial entities. Bultman studied Physics and obtained a doctorate in Nuclear Engineering at the Technical University Delft.

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Dr. Arno Stassen has worked as a research scientist in ECN's Crystalline Silicon PV Technology group since 2006, addressing chemical etching, oxidation and cleaning of silicon wafers. He is also involved in knowledge transfer of chemical processes to the industry. Dr. Stassen studied chemistry at the Radboud University Nijmegen and obtained his doctorate at Leiden University in 2002. From 2002 to 2006, he worked as a post-doctoral research fellow in chemistry at the Technical University of Vienna and Leiden University, and in applied physics at the Technical University of Delft and the ETH Zürich.

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Cell efficiency increase of 0.4% through light-induced plating

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ABSTRACT

A vast majority of silicon solar cells are manufactured using silver paste that is screen printed onto the front side of the wafer and fired to form the front-side contact. Though this method is well established within the industry, it continues to present several areas for potential efficiency improvements. The Fraunhofer Institute [1] has, among others, studied the potential of using electrodeposition of silver on top of the front side silver paste as a way to improve the front-side contact and increase cell efficiency. These results have shown cell efficiency increases of up to 0.4% absolute. This type of improvement has captured the interest of many manufacturers, but there has been a hesitancy to adopt electrodeposition as there is uncertainty as to what they can expect on their cells. Since efficiency gains are dependent upon many factors that can be unique to an individual cell, this paper provides a much-needed exploration of the potential effects of electrodeposition of silver in a way that isolates its effects from that of other factors.

Introduction

Standard PV silver pastes contain many components that are necessary for their functionality, but are not beneficial for conductivity. While pure silver metal has a resistivity of 1.59 microhm-centimeter at 20°C, most PV pastes have resistances that are two to three times that. In addition, since silver pastes flow when they are fired, there is a limitation in the aspect ratio that can be achieved. As a result, most manufacturers have to print a 120-micron or wider line for the front-side contact to achieve a cross-sectional area large enough to carry the current generated by the cell. To add to the cell manufacturer's problems, the silver paste process introduces much of the variability that cell makers experience in their efficiencies. The addition of electrodeposited silver to the cell can improve the front-side contacts and reduce the product variability.

Effect on efficiency

The effect of this process on the efficiency of a population of cells can be dependent on several factors. It can be difficult for cell manufacturers to look at data from past experiments and use those results to predict what they can expect from their cells. In an attempt to make a data set that could be more usable, an experiment was designed using 156 cells, prepared by Evergreen Solar. The electrical characteristics of these cells were measured both before and after the electrodeposition of silver metal onto the front-side contacts. Though all effects on the efficiencies were measured, the focus of the data analysis was on the change in the front-side resistance (R_{front}). This analysis gave a set of tangible results that demonstrated the impact of electrodeposited silver on cell efficiency.

> "The addition of electrodeposited silver to the cell can improve the front-side contacts and reduce the product variability."

Test conditions

The test cells were manufactured using a standard process flow. After firing, the cells went through a laser edge isolation, followed by electrical testing prior to the electrodeposition process.

The test cells were processed through a light-induced plating (LIP) tool where light was introduced to the cell to generate some of the power needed for the electrodeposition process. A rectifier was used to put a voltage potential on the backside of the cell to protect the backside contact from becoming the anode and dissolving during the electrochemical reaction.

The test cells were electroplated in Technic's TechniSol Ag silver plating bath for ten minutes at room temperature. These conditions resulted in 8 – 10 microns of fine grain plated silver being deposited on top of the silver paste front-side contacts. The silver metal was plated at a current density of 1.3 amps/decimeter^2 (ASD). Subsequent testing has shown this thickness can be achieved in five minutes if the solution temperature is raised to 40°C and agitation is increased, which allows for plating to occur with a fine grain deposit at 2.6ASD.

The cells were re-tested electrically after the electrodeposition process and, as the cells had been serialized, it was possible to look at the change in the electrical characteristics for each cell.

The results

By depositing the silver metal onto the silver paste contacts, the average R_{Front} was reduced dramatically. The batch of test cells started with an average R_{Front} of 122 milliohms (as measured from bus-bar to bus-bar) prior to the deposition of silver. After the plating process, the average

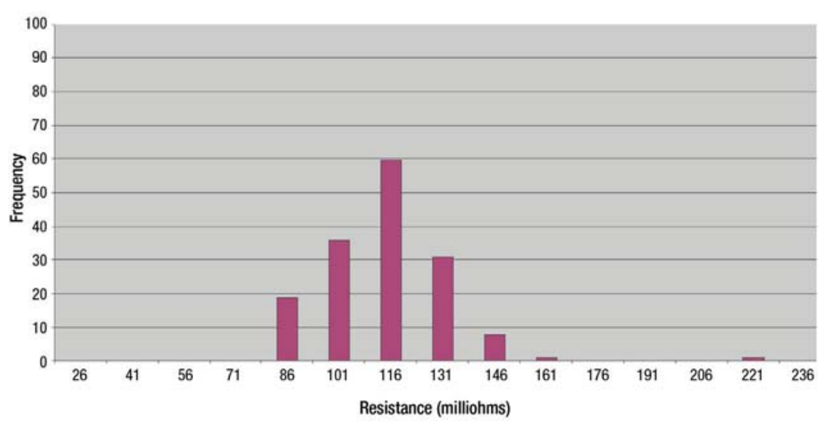

Figure 1. Front-side resistance distribution before electrodeposition.

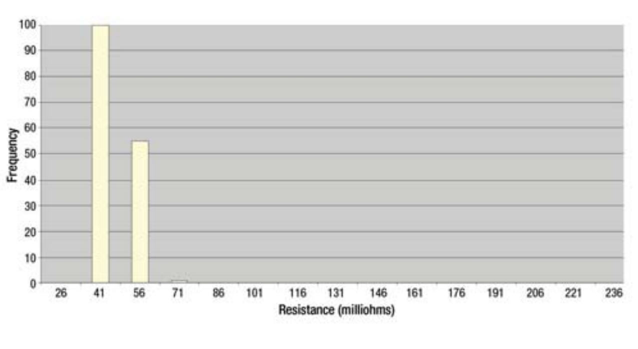

Figure 2. Front-side resistance distribution after electrodeposition.

R_{Front} was reduced to 54 milliohms. Perhaps the more telling result was the effect on the distribution of the data.

The silver paste and firing processes used in traditional cell manufacturing are wrought with variability. Whether the problems relate to screen-printing, furnace variability, or paste composition inconsistencies, the traditional process results in cells with a high standard deviation in the grid line resistances. The cells in this experiment started with a standard deviation of 18 milliohms prior to plating. After plating, the standard deviation had dropped to 6 milliohms. So, not only did the overall resistance drop, the variability in R_{Front} was reduced dramatically.

A closer look at the results on individual cells helps highlight the mechanism for improvement. If the change in the R_{Front} is plotted as a function of the initial R_{Front}, it becomes obvious that the plating process is capable of making a dramatic impact on those cells that have a high initial resistance. It is clear to see from Figure 3 that the cells with higher starting initial resistances benefited the most from the electrodeposition process.

As the resistance inherent in the common silver pastes are two to three times that of metallic silver, even a thin layer of electrodeposited silver metal quickly becomes the primary conductor on a cell's front-side contact. A cell that starts with a high quality silver paste contact only experiences a marginal improvement following the addition of metallic silver. In contrast, for cells that have a lower quality contact, the addition of the plated metal makes a dramatic difference to the ability to conduct the energy produced by the cell.

The final step for the test cells was to have them assembled into a module and subject to reliability testing. The module was tested and then subjected to 1000 hrs of damp heat conditioning (85°C at 85% relative humidity). After the conditioning, the module was then re-tested. The module using the electroplated cells experienced less than the allowable 5% degradation in power after the conditioning. In fact, the test module's power dropped by only 1% over the damp heat test.

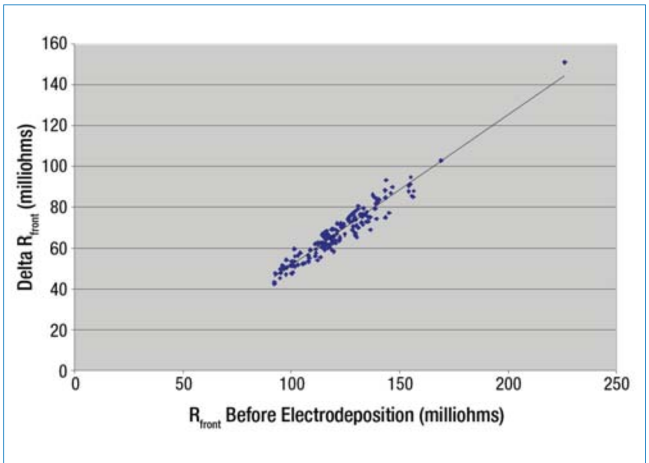

Figure 3. The reduction in the front-side resistance as a function of each cell's initial resistance.

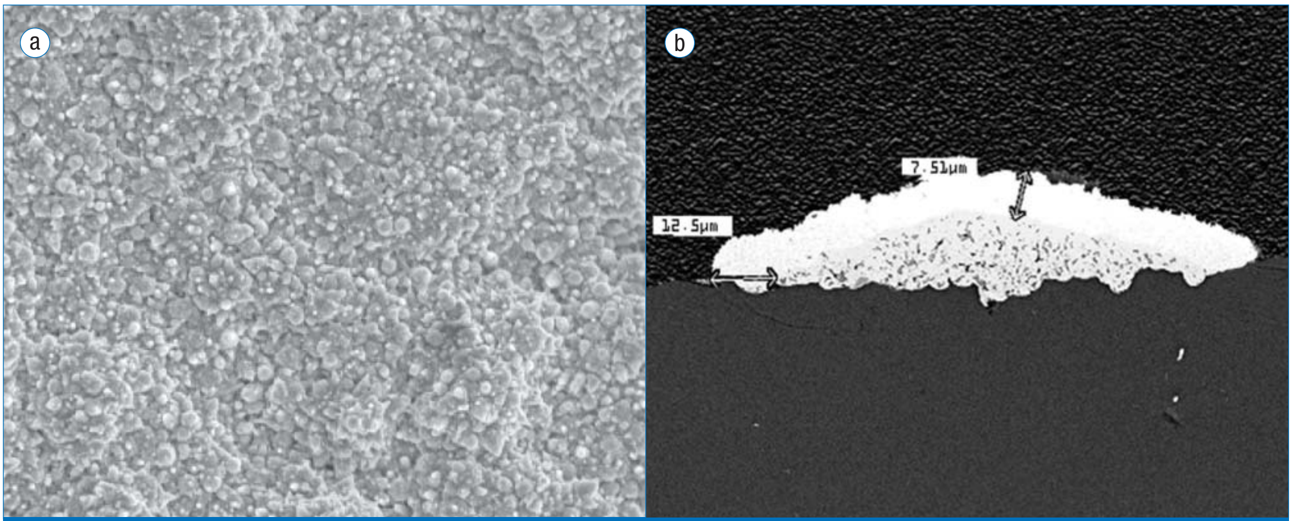

Figure 4. a) 2000× SEM of TechniSol AG surface morphology plated over silver paste at 2.0 ASD. b) Cross sectional view of front side contact plated with TechniSol Ag.

Two approaches to application

There are two ways that cell manufacturers can use electrodeposition to improve their product. Some producers have elected for a wholesale change in cell design while others may consider using electrodeposition as a remedial process to improve cells with low efficiency due to high resistance.

First approach: design change

Traditional front contacts require the fingers to be 120 microns wide to achieve enough cross sectional area to effectively allow the current to flow. This width is dictated by the shape that the contact takes during firing. Since the silver paste will flow during the contact firing, the final shape of the contact will only achieve 20 microns of height in that width. Due to this limitation, the manufacturers need these wide contacts to achieve the necessary area of approximately 1500 microns^2. The final result is that approximately 7% of the front of the cell is shaded by the resultant grid pattern.

In a cell design that uses electrodeposition to enhance the front-side contacts, it is only necessary to screen-print the fingers at 80 microns in width. With the addition of 10 microns of electrodeposited silver, the final contact width will be only 100 microns. By lowering the resistance within the contacts through electrodeposition of silver metal, it is possible to use a thinner conductor on the front side and match or exceed the conductivity of traditional cells. These thinner lines allow more light to enter the cell, and the subsequent reduction in shading translates directly into higher power output from the cells. This design change has been shown to increase cell efficiencies by 0.3 – 0.5% absolute, depending on the cell design and processing.

Second approach: remedial process

As with any process, the addition of silver electrodeposition into the cell manufacturing sequence is accompanied by an increase in processing costs. The results of this study open a possible path for manufacturers who are hesitant to add this cost to their entire product line.

The study clearly demonstrated that a certain population of the test cells benefitted the most from the electrodeposition process. As one may expect, the efficiency gains were the highest for the cells that saw the greatest reduction in R_{Front}. Even without a change in the contact design, cells that experienced a decrease in R_{Front} of 80 – 120 milliohms demonstrated an absolute increase in efficiency of 0.25 – 0.50%. As Figure 3 showed, it is possible to predict the change in R_{Front} that the electrodeposition process will induce by simply measuring the R_{Front} after firing.

This measurement does not require full characterization of the cells' electrical properties. In fact, a simple in-line resistance tester could be used to identify cells with a front-side resistance that is above a certain threshold. Those cells could then be passed through the electrodeposition process to enhance the contact and overcome the condition that is creating the increased resistance.

Since the electrodeposited silver has a different grain structure from that of the silver paste, different soldering conditions may be necessary during module assembly. Manufacturers who employ the selective strategy will have to deal with the logistics of two different product types. However, they will enjoy the benefit of increasing the efficiencies of their lowest output cells without investing in the electrodeposition process on their entire production volume.

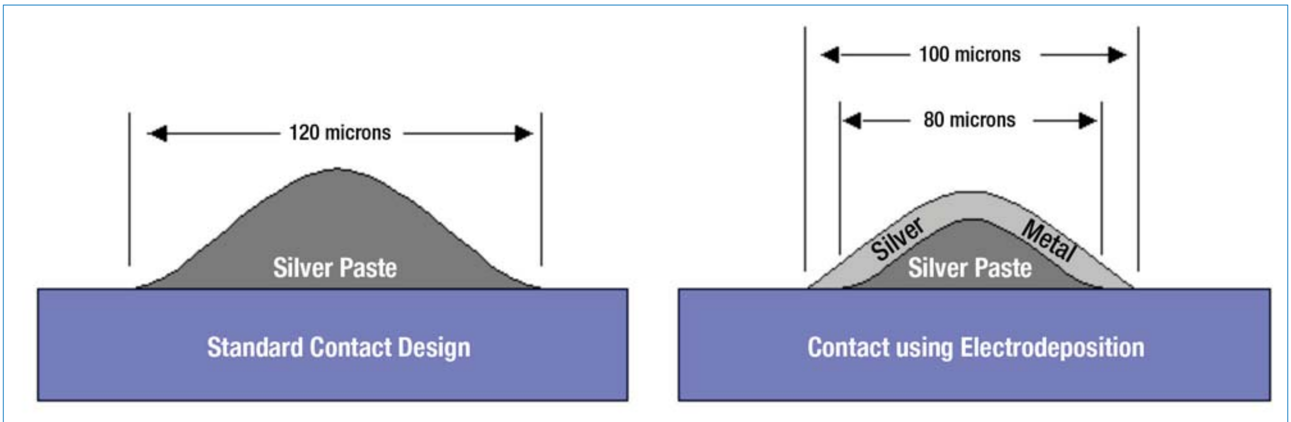

Figure 5. Traditional and alternate front-side contact cross-sectional view.

Process parameters: reducing the cost impact

The electrodeposition process is different from other processes that are used in most cell production lines. It is often the case that there is little or no electroplating experience within the manufacturer's technical staff. Keeping this in mind, there are a few essential aspects of the electroplating solution that need to be considered.

Perhaps the most important aspect to be considered is the cost of the solution. More silver is removed from the process as residue on the surface of the wafer leaving the plating tank (referred to as drag-out loss) than is deposited onto the cell. To minimize the loss due to drag-out, the concentration of silver in the solution should be kept to a minimum. A silver electrodeposition solution should be capable of running at 20g/l or less of silver metal. In addition, a silver recovery system should be installed on the rinse chambers of the electrodeposition tool to recover as much of the lost metal as possible.

Aside from the direct cost, there are also indirect costs to be considered. To reduce the overhead associated with the process, a good silver electrodeposition process will be easy to analyze and easy to control. It should also be stable and adjustable to the customer's specific requirements. Mistakes in the control of an electrodeposition process can result in the loss of precious metals, so great care needs to be taken to ensure that the responsible employees are trained by the solution supplier.

"With the addition of electrodeposited silver to the front-side contacts, manufacturers have a cost-effective method of increasing cell efficiency and improving their bottom lines."

Conclusion

Cell manufacturers are painfully aware of the problems they face with respect to the front-side contact metallization. As this study has demonstrated, there is a solution to those problems that can increase the contacts' conductivity, reduce the variability, and increase cell efficiencies. With the addition of electrodeposited silver to the front-side contacts, manufacturers have a cost-effective method of increasing cell efficiency and improving their bottom lines.

Acknowledgements

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Carbon footprint of PECVD chamber cleaning

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ABSTRACT

The use of perfluorinated gases such as NF_3, CF_4 or SF_6 for PECVD (plasma enhanced chemical vapor deposition) chamber cleaning has a much higher impact on global warming than does the use of onsite-generated F_2. This holds true even when supposing that in the future much more effort is paid for the correct abatement and a leak-free supply and take-back chain. This paper will discuss the steps available to the PV industry for control and reduction of carbon emissions in the chamber cleaning process.

Introduction

Fluorine and fluorine-containing gases are widely used in semiconductor, flat panel, and recently also in the solar industry to etch silicon, silicon nitride or silicon dioxide, respectively, in gas phase plasma reactors. An especially widespread application is the so called chamber-clean, a process that cleans SiO_2 residues from chamber inner surfaces by application of the cited gases. Historically, the nontoxic and noncorrosive CF_4, C_2F_6 and others were used, because of the convenience in flow control and storage. After much discussion about the global warming effects, specific abatements were developed and more reactive gases like C_4F_8 and NF_3 were introduced to allow higher depletion of the gas during application and thus arrive at lower emissions. Subsequently, gases without a GWP, such as ClF_3 and F_2, were used or introduced to industrial use [1,2]. SF_6 has been and is still widely used in the flat panel industry because of its relatively lower price compared to NF_3. Recently,

Chemical species	Formula	Lifetime years	100-yr GWP kg CO2-eq
carbon dioxide	CO_2	170-200*	1
methane	CH_4	12	25
nitrogen trifluoride	NF_3	740	17,200
nitrous oxide	N_2O	114	298
perfluoromethane	CF_4	50,000	7,390
perfluoroethane	C_2F_6	10,000	12,200
sulfurhexafluoride	SF_6	3,200	22,800

*the lifetime of CO_2 is a function of its concentration [4], pp. 212-213

Table 1. Global warming potential of certain greenhouse gases [4].

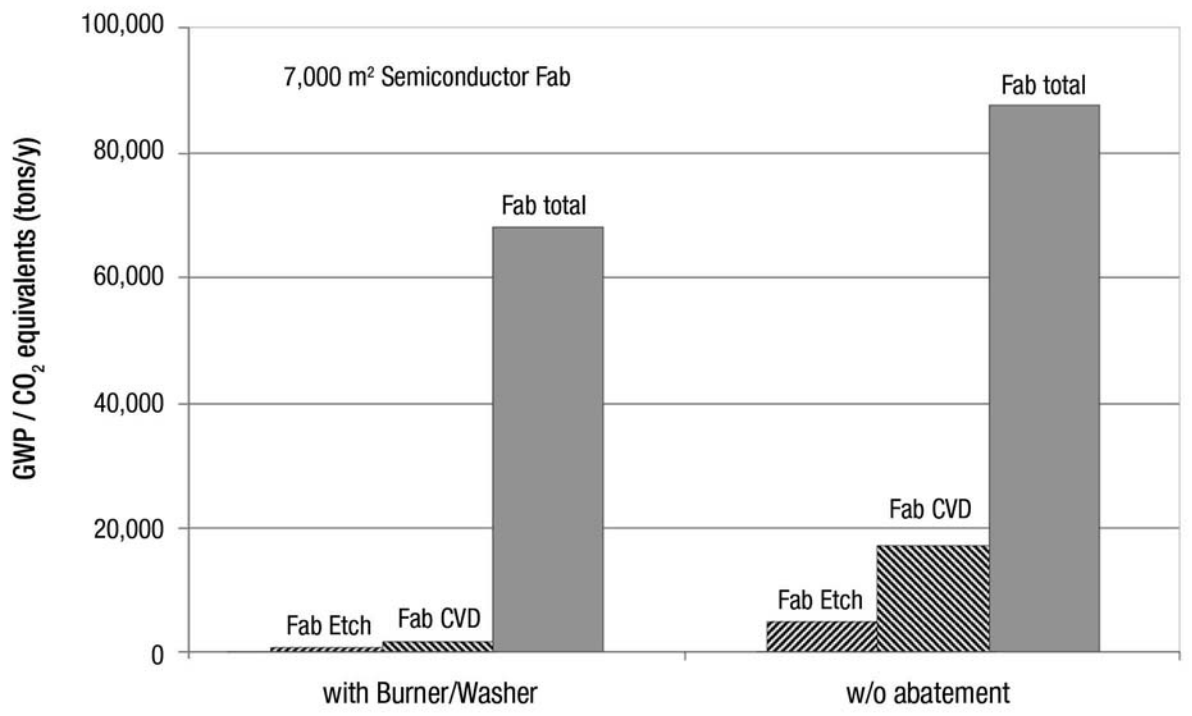

Figure 1. CO_2 equivalent emissions of a typical semiconductor fab [1].

- Chemical synthesis
- Distribution, transport, and connection to the users' system
- Application for the intended use, including emissions without abatement
  - emissions due to no abatements for PFC being installed
  - emissions resulting from abatements installed not being 100% reliable and lacking backup
- Return of the container for refill, and refilling.

Table 2. Principal contributions to carbon footprint of PFC and F_2 onsite.

some emerging technologies (thin-film Si) in solar cell production have started to use massive amounts of SF_6 (or NF_3) for the chamber clean application.

In a semiconductor fab, unfiltered PFC (perfluorocarbon) emissions with standard 200 or 300mm technology, although low on a kg/h basis, may represent as much as one quarter of the fab's total CO_2 equivalent emissions [3].

This difference is laid out in Figure 1, where the 'with burner/washer' columns represent the scenario utilizing a suitable abatement, whereas the others use no abatement ('unfiltered'). In the latter case, a reduction of the incoming (purchased) PFC gas is still carried out by the application (plasma cleaning of the reaction chamber and etch processes), but less efficiently than with an abatement. In the cited calculation, the respective etch and CVD areas were associated with emissions typical for 200/300mm technology, using a mix of different fluorine-containing gases. In conclusion, it is recognized that PFC emissions form a significant part of the global warming emissions, but that the major part is contributed by electrical power usage for tools and cooling purposes.

In the solar industry, two major groups of production technology are in use today: crystalline silicon, which represents the major part of the installed production capacity, and thin film technologies, which are emerging. While the former use minor amounts of PFC gases and tend to phase them out, some of the latter introduce increasing amounts of SF6 and NF3. The effect of this introduction is highlighted below.

Contributors to the emissions problem

The most important issue driving this investigation is that of the total life-cycle emissions of the respective application in terms of the cited global warming gases. The total CO_2 equivalent associated with the use of any global warming gas is more than just the combined physical emissions encountered during the application. Contributions are as shown in Table 2.

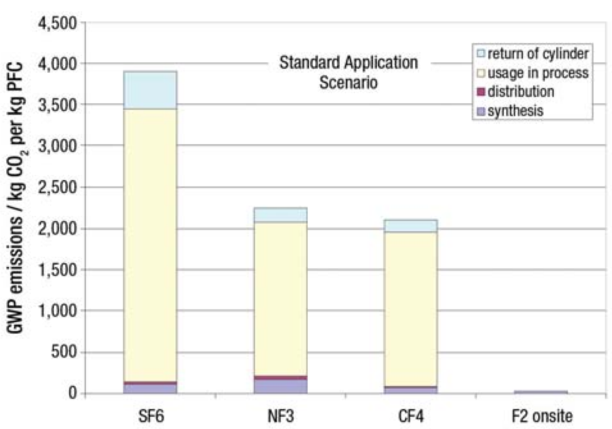

Figure 2. Carbon footprint of the investigated gases for chamber clean applications [5].

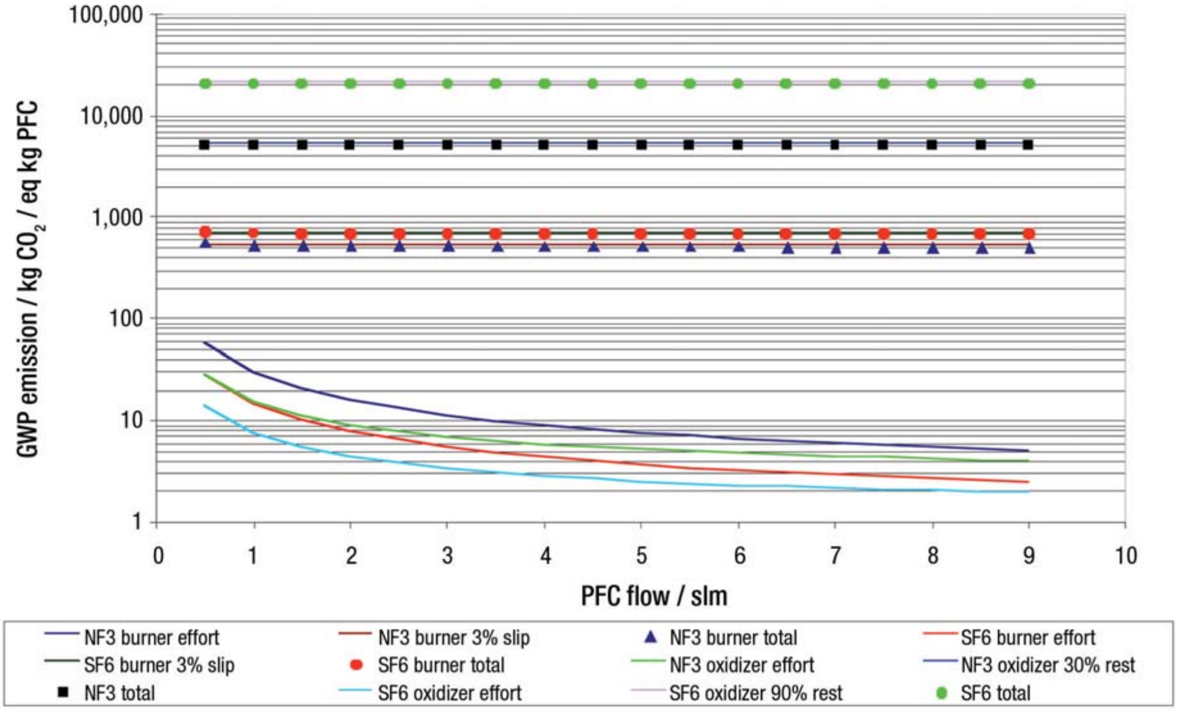

Figure 3. Determination of a typical abatement effort.

Users worldwide = 100%		100%=365 d/a Downtime of abatement	PFC input total worldwide = 100% VCovered by reduction	Not covered by reduction
No PFC reduction	15%	N.A.	0%	15% = fab input x fraction x users
Reduction concept "major streams (80% of PFC)"	65%	5%	49.4% = 80% (covered) x 0.95% (uptime) 65% (fraction of users)	15.6% = 20% (not covered) x 65% + 80% (covered) x 5% (downtime) x 65%
Reduction concept "all streams"	15%	5%	14.25% = 95% (uptime) x 15%	0.75% = 5% (abatement downtime) x 15%
Reduction concept as above including redundancy	5%	0%	5% = fab input	0%
			Sum covered 68.65%	Sum uncovered 31.35%

Table 3. Worldwide averaged user profile (semiconductors).

Chemical synthesis is associated with diffuse emissions, as there may remain traces of the global warming gas trapped during the steps of chemical reaction and subsequent purification, e.g. distillation. Also, as a significant amount of primary energy is associated with chemical synthesis, both contributions must be assessed.

Distribution and transport are considered to be major contributing factors, not only because of the use of fuel for transportation, but also due to undesired loss from leaking containers. The latter phenomenon is especially frequent with gases containing corrosive traces such as HF. The connection to a fab's distributions system implies vented volumes of the global warming gas, which is often not cleaned.

While the fab application may be equipped with abatement, it is quite common that there is no redundancy available; as a result, every abatement downtime leads to unfiltered PFC emission. The container or cylinder return can also lead to unfiltered emissions in case the filling station is not equipped with an abatement system suitable for fluorinated gases. In most cases, the system is absent.

Each of these steps is thus associated with CO_2 equivalent emissions, because of undesired unfiltered emissions, or because of the use of fuel or another primary energy source to perform the respective step. All possible contributions must be considered to yield a correct assessment of the CO_2 equivalent emissions.

CO_2 equivalent emissions / kg CO_2 per kg PFC used					
		CF_4	SF_6	NF_3	F_2 onsite
1 Outside Fab	Synthesis	81	118	180	35
	Transport/Distribution	8	23	35	0.2
	Cylinder/Container return	48	456	172	0
	Total	237	597	386	35
2 Inside Fab	Unfiltered Emissions	Calculated by user or taken from diagram as an estimate			
	Abatement efforts	From Diagram			

Table 4. CO_2 equivalent emissions (kg CO_2-eq/kg PFC) for the use of a compound without process application.

Scenario setup

Of all the gases involved, CF_4, SF_6, NF_3 and F_2 were chosen for this detailed

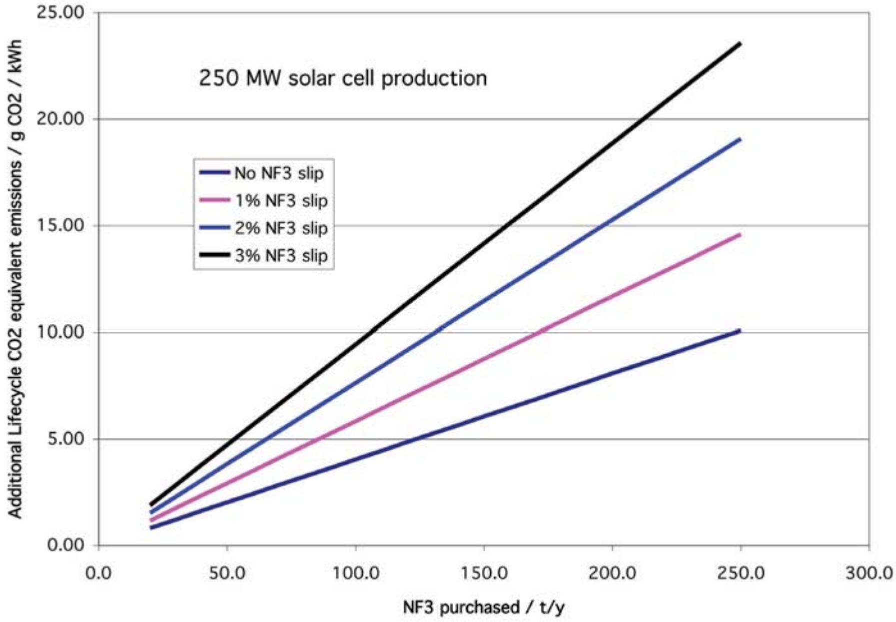

Figure 4. Effects of a 250MW thin film Fab consuming NF_3.

inspection. F_2 itself has no global warming potential, but its synthesis and disposal are associated with CO_2 equivalent emissions. These emissions are different for bottled F_2, F_2 generated offsite or F_2 generated onsite, the latter exhibiting larger emissions. However, since the only technically reasonable application of F_2 in the large scale is based on onsite generation, this type of generation is taken into consideration rather than that associated with bottled F_2 in this scenario setup. The determination of the level of these contributions, or by which scenario construction they have been derived, is given in [5].

Assessment of the CO_2 equivalent emissions requires the calculation of the kg CO_2 emitted per kg PFC used, with each additional contribution under consideration brought to this same scale. This format led to the result shown in Figure 2 for the CO_2 equivalent emissions, the values of which are balanced in a way that global averages are assumed to be obtained [5].

Moreover, the breakdown of different contributions is comparable for all gases except F_2. The intended use in process is most important, because there may be no abatement or no redundancy for abatements. F_2, however, features only 'important' contributions from the act of chemical synthesis.

Average Irradiation:	1,700 kW/m^2.y
Solar Module lifetime:	30 years
Module efficiency:	8% (not to be confounded with cell efficiency)

Table 5. CO_2 equivalent emissions payback calculation.

Results and discussion

Since abatement structure and performance is most important, driving factors for the overall effectiveness turn out to be more customer-specific than gas-specific. The different approaches of the respective different users' contributions are summarized in Table 3, data for which are taken from the M+W Zander installation database [3].

For the equipment uptime, a pessimistic figure of 95% was introduced. This implies a slip of 5% of the PFC as time-average, although the abatement could potentially reduce the PFC by 99%. Uptime and slip are not only dependent on the technical features of the abatement, but also on maintenance quality and intervals. Slip may be less than 5%, but this figure falls to virtually zero in cases where full backups of the abatement systems are installed. This refers to the last line of Table 3, but the investment required of such an abatement setup means that only 5% of the worldwide users have such a system installed.

The 'average user' as supposed in both Figure 2 and Table 3 is therefore mathematically represented by a mix of 'no abatements' (or non-PFC-effective abatements); 'abatements without backup'; and to a minor extent 'abatements with full backup'. So, for a customer having an installation different from average and wishing to calculate the actual CO_2 equivalent emissions of his application, another subset of numbers is required.

Table 4 illustrates the effort in kg CO_2 per kg PFC 'outside fab', i.e., all contributions without the use of the respective PFC in production. Unfiltered emissions resulting from either a slip in the abatement stage, or from a lack of abatements, can only be calculated on an individual basis by the user. In both cases, the depletion in the respective process application is taken into account. A further contribution in this same context is the abatement effort, which, if not easily calculable by the user, may be taken from Figure 4.

In converting kWh electrical power to CO_2 equivalent emissions, the ratio of 0.484 kg CO_2 per kWh was used. This supposes a power mix, which is, in this case, typical for Europe [6]. It is usually the case that the abatement efforts are a minor contribution, whereas the unfiltered emissions form a major part (see Figure 3).

Figure 3 shows the respective CO_2 equivalent emissions of both abatement effort and slip or rest of untreated PFC in a range of five decades. ('Slip' refers to the fraction not being treated because of installation up- or downtime, respectively, whereas 'rest' refers to the fraction not being treated because of the limited efficiency of the abatement.)

Two important types of abatement are considered in Figure 3: burner-type equipment using an oxygen-driven burner, thus reaching sufficiently high decomposition temperatures; and an electrically-heated oxidizer (without flame) reaching typically 800°C, which is too low for complete decomposition. In the semiconductor and solar industries, these two types of abatement play the dominant role in PFC abatement.

The burner-type abatements are usually very efficient, providing 99% or more abatement in the case of PFCs, meaning that the overall PFC emission is dominated by the slip. The oxidizer, however, does not show decomposition for a number of important PFCs, and a limited decomposition for NF_3, so the overall PFC emission is dominated by the other PFCs.

This difference is depicted as solid lines accordingly in Figure 3. Because the demand in primary energy and other facility media is higher with burners than with oxidizers, this part, the abatement effort, is generally lower for the oxidizer than for the burner (represented by four solid lines in the lower part of the diagram of Figure 3).

The overall (total) CO_2 equivalent emission is represented as dots in the upper part of the diagram, the resulting line for which is almost identical to the solid lines showing slip or rest. In the case of low PFC flow, a slight difference is discernible.

The total contribution of application of abatements is dominated by the slip or rest of unreacted PFC, both for the more effective burner-based and especially for the classical non-flame oxidizers. Nevertheless, the contribution of the pure abatement effort is given separately, so that users with very reliable abatements capable of less than 0.5% downtime, or having full backup installation, can do the proper calculation as shown in Table 4.

The PFC flow on the x-axis spans a wide range from 0.5 to 9slm (standard litres per minute). Whereas the former can be regarded as typical for 200mm semiconductor applications, the latter value reflects the demand of solar thin-film processes. In most cases, there is not one single abatement equipment serving the whole range, but different abatements of different generations of development.

These will be used for the different sectors of application. Therefore, the resulting effort curve will not be ideally smooth, but will show 'jumps' at the point where a switch from one abatement machine to another occurs. Figure 3, however, represents a generic average curve, showing the dependencies of the entire range required.

Estimation of the ecological effect of NF_3 chamber clean

For a long time, silicon solar module fabrication has not been influenced by the usage of PFC, or only to a minor extent. Emerging thin-film techniques, however, introduced significant amounts of SF_6 or NF_3 for the CVD chamber clean process. Since the use of this technology is still young, many installations are designed with high-performance burner-type abatements in all relevant emission points; a future trend prediction shall be derived based on this scenario. To come to a short and simple evaluation, the g CO_2 emitted per kWh solar energy produced by the respective cell is calculated. This expresses the relation of ecological effort and benefit.

Since a complete assessment of the CO_2 equivalent emissions is still not finished for the technology in question (Si thin film), only the additional CO_2 equivalents can be given, which are purely due to the usage of NF_3.

According to recent results, it was a relation of 38,250 kWh produced in cell lifetime per kWp produced has been used for conversion [7], and the assumption that the thin film fab shall have a capacity of 250MW(el) production per year.

Figure 4 gives the ecological cost of the usage of NF_3 in terms of additional CO_2 equivalent emissions per kWh produced. This is depending on the amount of NF_3 used per year and depending on the assumed slip, that is the rest of NF_3 remaining and emitted after abatement. In the best case, this is zero, but it may be higher, in the single digit percent range.

Even for completely effective abatement (0% slip) there is additional CO_2 equivalent emissions because of the efforts associated with the chemical synthesis of NF_3 according to Tab. 3. Since this additional CO_2 equivalent emissions come on top of the other equivalent emissions to be considered for the use of other resources than NF_3, like electrical energy, water, or chemicals, this impact is an environmental burden to those thin film technologies making use of PFC, even in the case of very effective abatement.

The values obtained are in a range of 5 to 15 g CO_2 per kWh. This additional contribution to the effort linked to NF_3 usage may be compared to the total CO_2 equivalent emissions for a polycrystalline Si solar cell, which are 30g/kWh [7]. So the NF3 contribution is significant.

It is out of question, that the use of less effective abatements, today unusual in solar industry, is a real threat to the ecological efficiency of Si thin film solar cells using NF_3 in production.

Conclusions

For the solar industry, it is clear that the recommendations are the use of abatements that are able to destroy PFC with better than 99% efficiency, and with full backup, or the avoidance of the use of PFCs. Better still is the introduction of F_2 for the same purpose.

Although the results are very much in favour of the F_2 onsite application, there remain a number of practical barriers. A qualification has to be carried out prior to replacement of a cleaning gas by another. In the flat panel industry, this process is already underway and replacement is ongoing. For the semiconductor and solar industries, however, there is still a need for action.

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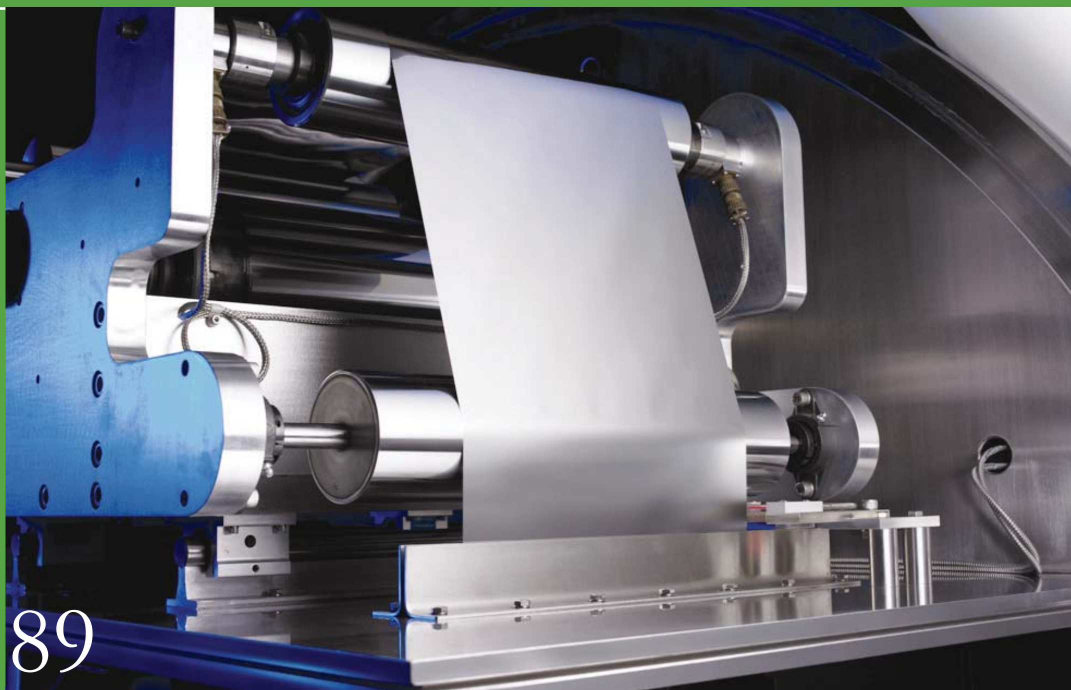
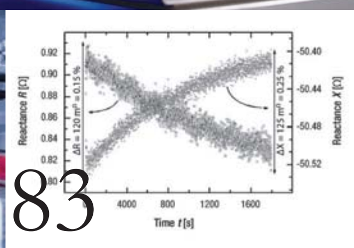




News

Konarka opens organic PV roll-to-roll manufacturing plant, claims 1GW potential capacity

Organic photovoltaics developer Konarka Technologies has converted a former Polaroid advanced printing plant into what it calls the world's largest roll-to-roll flexible thin-film solar manufacturing facility. The 250,000 square-foot factory, located in New Bedford, MA, will be used for the commercialization and volume production of the company's Power Plastic product line.

Built and further expanded in the 1990s for Polaroid's advanced technology development and large-scale manufacturing, the OPV firm's new facility has been retrofitted to immediately begin initial production of Power Plastic. Using multiple in-line processing stations with precision multilayer manufacturing processes that are adaptable to a variety of printing and coating technologies, the facility will enable the company to further develop and advance nano-enabled polymer photovoltaic materials that are lightweight, flexible and more versatile than traditional solar materials.

In addition to acquiring the fully automated roll-to-roll manufacturing line, the company has also hired the leading technology and process engineering teams from Polaroid, with plans to hire more than 100 additional employees as production increases toward capacity over the next two to three years.

Thin-Film Production News

Dubai starts ambitious 1GW PV production plan using Applied's SunFab technology

At a two day event held in Atlantis, Palm Jumeirah, Dubai, Mr. Sultan bin Sulayem, Chairman of Dubai World (pictured), announced the establishment of a photovoltaics manufacturing company, dubbed Solar Technologies FZE, which will build and operate a 130MW production plant in Dubai's Technopark. Future plans include establishing manufacturing facilities in China, Mexico and Bulgaria, which will increase the total production capacity to 1GW by 2015.

"The potential of solar energy is unbelievable. The energy from sunlight striking the earth for 40 minutes is equivalent to the global energy consumption for a whole year," commented Mr. Dilip Rahulan, Chairman and CEO, Solar Technologies FZE. "The mission of Solar Technologies is to accelerate the adoption of solar photovoltaic by rapidly expanding manufacturing capacity and significantly reducing the cost of solar modules through innovations and manufacturing excellence. We intend to become one of the largest solar photovoltaic module manufacturing units in the world over a period of time."

The Dubai news follows that of Masdar PV in May 2008 to invest initially US$600 million in two separate 'SunFab' turnkey module production lines supplied by Applied Materials in Erfurt, Germany and in Abu Dhabi.

Like Masdar PV, Solar Technologies FZE is planning to use Applied Materials 'SunFab' thin-film technology, as well as becoming a global player. The 130MW plant planned equates to two SunFab lines and will be operational by the end of 2010.

Sharp starts volume production at new thin-film plant

Sharp Corporation has said that it will start volume production of its 2nd-generation thin-film solar cell modules at its new plant in Katsuragi City, Nara Prefecture, Japan, this October. The new line raises its thin-film capacity to 160MW. Sharps 2nd-generation thin-film solar cells feature a claimed nine percent module conversion efficiency and high 128W power output on a 1,000 × 1,400mm glass substrate. Initially, modules from the new line will be shipped to large solar power generating plants in Europe, the company said.

Sharp also reiterated that it had invested approximately ¥22 billion in the new plant's capacity expansion. Sharp is also investing approximately ¥72 billion in the first phase expansion of a new plant in Sakai City, Osaka Prefecture, which will become operational in fiscal 2009, where plans are in place for module efficiencies of 10 percent, according to the company.

Signet Solar now ramping to capacity

Signet Solar has received Final Acceptance Test (FAT) certification from SGS Germany GmbH of its 'SunFab' thin-film production line at its manufacturing facility in Mochau, Germany. This now enables the company to fast-track its ramp of the facility to 20MW. Signet Solar has plans for a further expansion to 130MW by the end of 2009. The FAT certification is the first for Applied Materials 'SunFab' technology.

Signet Solar said that it had produced over 2,000 modules during its pilot production period. The company was also the first 'SunFab' customer to produce modules.

Moser Baer signs thin-film module supply contracts worth US$500 million

Moser Baer has signed new thin-film module supply contracts worth more than US$500 million through 2012 with several PV systems integrators, including Ralos Vertriebs and Colexon Energy, both based in Germany. The contracts are based on fixed prices with take or pay arrangements. Moser Baer recently raised US$93.5 million to expand production, bringing outside funding to US$193 million. Moser Baer is using Applied Materials' 'SunFab' thin-film manufacturing technology.

HelioVolt joins growing ranks of CIGS thin-film solar PV companies ramping manufacturing

HelioVolt has become the latest copper-indium-gallium-(di)selenide thin-film photovoltaics company to move into manufacturing. The company's 122,400 square-foot facility, rated at 20MW capacity, is slated to reach volume production levels by the second half of next year and will initially employ 160 workers once ramped. The company expects to have 300 employees by the end of 2009.

Largely financed by HelioVolt's US$101 million Series B funding round completed last October, the new facility will not only produce environmentally beneficial products but is also a certified green building. It has been awarded LEED (Leadership in Energy Efficiency and Design) certification by both Austin Energy's Green Building Program and the U.S. Green Building Council, the company said. Specific sustainability initiatives include efficiency in lighting, energy and water conservation, sustainable materials, indoor environmental quality, design process innovation, and creative water reuse.

Although specific details about the new production line remain sketchy, HelioVolt's process is based on what it calls FASST, a reactive transfer printing approach the company claims can produce CIGS cells faster and cheaper than other techniques, with better than 12 percent conversion efficiencies. HelioVolt and the National Renewable Energy Laboratory received an "Excellence in Technology Transfer" Award for the hybrid CIGS technology from the Federal Laboratory Consortium for Technology Transfer (FLC) in September.

SANYO and Nippon Oil planning thin-film solar joint venture

SANYO Electric Co. and Nippon Oil Corporation are working on a deal that could see the formation of a thin-film solar cell manufacturing joint venture between the two companies by April 2009. SANYO said that a partner for its thin-film solar plans would enable a faster development of its plans due to the possibility of sharing costs and raising of necessary funds. Nippon Oil is interested in diversifying its business further into renewable energy and teaming with an experienced player in the market.

SANYO also reiterated its commitment to develop and expand its existing crystalline solar cell business in tandem with thin-film. SANYO currently operates a 5MW thin-film pilot line; however, it lags behind other key players in Japan that are expanding thin-film production, according to data from RTS, the Japan-based market research firm.

The companies aim to commercialize highly efficient, low-cost thin-film solar cells by April 2010, after further consultations take place between the two companies.

Sunwell starts a-Si thin-film line from Oerlikon Solar in nine months

Sunwell, a wholly owned subsidiary of CMC Magnetics, located in Taiwan, has started volume production reaching over 10,000 solar panel output. Sunwell is a new entrant to the thin-film PV manufacturing market and is the first of three Oerlikon Solar a-Si thin-film production line customers to enter volume production in Taiwan. Oerlikon Solar said that from delivery of equipment to shipments was less than nine months.

The facility is based on amorphous silicon thin-film technology and has a yearly production capacity of 40MWp.

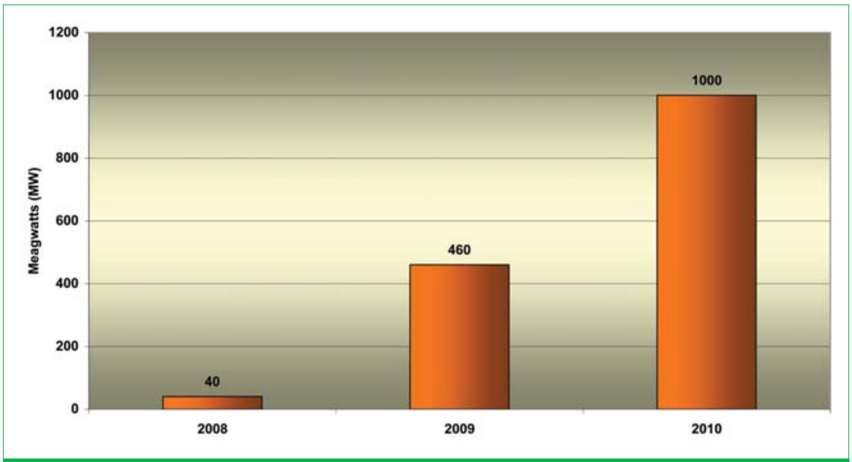
Two additional Oerlikon Solar end-to-end fab lines have already been purchased by Sunwell, which include a 60MW line for its existing site in Taiwan and one 120MW for a second location currently under construction. The second site will use Oerlikon Solar's, micromorph tandem junction technology.

Sunwell has currently one of the most aggressive MW ramp rates of all the thin-film solar manufacturers based in Taiwan. The company is targeting to reach a capacity of 460MW in 2009 and reach 1GW in 2010.

Q-Cells' venture Solibro ships first CIGS PV modules, plans capacity expansion

Solibro has begun to ship its copper indium gallium (di)selenide (CIGS) thin-film photovoltaic modules to customers. The German company, which is a joint venture between majority partner Q-Cells and Swedish firm Solibro, says that it has signed supply contracts for most of its production. Customers include Sunova, HaWi Energietechnik, thermovolt, Hecklogic, and Sunset Energietechnik.

The company broke ground on its Bitterfeld-Witten production site in April 2007 and started moving equipment into the fab in August 2007. Solibro, which uses a thermal coevaporation process to deposit its critical thin-film layers, produced its first full-size CIGS-on-glass module in April 2008. After manufacturing its first full-area module with a reported 11 percent conversion efficiency in April, the company continues to ramp up the facility and work on improving yields, throughputs, uptimes, and efficiency metrics, reaching its first megawatt-peak of produced output in mid-August.



Source: Photovoltaics International

Sunwell Solar Corp. thin-film capacity ramp forecast (September '08).

Earlier, the company announced its intention to increase capacity at the factory from 30 to 45MWp and to build a second line with a capacity of 90MWp, with first modules expected from the new line by fourth-quarter 2009 and full capacity on the line to be reached in 2010. Solibro says it has begun work on both expansion projects.

Solibro's projected 135MWp of CIGS capacity will contribute to Q-Cells' overall growth strategy to achieve more than 400MWp of TFPV production by 2010.

Ascent Solar, Texsa to develop thin-film PV roofing for European markets

Ascent Solar and Texsa have signed a definitive cooperation agreement focusing on the development of new flexible copper-indium-gallium(di)selenide thin-film photovoltaic roofing products for the European marketplace. The companies will collaborate in the development of building-integrated PV (BIPV) roofing materials based on Texsa's existing product lines of protective roofing and thermal insulating boards for inverted-system flat or pitched roofs. Ascent says it will supply the Spanish company with TFPV material from its existing 1.5MW CIGS production line in Littleton, CO, for Texsa to develop, test and certify integrated BIPV products.

After Ascent completes its planned expansion of production capacity, the thin-film solar company says it plans to increase deliveries of modules to Texsa. Subsequent demonstration-scale projects should help validate the system-level performance and to develop market demand for the jointly developed BIPV roofing products, according to the partners.

Ascent has also signed BIPV deals with French firm Icopal, Hydro Building Systems (which owns a minority interest in the TFPV company), and others. In its latest SEC filing, Ascent said it expects to qualify production tools for its initial 30MW CIGS production line in the company's new Thornton, CO, factory by the end of 2009 and then ramp to volume production in early 2010.

Energy Conversion Devices sees profits soar, signs thin-film solar PV deal with Marcegaglia

Energy Conversion Devices saw its quarterly revenues rise 16% and its net income increase 28%, largely because of the continued growth of its United Solar Ovonic subsidiary. The company also signed a long-term agreement with Marcegaglia to supply flexible thin-film photovoltaic cells to the Italian steel manufacturer for integrated commercial roofing products under development.

ECD's total consolidated revenues for its first fiscal quarter were $95.8 million, compared with $82.4 million in the previous quarter and $47.0 million in the first quarter of FY2008. Solar product sales made up $89.5 million of the total, a 16% sequential increase and a 124% increase over the prior-year quarter. First-quarter net income was $12.7 million, compared to net income of $9.9 million in the previous period.

The gross margin for solar product sales in the quarter was 33.4%, while the total gross margin was 34.1%. Uni-Solar produced 30.8 MW and shipped 29.5 MW of solar laminates in the first quarter, compared with production of 26.2 MW and shipments of 25.7 MW in the previous quarter. The average selling price for solar laminates during the quarter was $3.04.

The company said it expects revenues to end up between $100 million and $108 million for the second quarter and between $455 million and $485 million for the fiscal year ending June 30, with the lion's share of the revenue stream coming from the Uni-Solar unit.

AVANCIS starts production of CIS thin-film solar modules at new plant

The cooperative business enterprise between Shell and Saint-Gobain, AVANCIS, has begun manufacturing CIS thin-film solar modules. AVANCIS's new plant was completed within 12 months with an annual capacity of 20MW and the CIS thin-film modules producing an efficiency level of 11 percent. 85 new jobs were created at the new Torgau production site with another 45 hoping to be added in 2009. The research and development sector of the company is in Munich, Germany, which employs another 30 staff members.

NanoGram, Tokyo Electron sign thin-film solar PV joint development agreement

NanoGram and Tokyo Electron have signed a joint technology agreement focused on the development of thin-film photovoltaic process equipment based on the cleantech company's proprietary laser reactive deposition (LRD) process for thin crystalline silicon films.

The LRD process has a distinct deposition-rate advantage with the capability to lay down highly uniform amorphous and microcrystalline silicon films significantly faster than conventional TFPV CVD processes, according to NanoGram. The JDA work is also expected to be complementary to NanoGram's low-cost multicrystalline SilFoil PV module business.

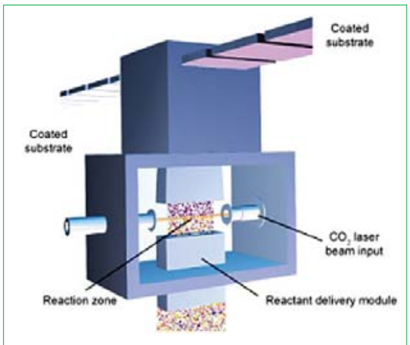


Diagram of LRD process.

NanoGram has said it expects to commission its SilFoil solar module pilot plant – which it's building out with the help of OTB Engineering – in second-quarter 2009. The company plans to have 5MW of capacity online at the Milpitas, CA, facility by the end of 2009.

TEL entered the solar manufacturing equipment sector in February via a partnership with Sharp to develop plasma CVD tools for TFPV cell production. The company recently said it had reorganized its FPD/PVE business division and is accelerating development efforts in order to have its first systems shipped in early 2009.

Germany's largest thin-film pitched roof system begins production

Germany's largest thin-film pitched roof system, constructed by Riedel Recycling, has been in operation and producing solar power in Moers near Duisburg. Over eleven thousand cadmium telluride modules from First Solar deliver a total of 837 KW. The company uses the former

The Riedel Recycling facility showing thin-film roof.

coal-mixing hall in Moers for the storage and preparation of building materials with its 9,500 square metre, south-facing, roof fully fitted with solar modules.

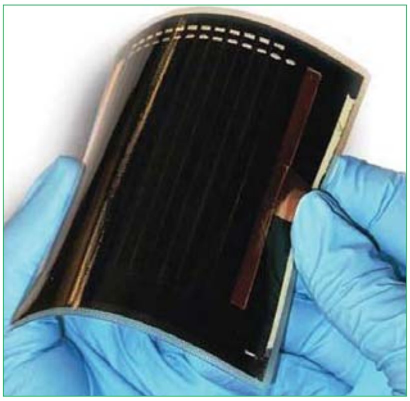
Four SolarMax central inverters run in the solar power system, with outputs of 300 (2x), 100 and 30 kilowatts respectively. However, inside their housings the inverters do not only convert the direct current from the solar modules into alternating current, they also are capable of heating the administrative buildings in the future. "The SolarMax inverters produce a total of around 45 kilowatts of waste heat," explains Günter Grandjean. "We divert this to air-conditioning systems with heat exchangers in the administration building." The roof will also be producing electricity in the future. Ludger Riedel and Günter Grandjean are already pondering the installation of additional solar power systems with SolarMax inverters to the external pillars.

Research and Development News Focus

Hague signs letter of intent to buy assets of quantum-dot PV cell company Solterra

Hague Corp. said it has signed a binding letter of intent to buy all of the assets of Solterra Renewable Technologies, a developer of thin-film quantum-dot solar PV cell technology. The agreement between Hague and Solterra requires Hague to fund the solar firm for a total of US$5 million within 60 days of signing a final asset purchase agreement.

Solterra holds the worldwide exclusive license for the quantum-dot solar cell technology (developed by Michael Wong and his team at Rice University) and says



it is about to enter the commercialization stage of development with the new cell technology. Proponents of the quantum-dot approach point to its ultra-low-cost, high-volume production potential through the use of continuous print-like processes and flexible substrates, potential to convert more than 90 percent of solar energy collected into electricity, tunability to either high voltage or high amperage, and the ability of the q-dot cells to be placed behind a protective shell for greater longevity.

Thin-film PV startup Sencera completes investment placement, accelerates development

Thin-film photovoltaic module start-up Sencera has completed a three-stage US$15.6 million equity investment. Under the terms of the deal, the Charlotte, NC-based company has received US$5.2 million in equity. The firm says the remaining investment will take place in two equal stages of US$5.2 million, based on completion of development milestones. Quercus Trust and Michael Draper of Equinox Securities led the most recent investment, as they had in the previous effort.

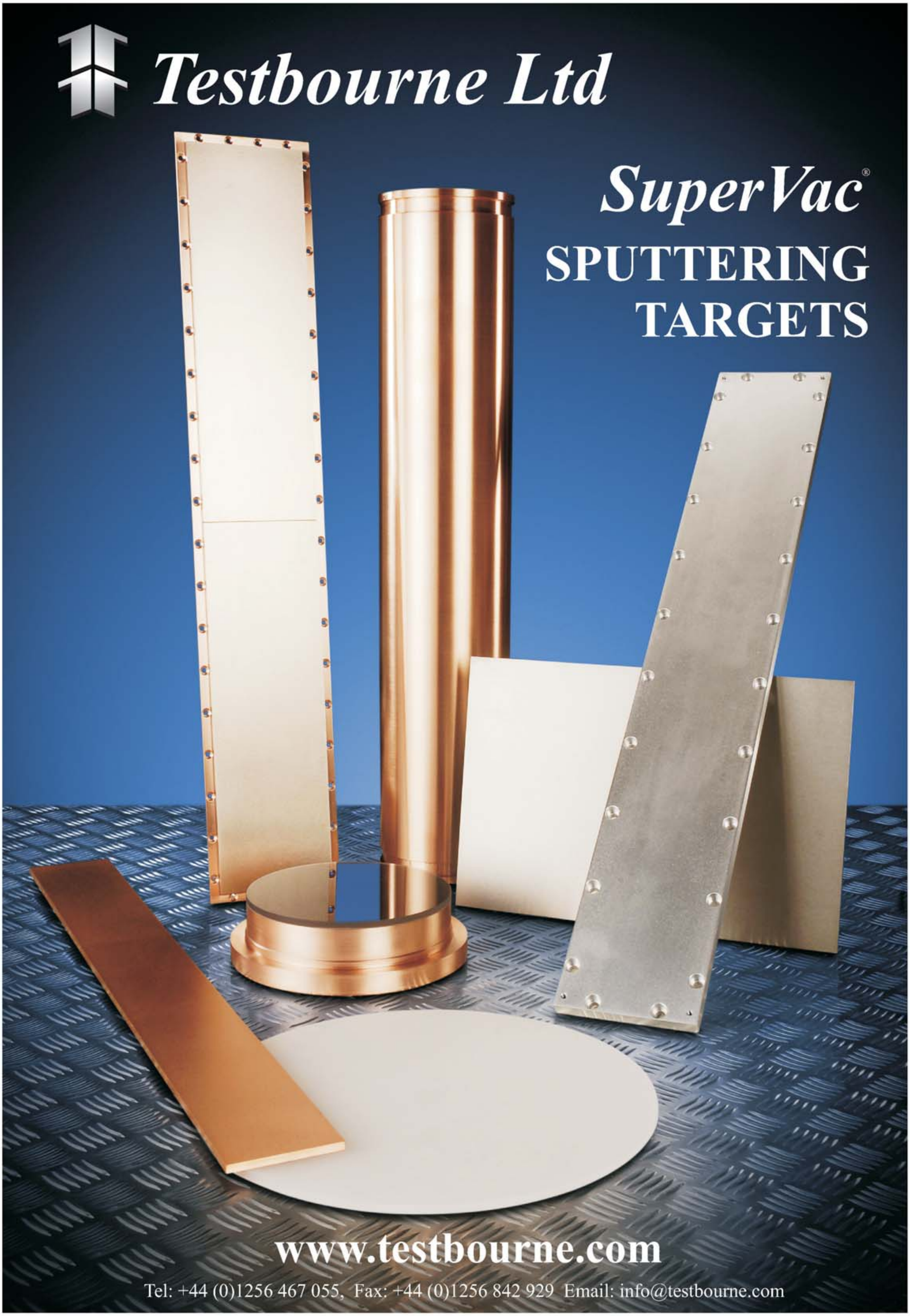
Sencera will use the proceeds to fund its first 35MW PV module factory in Charlotte and will also speed up the development of its second-generation high-efficiency amorphous/microcrystalline silicon solar module. In addition to the production of 1.1 × 1.4m a-Si modules, Sencera says it will enhance its R&D capabilities.

STANGL and HZB work on new thin-film process

STANGL Semiconductor Equipment and the Helmholtz Zentrum Berlin für Materialien und Energie (HZB) are to collaborate on the development of new process for the production of thin-film solar cells, using HZB's spray ion layer gas reaction process (ILGAR). The ILGAR process deposits indium sulphide buffer layers, which are capable of replacing cadmium sulphide in thin-film solar cells, the company said. STANGL will exclusively market the new production machine for ILGAR thin-film solar cells on glass and foil.

Roll-to-roll start-up Xunlight gets US$11 million of additional financing

Flexible thin-film, roll-to-roll start-up, Xunlight Corporation, has received a further US$11 million in funding from Rabo Ventures, Trident Capital and Emerald Technology Ventures. The extra funds are to be used to help complete and start operations at a 25MW roll-to-roll production line. The firm currently has a 2MW pilot line in operation. Xunlight has received over US$40 million in institutional funding during the past 16 months to build out its roll-to-roll production lines.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Special feature: Solyndra comes out of stealth mode with cylindrical approach to CIGS thin-film photovoltaics

Tom Cheyney, Senior Contributing Editor – USA, Photovoltaics International

ABSTRACT

Until recently, Solyndra had been one of the stealthiest thin-film photovoltaics operators, its glistening, prominently logoed headquarters building reminding tech-savvy commuters plowing up and down the I-880 corridor near Fremont, CA, of how little they knew about the company. But Solyndra has finally let the sunshine in and come out of the closet – even if it hasn't quite changed some of its stealthy ways. After a well-planned media and analyst rollout, the public knows that for this copper-indium-gallium-(di)selenide (CIGS) thin-film PV manufacturer, the world – or at least its solar-module form factor – is not flat. Like many TFPV purveyors, Solyndra loves glass as a substrate, but the company's meter-long CIGS-coated cylindrical modules look like a fluorescent light-bulb tube, not just another rectangular slab of the smooth stuff.

Tubular PV for the commercial rooftop market

During a recent visit to Solyndra (see Figure 1), Chris Gronet and Kelly Truman, the company's CEO and VP of Marketing/Sales/Business Development, told me about Solyndra's technology and manufacturing and its plans for targeting the commercial rooftop sector. Gronet says the market potential adds up to 30 billion square feet in the U.S. alone, translating into potential electricity capacity of 150GW and a PV market of around US$650 billion. With more than a billion square feet of CoolRoof and other reflective roofing material being put down every year in the U.S., the opportunity to turn rooftop space into revenue-generating PV exists today.

Gronet showed me one of the tubular modules, the critical element that has captured the attention of venture capitalists and private equity investors who've sunk about US$600 million so

Courtesy of Tom Cheyney

Figure 1. Solyndra's Fremont, CA, headquarters sits alongside the I-880 freeway.

far into Solyndra (see Figure 2). The glass cylinder is black, about an inch or so in circumference and is actually a tube within a tube. One can see that the inner CIGS portion of the monolithically integrated device has a series of swirling helical scribe lines, differentiating the 150 cells within. Between the inner and outer glass cylinders, a common industrial liquid described by the exec as an "optical coupling agent" fills the cavity and actually creates a modest concentrator effect – about 1.5x – when struck by sunlight.

There are no moving parts, as the sunlight automatically refracts through the outer tube to the inner substrate where the absorber layers do their thing. The endcaps are the only mechanical part, which are hermetically sealed using a proprietary glass-to-metal process (with no elastomers involved) that is then helium-leak-tested, according to the CEO.

Being tubular has its advantages when it comes to PV, says Gronet. Photons are not only collected directly from all angles, a kind of "self-tracking" mechanism, but diffused light is also harvested from almost every direction, and the sun's rays that don't get absorbed by the PV cylinder at first are captured when they reflect off the white membrane underneath (see Figure 3). The circular design also provides convective cooling advantages and the tubes don't get as dirty on the roof as conventional flat-plate units.

When pressed about the thicknesses of the various film layers, Gronet claimed Solyndra "has the thinnest layers of anyone out there... the absorber layer is about a factor of two thinner" than competing technologies. Since the CIGS stack is generally in the 1.0 to 2.5 micron range, and you can't go too much thinner than a micron, it's likely Solyndra is achieving something slightly submicron with its co-evaporation process. By using less of the active materials, the company reduces its deposition process times and thus might boost throughputs and bring down overall manufacturing costs.

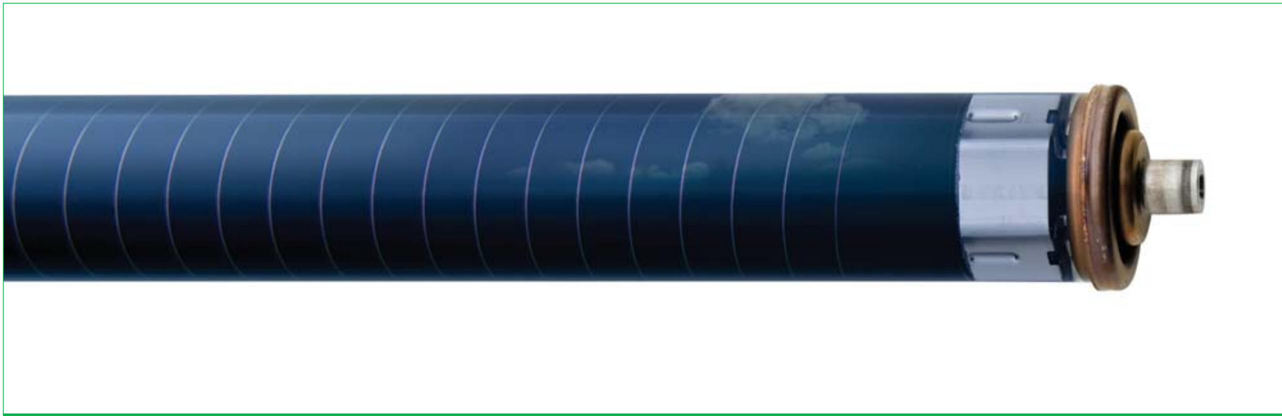
"There are no moving parts, as the sunlight automatically refracts through the outer tube to the inner substrate where the absorber layers do their thing."

As for conversion efficiencies, the CEO cites figures in the "12-14% range" for the inner cell. But he wouldn't discuss the module- or panel-level numbers, saying that "we don't measure efficiency at the module level" because of the widely varying "rooftop efficiencies" caused by different temperature, wind and sun conditions. He also stressed the company's focus on the system as a whole, not the components therein.

While much of the solar industry uses "module" and "panel" interchangeably, Solyndra has instituted its own differentiating nomenclature. Forty of the tubes or "modules" are mounted in what Solyndra calls its "panel," a 1.8 meter long by 1.08 meter wide, relatively simple non-penetrating framework that sits flat about a foot off the roof. The whole unit weighs about 32kg (70lbs).

Traditionally, the total expense of installed PV comes about half from the price of the manufactured panel and half from the cost of installation. While Gronet would not disclose Solyndra's current or projected cost per manufactured watt for its modules and panels, he did tout the system's simple design, ease of installation and superior electricity output per rooftop (see Figure 4).

He says that customers have validated that the Solyndra racks can be installed in one-third the time of a normal flat plate PV system, at about half the cost. The panels seem easy to carry and the proprietary mount hardware can be bolted down with simple hand or power tools. It doesn't take much time to place the panels, plug in the DC connectors and set up the ground strap. To connect one panel to another, a clip does the trick.



Courtesy of Solyndra

Figure 2. Solyndra's cylinidrical PV modules include 150 CIGS cells and a proprietary glass-to-metal endcap seal.

Each non-penetrating system is self-ballasted. The mounting design follows the contours of the average not-so-flat flat roof, Truman told me, and allows the panels to sit over most low-lying obstructions. A team of five workers can install about 40KW of Solyndra panels in a day, according to Gronet, and the system is as easy to take apart as it is to put together, offering mobility and flexibility for those who might want to move the PV to another location or do some work on the roof itself.

A highly automated manufacturing facility

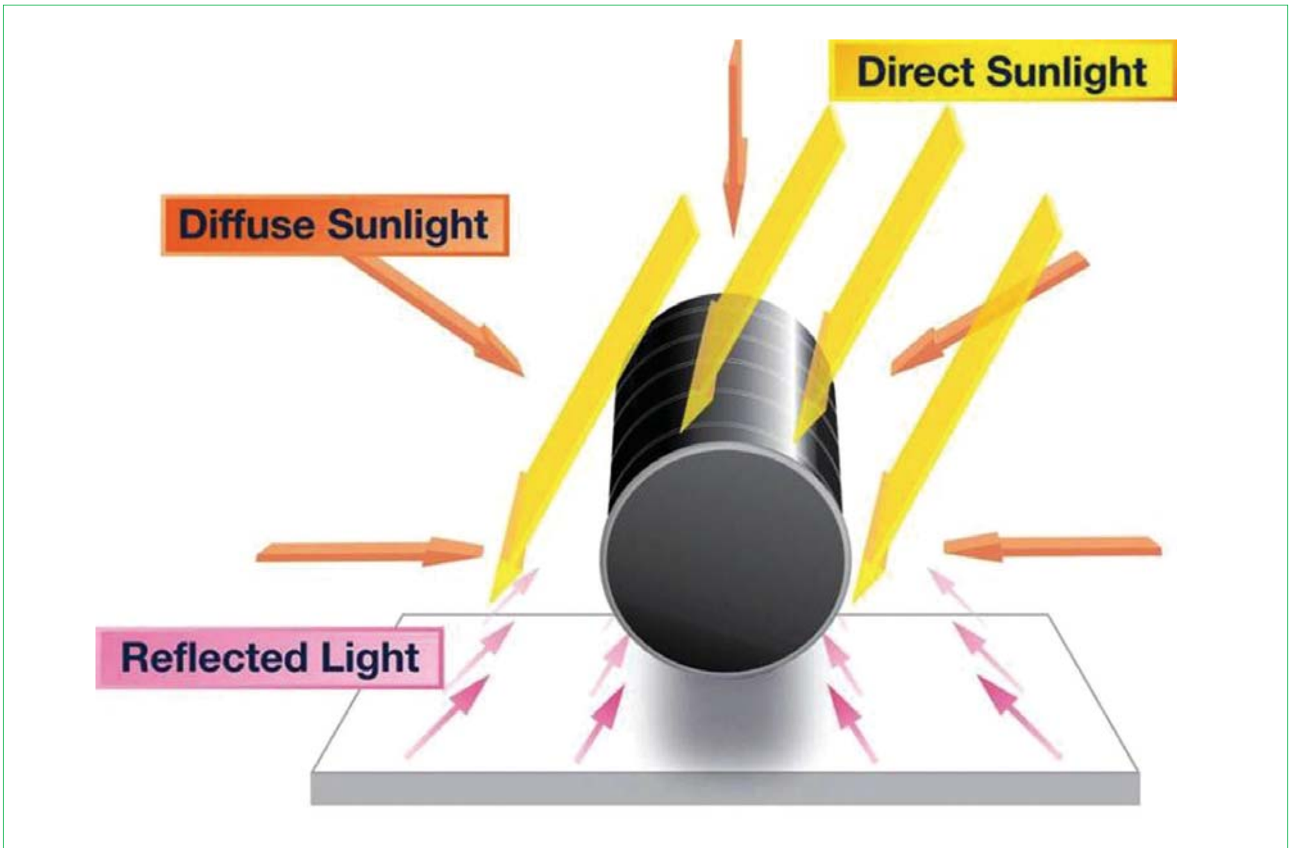
When you enter Solyndra's Fab 1, you notice a few things right off the bat. It's a biggish facility, but not mega-scale, with about 180,000 square feet of factory floor and related manufacturing space. Floor space is at a premium, with little room left for more tools. The conditions are tidy, but not ultraclean, nowhere near the stringent contamination control specs of a semiconductor or a hard-disk-drive fab.

The fab is highly automated with robots and conveyor systems of various sizes and shapes--from AGVs scurrying past on the floor to large, strong-armed palletizing robots, their limbs moving around with that mindless yet almost anthropomorphic precision of the industrial robot class (see Figure 5). Scores of 25-high stacks of tube-module trays, each holding 48 CIGS PV cylinders, are grouped on the floor in various spots.

The company took the keys to the Fremont facility in February 2007, and after some construction and equipment installation, had its first PV tube modules coming off the line by late summer of that year, according to Truman. Over the next year, the team focused on improving tube performance and enhancing yields.

Gronet told me that the first volume shipments of Solyndra's panels began in July 2008. At least 15 beta sites are running in the U.S. and Europe to validate the system's performance.

The company puts a nameplate capacity of 110MW on what it calls its "front-end" fab. It has borrowed this terminology from the chipmaking realm to differentiate its core CIGS tube production from the "back-end" processing down the road in Milpitas, where an outer tube sheaths the inner one, the unit's endcaps are plugged in and sealed, the optical coupling liquid is injected between the inner and outer tubes and the finished cylinder modules are inserted in the panel arrays, 40 at a time.



Courtesy of Solyndra

Figure 3. The tubular design of Solyndra's modules optimizes the collection of direct, diffuse, and reflected sunlight.

Because Solyndra's front-end fab building once housed a succession of HDD fabs, it was not purpose built for the company's process. The floor plan isn't bad, especially with the level of automation helping out, but the flow is less than optimal. Truman told me that in the second factory, they "will do the layout optimally for the logistics."

He leads me around to the large, multi-dunk-tank cleaning equipment where the incoming soda-lime glass tubes are cleaned and prepped for process. Truman pointed out that there's quite a bit of worldwide capacity with this kind of glass since the medtech/pharma crowd has been switching over to plastic for their test tubes and vials. "We actually have a segment of the glass industry where there's an excess of supply," he related.

The robots transport the tubes to the molybdenum deposition tool, where, like with CIGS done on flat glass or flexible foil, the metallic back contacts are put down on the glass substrates. The individually RFIDed tubes are rotated, with careful attention to film uniformity. The Solyndra fab boasts a proprietary manufacturing control system with an arsenal of sensors, creating a closed-loop metrology system reminiscent of a flat-panel display or chipmaking plant.

"We have alot of custom metrology in these things," Truman explained. "At every step of the way every tube is tested, whether it's in deposition or scribing for the monolithic integration. Even during our monolithic integration steps, there are metrology devices on the head of the scribing machines measuring a variety of properties as we go along. Every tube is tracked through the automation system and through every aspect of the deposition – each tube has its own identifier."

After the moly layers are deposited and a quick patterning-step is completed, the PV cylinders are robotically transported to the most important equipment set on the floor – the CIGS absorber tool. Solyndra designed and built (with the help of subcontractors) the 45MW system, which boasts an impressive footprint, stretching about 100 feet. The company uses the co-evaporation approach to lay down its copper, indium, gallium and (di)selenide because, as Gronet reminded me, the highest conversion efficiencies for CIGS have been achieved using that type of deposition.

Once the CIGS film stack has been put down, the tubes move to the junction partner/buffer layer tool. The company uses a proprietary wet solution process here, in which the tubes are spray-coated with nanometer-scale layers of cadmium sulfide (although there's apparently work going on to make the buffer cadmium-free). Finally, the transparent conductive oxide (TCO) topcoat, reportedly an optimized i-ZnO/Al:ZnO cocktail, is sputtered on.

Then the tubes are moved to Solyndra's proprietary laser-scribing tools for the monolithic integration process. Truman told me that the scribes, done six tubes at a time, are mostly helical, with "one linear scribe done at the very end to define each cell." He showed me how the individual cells, rather than being cylindrical per se, are slightly curved in a croissant-like shape.

Before the cylinders are sent down to the back-end facility for packaging and paneling, each one is tested for its performance, electrical output and the like on a tool familiar to any PV manufacturer – the solar simulator and its pulsing bright lights.

Impressive debut, but questions remain

Solyndra's launch story may be impressive, but there remain several areas of concern in need of clarification so that the company's prospects for success can be more comprehensively evaluated.

Aside from the difficulties facing any manufacturer seeking capital during the emerging global recession, Solyndra could be more open about the actual retail or wholesale price tags of the panels and systems. There's been ample lip service paid to the company's ability to drive toward a variety of definitions of unsubsidized grid parity, but without those dollar figures, we have to take their word for it.

They also aren't ready to talk about their current cost-per-watt manufacturing metric, let alone the roadmap to getting to that buck-a-watt sweetspot and beyond. They may have a fully

Courtesy of Solyndra

Figure 4. Solyndra claims installation of its rooftop PV panels can be done in about one-third the time and one-half the cost of traditional flat-plate module systems.

Courtesy of Solyndra

Figure 5. Solyndra's highly automated fab features a proprietary manufacturing and process control system.

automated, highly controlled, even high yielding factory and a proprietary process that uses less absorber materials than other CIGS schemes, but what was on the fab floor did not strike me as a disruptively inexpensive approach. Three out of the four main process steps use vacuum deposition, the other (for the junction partner/buffer layer) employs a wet-spray technique – none of which screams "low-cost manufacturing solution."

The claimed 12-14% conversion efficiencies for Solyndra's tube modules are certainly competitive with other CIGS, CdTe and amorphous-silicon TFPV players and even match up well with the low end of the crystalline silicon module spectrum. But what's lacking is a third-party, NREL or NREL-like evaluation of the cylinders' efficiencies, let alone any efficiency numbers for the panels or reporting on the tightness of their product's overall efficiency distribution curve.

Of course, the actual geographics and climatic placement of the PV systems have a big impact on their ultimate efficiencies and at the end of the day, it's about the electricity produced by the panels, not just how well they convert those photons to electrons. But there's a bit of gamesmanship in Solyndra's refusal to play by the established rules of stated conversion efficiencies.

The ingenious glass-to-metal sealed end-cap on each tube seems to be an elegant, robust approach to keeping CIGS-killing moisture out. But can the hermetically sealed caps survive the necessary 20 to 25 years and demonstrate the level of reliability needed to compete with silicon and other thin-film PV? The Solyndra systems have all been run through their testing paces and they apparently passed with flying colors. But testing's one thing, actual field life is another.

Then there's the question of scalability. The initial 40MW line in Fab 1 is running close to capacity, I'm told. The second line – the to-be-standard 70MW – is still a work in progress, with a limited amount of product coming off of it and heading for the back-end facility. Some tools remain in what Truman called "various stages of startup." The plan is to build out capacity in the second fab (and future ones) in increments of 70MW, cookie cutter-style.

Before building out the new factory, the Solyndra crew has to crank up the initial 70MW line in a timely, high-yielding manner. Some CIGS aficionados question the ultimate ability of a co-evaporation-style process like that in use at the Fremont fab to scale economically to high volume. At the end of the day, nameplate is not the same as run rate. PV factories of many flavors are notorious for their low capacity utilization numbers, and CIGS companies still have yet to prove their high-volume, 100MW-plus production mettle.

Despite these questions, with US$1.2 billion in orders already booked, the likes of customers Phoenix Solar, Solar Power Inc. and GeckoLogic must obviously believe in the company and its product. Solyndra must now demonstrate a First Solar-like focus on executing the remaining ramp of its first fab and then building, equipping, and scaling its planned six-line, 420MW factory up in order to take its place in the photovoltaic pantheon.

This feature is an abridged/edited version of a three-part blog series on Solyndra that originally appeared on PV-Tech.org.

Product Briefings

Dr. Schenk

Dr. Schenk's thin film module insulation tester detects shorts between cells

Product Briefing Outline: The Electrical Insulation Tester from Dr. Schenk is a measurement solution for thin-film solar modules. It performs an electrical insulation test between the solar cells after scribing. The system detects shorts and minimum resistance between neighboring cells.

Problem: In thin-film PV modules, the electric current flows between the solar cells which are defined during the laser scribing processes on the conductive layer (e.g. TCO or molybdenum). A discontinuity of these scribes will cause short circuits and minimum resistance between neighboring cells.

Solution: Dr. Schenk offers all-in-one quality assurance and process control systems for the solar panel production. The surface inspection systems, SolarInspect, can now be combined with beneficial measurement tasks in just one solution for higher yield.

With the Electrical Insulation Tester from the product line SolarMeasure, shorts and minimum resistance between cells can reliably be detected. The Electrical Insulation tester's main component is a measurement interface. A row of metal contact probes is installed along a contact bar. This board-like interface is easily installed on a frame and is placed horizontal above the solar modules flowing through the production line after scribing. The amount and distance of the lined up contact probes depends on the size of the panel and, more importantly, on the number of cells – one probe for each cell. The modular design of the bar interface enables customers to easily exchange the contact bar for applications with different panel sizes.

Applications: Thin film solar modules with a wide range of dimension and thickness. System is installed in-line after the P1 scribing.

Platform: The system is available as add-on to Dr. Schenk inspection systems SolarInspect or as stand-alone product. The measurement cycle is (max 3 seconds).

Availability: Q3 2008 onwards.

Angstrom Sciences

Angstrom Sciences targets thin-film deposition with rotating cylindrical magnetron

Product Briefing Outline: Angstrom Sciences has developed a rotating cylindrical magnetron assembly that is compact, economical and lightweight. By utilizing the patented technology already incorporated into other 'Onyx'-series magnetrons, Angstrom Sciences provides a 10.6° deposition profile, 85%+ target utilization and power savings up to 20% compared to conventional cylindrical magnetrons.

Problem: The traditional approach to sputtering or depositing a thin metal film uses a planar magnetron cathode. The weakness of this approach is that the usable volume of a planar is limited – a typical 5"×20"×1⁄2" planar target has a volume available for sputtering of about 50 cubic inches. The utilization of a target by a typical planar magnetron is limited to about 40%. Each time a target is exhausted, the manufacturing process must be shut down so it can be replaced, thus low usable volume and low utilization increases manufacturing downtime.

Solution: These concerns are being addressed by a new generation of rotating cylindrical magnetrons that offer significant advantages over planar magnetrons. Angstrom Sciences has developed the 'ONYX-REVOLUTION' with a new magnet array design to improve rotating cylindrical magnetron performance in flat panel display and web coating applications. The improved deposition profile offers reduced debris accumulation on the chamber walls, allowing for longer runtimes and higher throughput for industrial applications. The Angstrom Sciences magnet array offers a higher magnetic field intensity, which allows the sputtering process to run at lower power levels while maintaining typical deposition rates. Field-testing has verified a power savings of 20% and target utilization of 92%.

Applications: Available in 6", 5"and 4" diameters, is designed for in-line systems and is compatible with both horizontal and vertical applications.

Platform: An optimized electrical transfer design to deliver high power while avoiding arcing as well as reduced brush wear and debris.

Availability: Currently available.

Oerlikon Solar

Oerlikon Solar launches 'Amorph High Performance' thin-film technology

Product Briefing Outline: Oerlikon Solar has introduced its next generation 'Amorph High Performance' thin-film technology. Oerlikon Solar has claimed a major leap forward in panel performance by achieving more than 7% stabilized efficiency that has enabled a 16% increase in panel power output. The company said that more than 500,000 panels of the new technology have been produced. 'Amorph High Performance' fab capacity is also claimed to be up by more than 50% without an increase in fab cost. This has significantly raised economic viability for this high growth PV technology. Oerlikon has already been granted the requisite master certificates from TÜV.

Problem: A key driver is the need to increase the efficiency of amorphous thin film panels as a key effort of reducing the cost per watt. As a low cost production method, emphasis is required on improving cell efficiencies while retaining low cost high volume manufacturing processes.

Solution: The new a-Si panel utilizes an advanced Oerlikon Solar Zinc Oxide TCO layer, which significantly increases the performance characteristics of the panel through better light trapping properties. The importance of optimizing the panel design from a system viewpoint is being demonstrated in this generation of the technology. Optimization of the process elements in the end-to-end fabrication system have resulted in considerable increase in the plant throughput capability. Experience with the first generation amorphous end-to-end lines has lead to important yield, line uptime and TACT time optimization. These improvements have resulted in a 50% increase in the output capacity of the line, without an increase in the total capital cost.

Applications: 1.4m^2 thin film panel.

Platform: TÜV Rhineland has certified Oerlikon Solar's 'Amorph High Performance' thin film silicon modules. All Module Performance (IEC 61646:2008) and Module Safety (IEC 61730-1:2004/61730-2:2004) criteria were satisfied.

Availability: November 2008 onwards.

Product Briefings

Testbourne Limited

Testbourne's rotatable cylindrical targets offer greater utilization, longer production runs and use of higher power densities

Product Briefing Outline: Testbourne Limited is now offering an extensive range of cast, plasma sprayed and extruded rotating cylindrical metal and ceramic sputtering targets. Rotatable targets are proving to be increasingly popular in the PV industry due to various advantages over planar sputtering targets. The most commonly used C-MAG rotary targets are available in chromium, silver, aluminium-silicon, tin, titanium oxide, stainless steel, aluminium, tungsten, tantalum, molybdenum, niobium, copper and zinc alloys.

Problem: Typical utilisation ratios for planar targets range from 20-40%, which presents a challenge of high production cost and short lifetime of the targets to the large area coating industry.

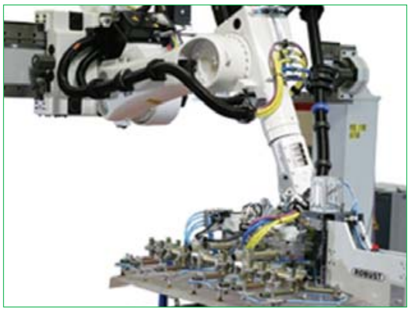
Solution: Rotatable targets normally contain more material and offer a greater utilisation (up to 80%) in comparison to planar targets. This in turn results in much longer production runs and reduced downtime of the system. The overall benefit is an increase in the throughput of the coating equipment and lower cost of ownership. Furthermore, the rotatable targets allow the use of higher power densities due to the heat build-up being spread evenly over the surface area of the target. As a consequence, an increased deposition speed can be seen along with an improved performance during reactive sputtering.

Applications: Thin-film coatings: photovoltaic solar cells, architectural glass and flat panel displays.

Platform: Testbourne Ltd. is now supplying cylindrical magnetron sputtering targets which are manufactured in many sizes, ranging from 2" up to 8.625" in diameter, with lengths from a few inches up to 160 inches.

Availability: March 2007 onwards.

KUKA Systems



KUKA Systems offers full service automation solutions for thin-film production

Product Briefing Outline: Thin film production is characterized by the need for full automation and low cost production that requires careful planning and engineering to ensure production targets per line are met or exceeded. Full service planning and engineering coupled to flexible and customized automation solutions are a key part of KUKA Systems product offerings.

Problem: The manufacture of thin-film modules is particularly demanding: high temperatures, clean-room conditions, extremely stringent requirements with regard to positioning accuracy and technical availability. A key aspect is the need for greater levels of automation throughout the process flow as thin-film manufacturing has to be on a larger scale than conventional crystalline silicon solar cell production.

Solution: A multitude of details must be considered, analysed and simulated before the perfect layout can be prepared. The key to meet thin-film production goals is thorough engineering to ensure a constant production output and the foundation for this is laid in the planning stage. As a world-wide operating supplier of flexible turnkey installations, KUKA Systems has the expertise to design and build complex production systems while offering flexible turnkey installations.

Applications: Thin-film and c-Si production.

Platform: KUKA offers modular systems, which are designed specifically for use in the photovoltaic industry that can be deployed as part of a KUKA turnkey installation.

Availability: Currently available.

Veeco Instruments

Veeco's 'FastFlex' web coating platform ideal for flexible thin-film solar cell production

Product Briefing Outline: Veeco Instruments has introduced its 'FastFlex' line of Web Coating Systems designed for manufacturing of CIGS solar cells. Veeco's 'FastFlex' web deposition platform offers high throughput and improved performance for flexible thin film solar cell production that is claimed to contribute to a lower cost-of-ownership, due to its high quantity of deposition zones in a compact footprint.

Problem: The high temperature and high-volume throughput demands of CIGS solar cell manufacturing requires highly uniform deposition while maintaining high tool up-time. Due to cost per watt requirements for thin film, greater levels of economic consumption of materials is required resulting in the need for higher total material utilization.

Solution: Veeco is the industry's only thin-film deposition equipment supplier that provides production-proven thermal sources integrated into a CIGS web coating system. This differentiation allows our FastFlex platform to provide CIGS customers with an excellent, high-throughput deposition solution as they move from R&D to production. Veeco's FastFlex systems offer superior material utilization, excellent thickness uniformity, and the ability to process web widths up to 350mm with an architecture that supports widths of one metre or more for metal as well as polyimide substrates.

Applications: CIGS solar cells.

Platform: The FastFlex platform consists of three systems – one for the Transparent Conductive Oxide (TCO) utilizing reactive sputtering, one for metal deposition with sputtering (the Molybdenum layer), and one for the CIGS layer, integrating Veeco's proven PV-Series Thermal Deposition Sources. To help deliver high throughput, the FastFlex system features flexible architecture that can be configured to specific needs, with a choice of rotary or planar magnetron cathode assemblies, loading and maintenance requirements, and more.

Availability: September 2008 onwards.

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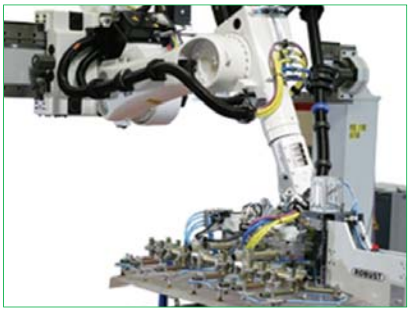

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Availability: September 2008 onwards.

Analysis and minimisation of plasma process instabilities during thin silicon film deposition

D. Hrunski, **A. Gordijn**, **U. Stickelmann**, **T. Kilper** & **W. Appenzeller**, IEF-5 Photovoltaik, Forschungszentrum Jülich GmbH, Germany; **W. Grählert** & **H. Beese**, Fraunhofer Institut Werkstoff- und Strahltechnik, Germany

ABSTRACT

With the thin-film silicon industry facing the problems of high-quality material deposition at high rates and narrowing deposition process windows, the "no-drift regime" is an important part of this development. In the case of plasma-enhanced chemical vapor deposition (PECVD) of thin silicon films, the inconstancy of the concentration of silicon-containing particles (SCP) in the plasma leads to changes in deposition conditions, causing a deterioration of film properties, therefore decreasing the performance of the solar cells. During the last few decades, evidence about the process instabilities has been accumulated in different laboratories. In this study, Fourier transform infrared absorption spectroscopy (FTIR), optical emission spectroscopy (OES), self-bias voltage and plasma impedance controls were applied as in-situ process diagnostics during the deposition of amorphous and microcrystalline silicon thin-films. Results of the study were then discussed.

Introduction

The in-situ process diagnostics clearly indicate inconstancy of plasma properties and therefore of deposition conditions. These instabilities could take several minutes and are comparable with the film deposition time. Two scales for process drifts could be identified: a strong short-term drift or initial transient state phenomena (ITS) for the first several minutes of deposition, and a long-term drift (LTD) for the whole deposition process time.

For example, a variation of the bias voltage of ±10% and of the SiH* emission intensity (6% decrease) during the first few minutes was observed. The FTIR measurement of reactant concentration in the process chamber evidence that the strong SCP concentration drop (about 50%) in a plasma is the cause of the short-term drift of OES signals (SiH* emission), plasma impedance and self-bias voltage signals. On the other hand, a weak plasma impedance change is one of the reasons for the long-term drift of OES signals and self-bias voltage signals as the silicon particle concentration in the exhaust remains constant. In this article, the influences of the deposition chamber geometry and technological parameters on process drifts are considered. It is shown that the decrease of the gas residence time in the reactor leads to a decrease of ITS, while options for active and passive process control during plasma deposition are discussed. The improvement of solar cell performance based on thin silicon films is demonstrated when drifts are reduced.

An important step in the production of Si-based thin-film solar cells is the preparation of amorphous or microcrystalline thin silicon layers by plasma-enhanced chemical vapor deposition (PECVD). The inconstancy of the concentration of silicon-containing particles (SCP) in the plasma leads to changes in deposition conditions, thus possibly decreasing solar cell performance [1,2]. In the eighties, several researchers from different laboratories showed that the PECVD process has an initial transient state phenomenon (ITS) in semi-batch reactors [3,4,5]. This is an important phenomenon, because the quality of the material is closely related to the plasma parameters and the improvement of the film interface properties is crucial for raising the performance of thin-film devices. It is clear that the interface properties depend on the history of a PECVD chamber (cross-contamination [6], chemical memory [7], remaining impurities, silicon powder etc.) and the initial transient state of the plasma.

"The quality of the material is closely related to the plasma parameters and the improvement of the film interface properties is crucial for raising the performance of thin-film devices."

Both Y. Nakayama et al. [5] from the University of Osaka and Y. Ashida et al. [3] from Mitsui Toatsu Chemicals Inc. have observed the instability of emission intensities I_{SiH^*} and I_H measured during the deposition process. Similar observations were made by M. N. van den Donker [1]: after starting the glow discharge, the intensity of the SiH radicals (I_{SiH^*}) decreased and then leveled off. Following an increase, the atomic hydrogen intensity stabilised. Similar observations were made in a modified KAI-S large area industrial reactor (37×47cm^2) from Oerlikon Solar AG even when gas residence time was very small (about 1s) [8]. In each of these studies, using different reactors, the ITS of the plasma took place over times ranging from 2 to 60 seconds and, more importantly, a strong influence on the devices' response was observed. For example, Y. Nakayama et al. [9] showed that the deposition rate, hydrogen content, hydrogen bonding states and photoluminescence spectra of the a-Si:H interface layer correlated strongly with the initial transient state of the plasma and differ from those of the bulk deposited in the steady state of the plasma, especially at a high consumption of SiH_4.

Today, the production of industrial PECVD systems is growing. The backmixed reactor type is the most popular concept, because it offers good control of reaction speed, lower labor and handling costs, has a low shutdown time to empty, clean out, and refill, and an acceptable quality control of the product [10]. The backmixed reactor (semi-batch, stirred tank reactor or constant flow stirred tank reactor), a common ideal reactor type where gas is uniformly mixed, has the same composition both within the reactor and at the chamber exit. However, the inherent property of such reactors is ITS (start time).

This paper addresses the latter aspect and focuses on the origin of ITS and its influence on device fabrication.

The aims are increasing layer homogeneity in the growing direction and an increase of deposition preciseness.

Experimental details

The deposition reactor used in this work has a 30×30cm^2 deposition area (see [11,12] for more details). The vacuum chamber volume is 4×10^{5}cm^3. The system has a radio frequency (rf = 13.56 MHz) showerhead electrode jointly developed by Forschungs- und Applikationslabor Plasmatechnik (FAP GmbH, Dresden, Germany) and IEF-5 Photovoltaik at Forschungszentrum Jülich. The electrode distance was 1cm and, therefore, the plasma volume between the electrodes was about 1000cm^3. The rf-power feeding, process gas flow and pumping unit were optimised to provide homogeneous plasma conditions in a deposition regime.

The deposition system was also equipped with Fourier transform infrared absorption spectroscopy (FTIR) installed in the deposition chamber exhaust line with a path length of 1m between two ZnSe windows, which was used to measure the partial pressure of silane. Previously, this method had been successfully used in Centre de Recherches en Physique des Plasmas (Ecole Polytechnique Federale de Lausanne, Switzerland), for the optimisation of microcrystalline silicon deposition efficiency (gas utilisation efficiency) [13,14]. The Fourier transform of the detector signal yields a spectrum in the 600–4000cm^{-1} range with an instrumental spectral resolution of 0.5cm^{-1}. To obtain a reasonable signal-to-noise ratio, the measurements were performed by averaging over 32 spectral scans, for static measurements (reference measurement before process start) and one scan for dynamic measurements every three seconds. To determine the SiH_4 density, a calibration curve for the integral of the Q branch versus the SiH_4 pressure was obtained from SiH_4 gas spectra at different silane partial pressures and a reactor heater temperature of 200°C. The integral limits were chosen to be from 2163 to 2199 cm^{-1}. The SiH_4 density for the different plasma conditions was then obtained from the Q branch area using the calibration curve.

Parallel to real-time control of the SiH_4 concentration in the exhaust line, optical emission spectroscopy (OES), rf – electrode self-bias voltage (V_{bias}) monitoring and plasma (together with part of the reactor) impedance control were applied as in-situ process diagnostics during deposition of amorphous and microcrystalline silicon thin films. The plasma-emitted light was guided by the optical fiber to a monochromator (type Ocean Optics HR2000). The I_{SiH^*} line at 414nm was monitored.

The rf voltage (V_{rf}) and plasma impedance (phase shift - φ) were measured with the rf voltage–current probe (Z'SCAN, Advanced Energy). The detector and control point of the rf bias voltage were situated as close as possible to the rf electrode. The accuracy of the V_{rf} (peak-to-peak value) measurement is greater than 0.2V or 0.2% of the measured value, while the precision is lower (about 0.4V) due to rf signal deviation in the generator output, vibration of a matching box etc. The inductance of the rf antenna between the Z'Scan probe and the powered electrode is about 0.1µH. Rf power is supplied by an rf generator (Dressler V1000) via an L-type matchbox.

The deposition parameters are described in the following section. 350nm thick p-i-n thin amorphous silicon film solar cells were deposited. Details of the preparation and measurement of the typical amorphous (a-Si:H) thin silicon film solar cells can be found in [15,16].

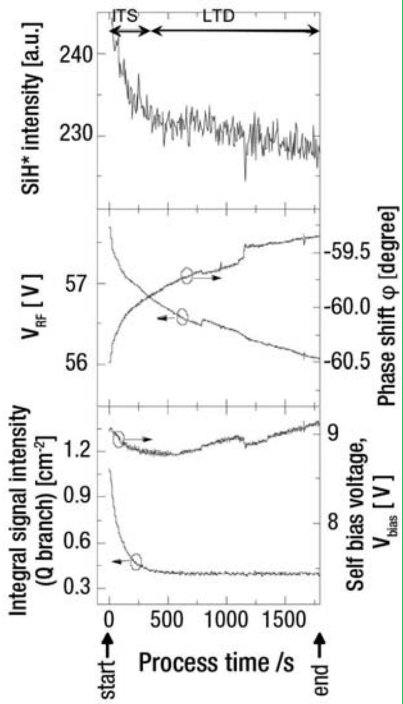

Figure 1. Time dependence of OES signal (I_{SiH^*}), of the rf probe signals (V_{RF}, φ, V_{bias}) and integral intensity of Q branch after turning on the rf discharge for regime A.

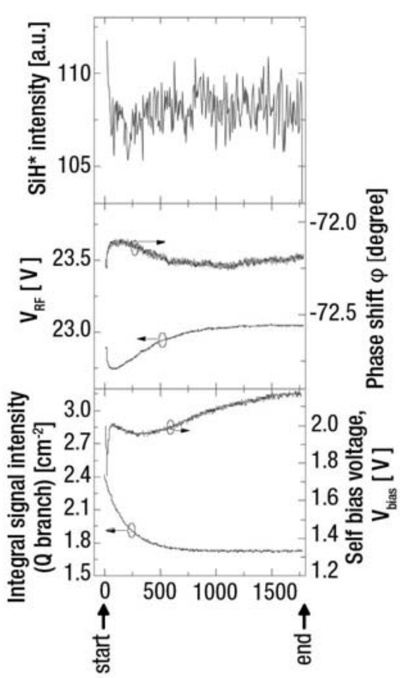

Figure 2. Time dependence of OES signal (I_{SiH^*}), of the rf probe signals (V_{RF}, φ, V_{bias}) and integral intensity of Q branch after turning on the rf discharge for regime B.

Results and discussion

Origin of the initial transient state

Figures 1 and 2 show variations of OES signals, of the rf probe signals and integral intensity of the Q branch after turning on the rf discharge for the different deposition regimes. The technological parameters (hydrogen, silane gas flows, rf power, heater temperature (T_h) and gas pressure in the chamber) of the regimes are presented in Table 1.

After starting the glow discharge, the I_{SiH^*} strongly decreases (-6.5%) (ITS), becomes more stable, but still shows a long-term drift (LTD). The initial transient time is defined as a time when the FTIR integral intensity signal becomes 102.5% of its stable value. It is important to note that a linear relation between SiH* emission and SiH_4 density is usually assumed, since excited SiH radicals (denoted as SiH*) originate from the electron-impact dissociative excitation of SiH_4 [17].

> "The quality of the material is closely related to the plasma parameters and the improvement of the film interface properties is crucial for raising the performance of thin-film devices."

ITS and LTD effects are also observed in other in-situ signals. Inconstancies of the rf voltage, plasma impedance and self bias voltage on the powered electrode are observed. It is interesting to note that in both deposition regimes, rf voltage and phase shift signals show opposite trends.

The ITS in the in-situ signals is longer for regime B compared to regime A (about 530 s vs. 370 s). Although the relative change of V_{rf}, φ and V_{bias} signals is not so strong as for OES, these changes cannot be ignored because even a small change of V_{rf} on an electrode has a very strong, nonlinear influence on ionisation degree and electron energy in the plasma [18].

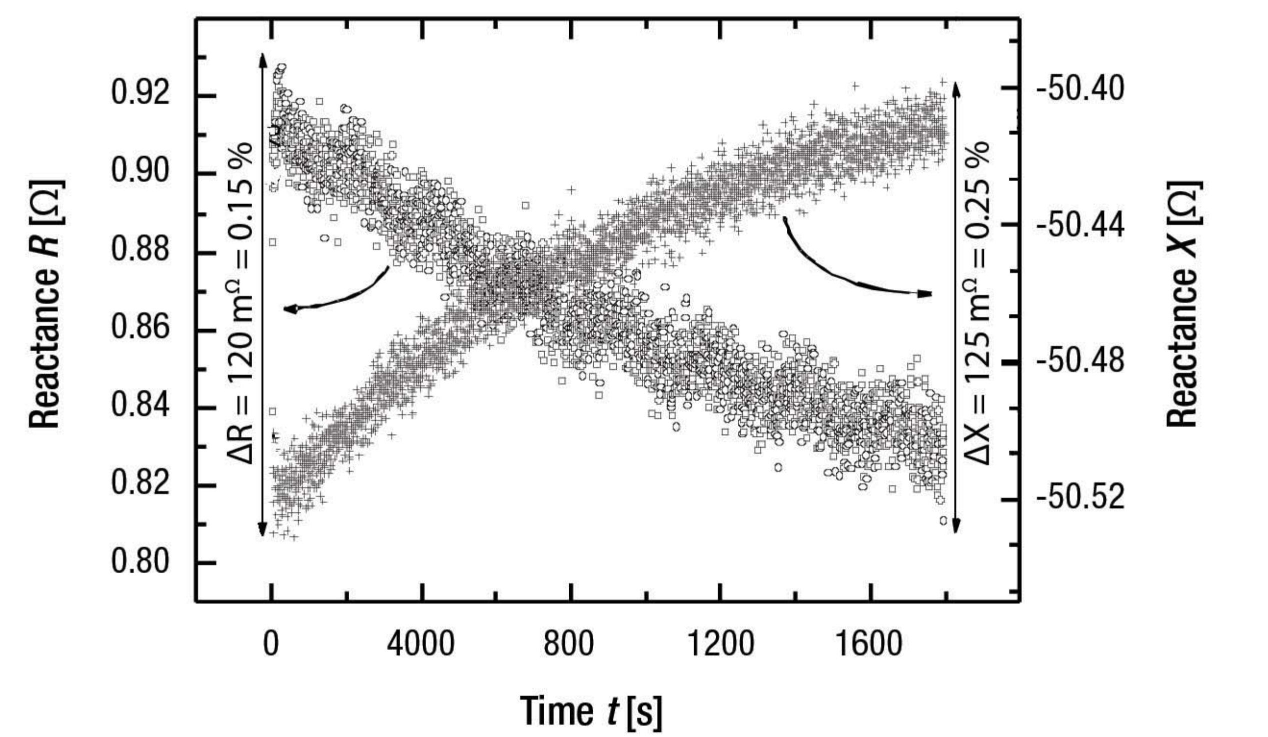

Figure 3. Resistance and reactance during 30 minutes' measurement in vacuum. The characteristic is reproducible.

For example, a good correlation is found between the character of drifts of the OES signal and V_{rf} in Figures 1 and 2, because the SiH* intensity depends not only on the SCP concentration in the plasma, but also on the electron energy and density [19], therefore depending on the rf voltage applied. In turn, inconstancy of a V_{bias} signal is an additional fact showing the inconstancy of deposition conditions.

The FTIR signals in Figures 1 and 2 clearly demonstrate that the SCP concentration is stable after ITS (after about 400 s under regime A and after about 600 s under regime B). This confirms observations made earlier [3,4,5,9] that the initial stabilisation time depends on the variation of silicon-containing radicals and polymers in SiH_4+H_2 plasma rather than on the other parameters. Therefore the ITS is a drift of plasma parameters due to the drop in silane concentration in the plasma.

Nevertheless, the LTDs were observed when the SCP concentration in the plasma was stable. It is very likely that the gradual reactor heating could be a reason for LTD, because increasing wall and gas temperatures have a strong influence on plasma properties [18.] and therefore on plasma + reactor impedance (see inconstancy of impedance signals in Figures 1 and 2). Another reason for LTD could be the phenomena of silicon powder formation and growth in the plasma bulk, topics that have been extensively investigated recently [20,21,22,23].

The next experiment demonstrates the influence of reactor heating on reactor impedance. Figure 3 shows the instability of reactor impedance (without plasma ignition). A decrease in the resistance of about 15% and a rather small increase of the absolute reactance of 0.25% are observed for the 30-minute experiment in the small-area rector (about 10L reactor volume). The relatively small change of the reactance appears negligible, but the decrease of the resistance seems to be considerable. Since the plasma is not ignited, the delivered electrical power of 20W is only dissipated in the stray elements of the reactor. It is likely that parts of the reactor are heated up and the contact resistances between different elements (screws, for example) determine the measured resistance. Since the components of the reactor expand during

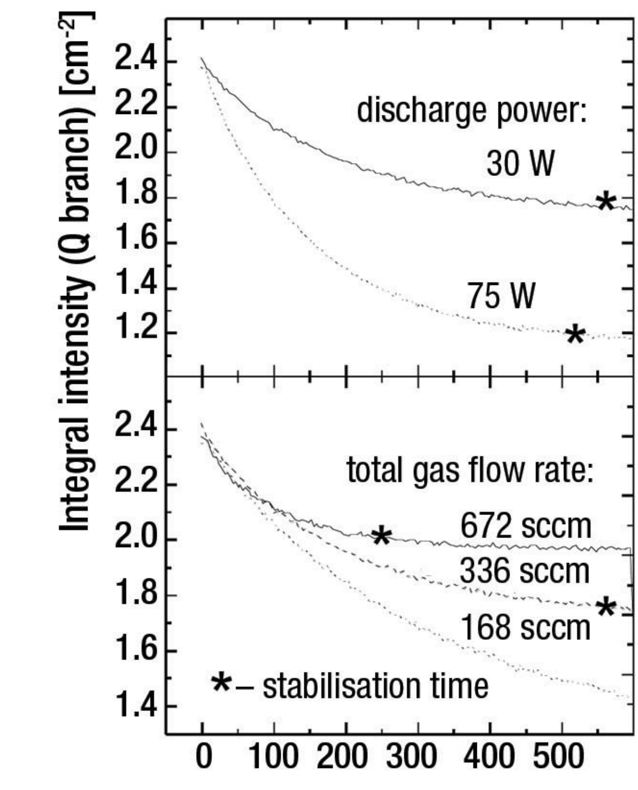

Figure 4. FTIR signal after turning on various rf powers (a) and for different total gas flow rates (b).

heating, the contact could improve and the measured resistance could decrease. It is important to note that during deposition this effect of rf power heating plays a smaller role because the resistance of the plasma is much higher and the major part of the power dissipates in the plasma. Nevertheless, the experiment shows the influence of reactor heating on rf matching.

Influence of the technological parameters on the initial transient state

Figure 4 shows the ITS for different power and total gas flow rate regimes. The inconstancy is shorter when the rf power and the total gas flow rate are higher. Figure 4(a) demonstrates that the variations of SCP concentration in the reactor depend on the degree of SiH_4, consumption since this value strongly depends upon the discharge power.

Figure 5 shows the ITS time plotted as a function of the gas residence time in different reactors and under different deposition conditions (substrate temperature, process gas pressure). The gas residence time is the time required to process one reactor volume of feed measured under specified conditions [10]:

$$t = \frac{V}{\upsilon_0} = \frac{\text{(reactor volume)}}{\text{(volumetric feed rate)}} \qquad (1)$$

Figures 4 and 5 clearly demonstrate that the increase of the total gas flow rate (decrease of residence time) is effective in order to decrease the transient time; interestingly, in all cases the ITS time is about four times longer than the residence time in the deposition chambers. This means that equilibrium or steady-state conditions result when reactor volumes are refreshed about four times by the gas feed.

It is important to note that since the gas volumetric feed rate depends on the temperature of the gas and the pressure in accordance with the ideal gas law, the decrease of process temperature and increase of total gas pressure in the reactor should lead to an increase of ITS magnitude.

The decrease and leveling off of silane density in the exhaust line (see FTIR signal, Figures 1 and 2), decrease of ITS time with increasing silane consumption in the reactor (Figure 4(a)) and dependence upon gas residence time (see Figure 4(b)), all imply that a variation of SCP concentration at the plasma region is the main origin of the initial transient state period. These findings correlate with the result for pure SiH_4 [5] and CH_4 [24], which found that the consumption of reagent plays an important role in the ITS phenomenon. Unfortunately, the shortening of ITS time by the decrease of the gas residence time (increasing total gas flow rate) conflicts with the problem of increasing silane consumption rate in industry.

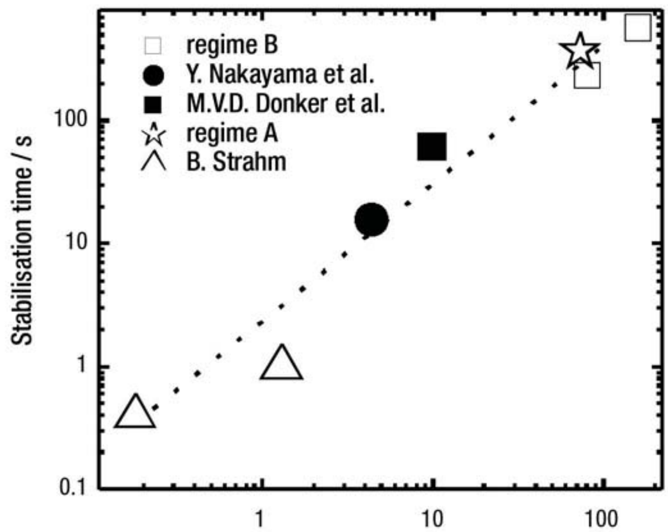

Figure 5. Stabilisation time (ITS) of I_{SiH^*} plotted as a function of gas residence time in different deposition chambers. Gas residence times were calculated for specified conditions described in [1, 5, 8].

Deposition regime:	H_2 (sccm)	SiH_4 (sccm)	rf power (W)	T_h (°C)	Pressure (Pa)
A	2000	20	400	150	1065
B	300	36	30	180	400

Table 1. Deposition conditions of regimes A and B. H_2, SiH_4, and T_h are flows of hydrogen, silane and substrate temperature, respectively.

Deposition regime:	η (%)	FF (%)	V_{oc} (V)	J_{sc} (mA/cm^2)
No CP method	9.45	68.9	0.91	15
CP method	10	72	0.93	15.1

Table 2. Performance of a-Si:H solar cells with and without the continuous plasma deposition method. Solar cell parameters are: cell efficiency (η), fill factor (FF), short-circuit current (J_{sc}) and open-circuit voltage (V_{OC}) (the maximum current and voltage, respectively, from a solar cell). The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}.

Influence of ITS on amorphous thin-film silicon solar cell fabrication

The ITS is harmful to the deposition of films with high requirements for uniformity of composition. Thus the transient depletion of the initially present SiH_4 source gas induces the formation of an amorphous incubation layer that prevents crystallite nucleation in the i-layer, leads to poor microcrystalline solar cell performance [2,25,26] and induces low-quality material deposition at the sensitive p-i interface of amorphous silicon solar cells [3]. As shown above, an effective way of reducing ITS is to shorten the gas residence time. This parameter could be reduced by: (i) increasing the total gas flow rate, (ii) using a PECVD system with a small reactor volume, or (iii) decreasing the process pressure. Unfortunately, reducing the gas residence time is restricted within a rather narrow process window. Using a PECVD system with a small reactor volume and/or using a shutter needs the reconstruction or even a completely new design of the PECVD system.

A possible solution is a silane profiling method (also known as continuous plasma method (CP) [27]). Under this condition, the process was started by using H_2 plasma, after which SiH_4 was fed in, keeping the same H_2 flow used to ignite the plasma. The p-i-n structure of thin solar cells has a sensitive p-i interface located at the interface layer, which is usually deposited in the ITS regime. Therefore, it is quite likely that the performance of this type of solar cell is sensitive to the ITS of the plasma. The deposition conditions of amorphous silicon intrinsic layer (a-Si:H) with a thickness of 350nm was regime B (see Table 1). The usual solar cell characteristics and the solar cell characteristics when the continuous plasma method was used are shown in Table 2. As compared to cells produced without CP, the efficiency of cells produced by the silane control method was higher due to the higher fill factor (FF).

These results indicate that the initial plasma instability period leads to the deposition of a low-quality (void- and defect-rich) interface layer. Experiments show that the CP method used to minimise the ITS in the plasma deposition of this silicon layer plays an important role in the uniform composition of material, and consequently in the performance of devices.

> "The main reason for plasma instability is a drop in the silane concentration of the plasma."

Conclusions

The origin of the initial transient state in the silane plasma is investigated using optical emission spectroscopy, plasma impedance monitoring and FTIR of exhaust gases. The main reason for plasma instability is a drop in the silane concentration of the plasma. The instabilities may take several minutes and are comparable with the film deposition time. Two scales for process drifts could be distinguished: a strong short-term drift (ITS) for the first several minutes of deposition and a long-term drift (LTD) for the whole deposition process time. By using the silane profiling method, the influence of the ITS on the fabrication of thin silicon film amorphous solar cells is shown. An improvement in solar cell performance of 5% is demonstrated when drifts are reduced.

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CIGS, CdTe thin-film PV equipment sector emerges, but standardization remains elusive

Tom Cheyney, Senior Contributing Editor – USA, Photovoltaics International

ABSTRACT

Although the entire solar manufacturing industry, from raw materials to finished modules, has enjoyed strong double-digit growth rates over the past several years, few sectors have soared like the amorphous-silicon thin-film photovoltaic equipment space. Much of this prodigious multibillion-dollar booking activity can be attributed to the acceptance of the turnkey production packages offered by the likes of Applied Materials, Oerlikon and Ulvac. These suppliers' plug-and-play, standard toolset solutions are attractive to companies seeking to get into the TFPV module business on a fast track and then scale up their capacities in multimegawatt chunks to achieve grid-competitive cost-per-manufactured-watt metrics. One notable exception to this turnkey trend is United Solar Ovonic, which has spent years developing its proprietary roll-to-roll a-Si TFPV production equipment and factories. But what about the equipment sector for the two main non-silicon thin-film PV technologies, the direct-bandgap polycrystalline pair of cadmium telluride (CdTe) and copper indium gallium (di)selenide (CIS/CIGS)?

The vast majority of nonsilicon TFPV cell and module manufacturers have developed their own processes and designed their own custom toolsets, especially for the semiconducting absorber layers, often building the gear with the help of contract manufacturers and OEMs. CdTe pioneer First Solar regards manufacturing technology as one of its IP crown jewels and a crucial part of the company's successful 'copy smart' capacity-scaling strategy.

This nonstandardized situation is unlikely to change in the near term, since CIGS companies in particular are placing their bets on a wide variety of absorber-layer growth/deposition strategies and substrate types to differentiate themselves competitively as low-cost, volume-manufacturing TFPV contenders. The vacuum and atmospheric processes range from thermal coevaporation to sputtering, electroplating to nanoink printing, sometimes in combination with some sort of selenization or rapid thermal step. The integration approaches can be either discrete or monolithic, and the substrate materials receiving those critical films range from flat-plate or cylindrical glass to flexible steel foils and polymer sheets.

For both CdTe and CIGS, the U.S. National Renewable Energy Laboratory (NREL) has identified the standardization of equipment for the growth/deposition of the absorber layer as a critical issue for the development of lower-cost, reliable TFPV modules. Two early examples of de-facto standard processes (though by no means standardized handling systems, substrates, or tool designs) exist in the CIGS realm: molybdenum, deposited via

Figure 1. Zinc oxide TCO sputtering tools for CIGS thin-film PV being assembled at centrotherm's factory.

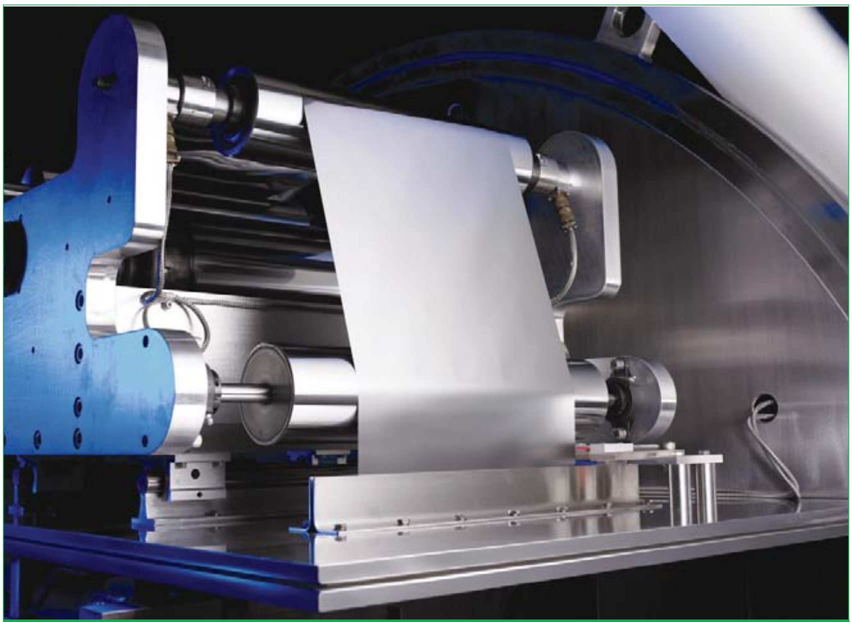

Figure 2. The web payout system of the molybdenum and TCO modules on Veeco's FastFlex CIGS processing platform.

sputtering, remains the back-contact film of choice; and most device-makers use zinc oxide, laid down via sputtering or chemical vapor deposition, as their front contact/transparent conducting oxide (TCO) layer (although a few use indium tin oxide). Laser scribing, curing, and testing tools also have a fair amount of commonality across some platforms.

Off-the-shelf integrated systems solutions, especially for CdTe/CIGS absorber tools, may be years from widespread acceptance. Yet a growing number of OEMs and custom tool developers are jumping into the fray, betting that the nonsilicon portion of the thin-film/organic PV equipment sector will be a substantial part of an overall market forecast by NanoMarkets to reach nearly US$1.44 billion by 2011.

While Applied Materials and Oerlikon stay focused on their a-Si TFPV equipment and turnkey factory efforts and have yet to confirm any CdTe or CIGS business, process-oriented companies like Veeco, centrotherm, BTU, Stangl, and Solarcoating have made inroads in the nonsilicon TF sectors. Custom equipment and automation systems outfits like Northfield and Owens Design are also working with a growing number of PV start-ups for their tool design, engineering, and manufacturing needs.

To turnkey or not to turnkey

One company taking a page from AMAT's playbook – and its own – is centrotherm, which launched what it calls the first turnkey CIGS module production line in early 2008. The German company hopes to leverage both its years of experience in the crystalline-silicon side of the solar business, where it has made a tidy sum selling turnkey manufacturing systems, and the thin-film sputtering expertise of its FHR unit.

Figure 3. BTU's thin-film PV furnaces offer tight thermal uniformities for CdTe and CIGS manufacturing.

"We want to offer to someone new to the industry or sector a low-risk, complete production solution," said Wolfgang Herbst, Senior Manager of market and technology research. Throughput, efficiency, and yield guarantees are part of the package, as well as project management, equipment installation and start-up, production ramp, and customer staff training components.

To target the "large-scale, high-volume markets," centrotherm has chosen to go with a CIGS-on-glass ($1.5m^2$) approach, using thermal coevaporation for the absorber-layer process and sputtering for the precursor and back-contact metal films, he explained. The company claims its 550°C self-adjusting process has a speedy 60-second cycle time, compositional uniformity of ±2% and thermal process uniformity of ±2.

Although the company has an R&D pilot line and well-equipped thin-film analysis lab in Blaubeuren, Herbst was quick to point out that, "we are not getting into the module business." Centrotherm has yet to receive any orders for its compact $5000m^2$, 35 to 50MW CIGS turnkey lines, but the company is "in negotiations with potential customers."

Flexible process, flexible substrate

Although Veeco does not characterize its CIGS tools as being part of a turnkey solution, its FastFlex equipment platform, much of which came through the door with the purchase of Mill Lane Engineering in May 2008, integrates all of the core process steps except the cadmium-sulfide buffer/junction layer. The product name suggests the substrate and production method at work: spools of flexible steel foil or polyimide material, run on a roll-to-roll or web-process system.

John Patrin, Director of business development and product marketing, explains the rationale behind the acquisition. "Customers had asked, 'since you sell (deposition) sources), why don't you sell the whole system? It would be advantageous to have one vendor to work with.'" Mill Lane was already shipping molybdenum and TCO systems at the time of the buyout, then Veeco added its sources for the CIGS thermal evaporation steps. "One of the biggest challenges is integrating the thermal source technology into these (flexible) architectures, because of the demanding process temperatures."

Veeco's modular system architecture employs what Patrin calls "deposition zones," up to five each for the Mo and TCO films, and one to three for the CIGS, currently allowing the user to optimize its process and increase throughput for flexible webs up to 350mm wide, and scalable to a metre in width soon. He says total thickness variation for the sputtering and coevaporation sequences is better than ±5%, with TTV often seen down to ±3%. As for materials utilization of the 1.7μm- to

2μm-thick CIGS layers, he claims "results of better than 50%" using the thermal sources.

Patrin pointed out the possible pitfalls of processing flexible TFPV materials without proper metrology and control measures. "If you have a thousand-metre roll, you don't want to finish that roll and realize that your stoichiometry wasn't right, or there was some problem that you could have fixed right away if you had a thickness monitor or compositional measurement in situ. You can't run for a day and a half, and measure it and say, 'oh shoot!' That's a lot of material and a lot of cost that you could just throw in the garbage. There needs to be better in-situ metrology, so then they can maybe have longer rolls and higher uptime."

"It's an area that we'll be spending a lot of time on, since we think it's something really critical to bringing down the cost of solar, because it will help improve yields," he noted. In addition to the potential for using optical inspection tools to measure scribe widths and depths in a production setting, another process control application that Veeco is exploring is the "integration of XRF (x-ray fluorescence) capability into the system." He believes that this might be done "on a per-module basis, because then you can understand that the copper in a particular module needs to go higher or lower, that the rate wasn't sufficient or was too high."

The heat is on

Although BTU's Jack McCaffrey admits that several of his CIGS and CdTe customers are asking about in-line process controls, he believes it is "not a big concern yet." People are more likely to say, "get me capability and get me volume," with "get me quality" coming once the production lines are more mature, according to the VP of engineering and product development of the company's alternative energy group.

"People are more likely to say, 'get me capability and get me volume,' with 'get me quality' coming once the production lines are more mature."

BTU's bailiwick is providing high-quality belt furnaces, some notably customized, others more standard, for several process steps for the pair of II-VI compounds. Its cadmium chloride ($CdCl_2$) annealing tool for CdTe, which operates in the mid-400s°C, features tight uniformity and thermal controls specifications, with performance around ±2°C under steady-state conditions. The company's gas containment and atmospheric control also helps manage uniformity but more importantly features a barrier technology that keeps the nasty likes of cadmium contained.

"We're focusing in an area which isn't the crown jewels, it's really a middle step – CdTe's real crown jewels are laying down the cad telluride and cad sulfide," explained McCaffrey. "We're in an area where most people do it the same way, so it's about getting market share, and not that big a change from something we've already built. It's a real sweetspot for us."

As for CIGS, BTU does not work with any of the companies using thermal coevaporation but "plays best in the two-step/RTP process," where companies sputter, plate, or nanoprint the CIG absorbers in some fashion, and then need to "find a way to get selenium into the matrix to react" and activate those key layers, according to McCaffrey. "Some use hydrogen passivation just prior to the selenization step, some do not, but where they use it, we have a play and can deliver hydrogen either to a sheet of glass or a moving web, typically in the 400°C range."

"Selenization is probably the most crucial step in CIGS," he continues, "and the most common method used is solid-source selenium deposition, which we can

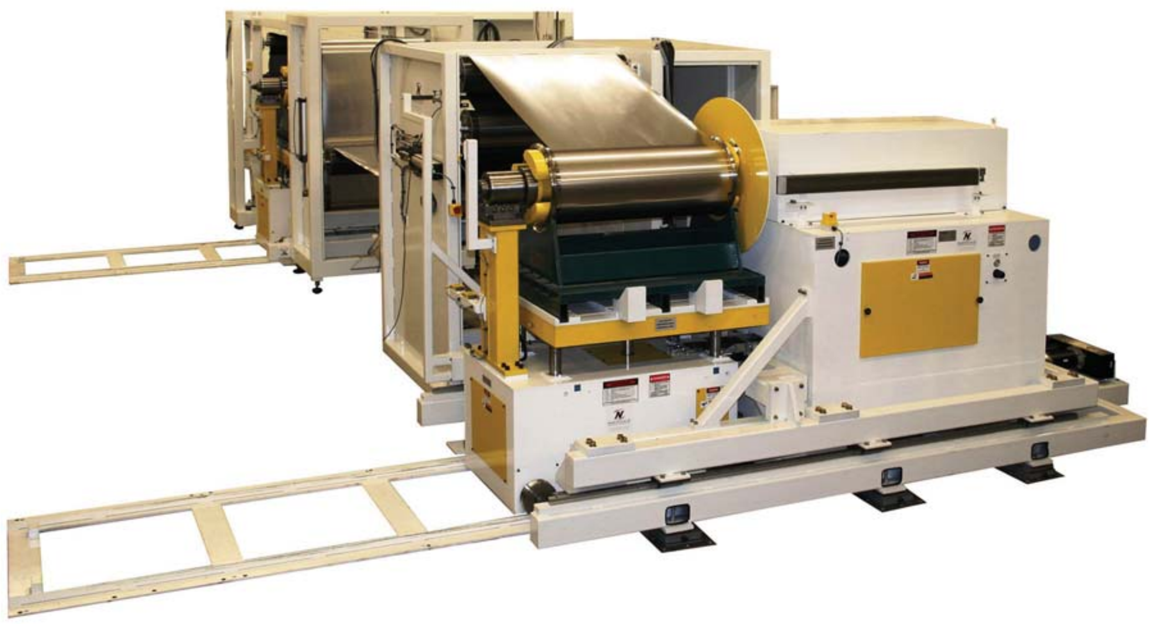

Figure 4. A 12,000lb (5455kg) heavy roll system developed for flexible thin-film PV applications by Northfield Automation.

deliver, with good temperature uniformity and control in the 500°-550°C range. For those who add sulphur in their zeal to get higher efficiencies, it's usually deployed in a similar way to how the selenium is, and we can provide a similar machine."

With some CIGS customers that boast "very fast front ends" asking first for 30-metre-long furnaces with 60MW capacities and now seeking something double that size or more, and flexible webs widening to a metre across and more than one web possibly running through the tool, BTU's vaunted thermal uniformity is being put to the test. To deal with this trend, McCaffrey said the company has a "configurator project" with an objective of "working on standard heater designs and the like so we can really work out a scheme where we'll be able to model that quickly and cut down on some of the engineering lead time that we need to do to (design and build) a longer, wider system."

Web automation situation

One company thoroughly versed in the vagaries and nuances of advanced thin-film roll-to-roll web processing is Northfield Automation, which works with customers in the flexible display, battery, and microdevice sectors as well as with photovoltaics players. The firm recently partnered with Solarcoating Machinery, a German company also expert in the realm of flexible TFPV process and equipment, especially coating and deposition.

Helping new customers understand that flex TFPV processing is not just "unrolling and rolling the web" is a "big battle," according to Mark Wegner, Executive VP of Northfield. "As an equipment manufacturer providing the automation, you're working with them and educating them" about issues such as "thermal cycling over a lifetime" and the challenges of transitioning "from a benchop sheet process to production-scale R2R manufacturing."

> "Helping new customers understand that flex TFPV processing is not just 'unrolling and rolling the web' is a 'big battle.'"

"As you're working with each layer and building that stack up," he said, "it's about the tolerances of what you're trying to hold with each of those layers and matching them up. You're dealing with adhesives, coating and thickness, all those variables – the overall tolerance of that package as it's completed needs to be very tightly controlled.

"You're dealing with plastics expanding as you're curing on a particular web, and the thermal properties that you're getting from the plastic, but then you're doing an additive process in a state where it's not truly stabilized. How do you achieve that end window you're looking for, when you've already burned up three-quarters of that window of tolerance with the previous processes?"

Another nagging issue is the quality of the web material itself (with certain polymers said to vary ±10% across the width of the film) and the impact it has on processing quality and efficiency, Wegner believes. "The incoming material has to have certain characteristics and tolerances that are maintained. Otherwise, if you want a manufacturing tool that does this process, you need to have vision registration and capabilities because the stresses and changes to that material must be compensated for. If you have to localize registration and do that on a wider web, it creates more capital cost and slower throughputs."

The customer speaks

Although the equipment vendors pursuing CdTe and CIGS contracts are winning an increasing amount of business and seeing a few early signs of standardization, some basic customer wish-list items have nothing to do with a system's capabilities or reliability and reveal that tool suppliers still have some improvements to make in their own operations.

Bret Adams, Senior Director of sales and marketing of CIGS start-up DayStar Technologies, said his company takes a "commodity approach" toward equipment, except for the IP embedded in its critical absorber-layer processing system. When asked in what areas OEMs needed to improve, he didn't hesitate. "First and foremost, tool vendors have lead times that are too long. Sometimes their lead times take them out of consideration; in some cases, we can design things faster than the tool guys."

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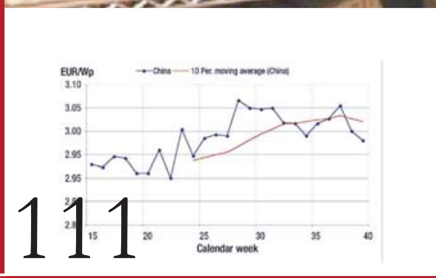

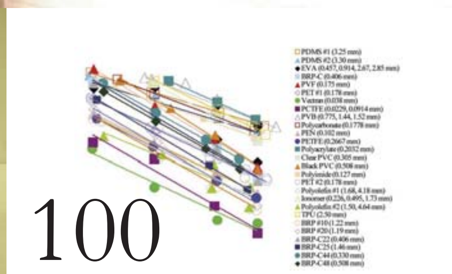

SANYO more than doubles module production at Monterrey site

SANYO Electric Co., Ltd. has announced the more than twofold increase in production of PV modules at its Mexico Monterrey site. Current output capacity for the site is 20MW annually, a figure that is expected to reach 50MW following the planned production capacity increase. The company's aim is to more than double the company's overall output from 260MW to 600MW by end of FY 2010. Operations are scheduled to start from December, reaching full capacity within this fiscal year.

The company also announced its intention to build a new ingot and wafer production plant in Salem, Oregon in response to increased demand. Combined with the company's existing plant in Carson, California, total output is expected to reach approximately 100MW.

Module Production News Focus

Spire wins new business in India

The module manufacturing arm of GreenBrilliance, GreenBrilliance Energy Private, Ltd, based in India, has placed a turnkey solar module manufacturing line order with Spire Corporation. The semi-automated crystalline module manufacturing line is to be capable of producing up to 12MW of solar modules per year. The new module line will be designed to be easily expandable will integrate Spire's assembly, lamination, and testing machines, along with intermediate tooling stations.

Trina Solar reaches 70 percent 2009 MW production target in secured sales

Trina Solar has secured the sale of 70 percent of its targeted 450MW production levels for 2009, with approximately 40 percent of the target secured at predetermined prices. The 70 percent figure was reached with the signing of a new contract with Invictus NV, which will see the company purchase 20MW in 2009 and 30MW in 2010. The deal includes an option for an extra 10MW per annum.

Quantum Fuel, Asola to partner with Q&Tech to build South Korean solar module factory

Quantum Fuel Systems Technologies and its German solar photovoltaic partner, Asola, have signed a memorandum of understanding with Korean partner Q&Tech to establish a joint-venture solar-module manufacturing plant in South Korea. The companies say the initial module-making capacity of the fab will be 30MWp, with a potential to generate annual revenues of more than US$100 million.

The manufacturing facility in Korea will use equipment, processes and quality controls that are identical to Asola's recently expanded state-of-the-art 45MW facility in Germany. The modules, both mono- and multicrystalline, will be designed in Germany, with the silicon solar cells expected to be centrally purchased in Germany, to benefit from economies of scale, according to the partners.

Quantum and Asola have also entered into a long-term supply agreement with ersol Solar Energy for the procurement of 155MW of high-efficiency silicon cells, starting in 2008, as well as supply deals with Sunergy, Motech and other manufacturers. The partners anticipate that resulting sales from these supply agreements will generate more than US$600 million for Asola and Quantum.

Advent Solar secures long-term solar cell supply deal with Deutsche Solar

Advent Solar has placed a long-term solar cell supply contract with Deutsche Solar worth more than US$350 million through 2018 to assist in Advent's PV module expansion plans. Deutsche Solar will supply SolarWorld SOLSIX wafers, the company said.

"Advent Solar 'Ventura' Technology is designed to increase efficiencies at every stage of development, from cell design to manufacturing and production, and wafers are a critical component of this approach," said Peter Green, President and CEO of Advent Solar.

Advent Solar Ventura Technology provides a system-level design approach by combining Emitter-Wrap Through (EWT) back-contact cells with semiconductor device manufacturing methods to create a highly scalable platform for module manufacturing.

"The SOLSIX wafers have shown excellent results during initial testing with our high-performance solar modules," said Martin Hermann, Advent Solar's Chief Strategy Officer, who is responsible for the company's sourcing strategy.

Module Sales News Focus

Yingli Green Energy to provide 1.5MW of PV modules to China Mobile

Yingli Green Energy Holding Company Limited publicized that its principal operating subsidiary in China, Baoding Tianwei Yingli New Energy Resources Co., will begin to distribute roughly 1.5MW of photovoltaic modules to China Mobile Communications Corporation, the biggest mobile phone operator in China.

Their bid made up over 31 percent of China Mobile's recent photovoltaic module gain.

ET Solar Group modules.

ET Solar Group Corporation and Helios team up on 15MW module sales

ET Solar Group Corporation and Helios Technology, an Italian manufacturer of photovoltaic cells, photovoltaic modules, inverters and charge regulators, recently announced plans for a contract on 15MW module sales. The contract will run from October 2008 through March 2009, wherein those six months ET Solar will ship a total of 15MW modules to Helios.

Canadian Solar to supply 28MW of modules to German installers in 2009

Iliotec Solar GmbH and Iliotec Solar International have signed PV module contracts with Canadian Solar that equate to 28MW through 2009 with an option for a further 20MW. The module prices will only be fixed for the first six months, the PV manufacturer said.

Canadian Solar said that customers have noted that solar project financing was still available, despite the credit crunch now impacting Europe and the U.S. The company also expects the U.S. market to be strong in 2009 after the renewal of ITC incentives.


A Perfect Fit.
komax xcell 3400

EN-NEO exercises extra 9MW of modules from Yingli Green Energy for 2009

German PV installer EN-NEO has exercised an option for an additional 9MW of modules for 2009 with Yingli Green Energy for installations in Germany during 2009. Under the original deal, Yingli Green Energy agreed to supply 9.19MW of PV modules to EN-NEO from October 2008 to December 2008. The new deal will see the extra 9MW supply of modules delivered between February and April 2009.

News

Yingli enters two modules supply agreements with GeckoLogic and Sinosol

In two supply agreements totalling 58MW, Yingli Green Energy has signed contracts with German PV companies GeckoLogic GmbH and Sinosol AG. GeckoLogic has ordered 28MW of modules, with an option to order an additional 7MW, while Sinosol will be supplied with 30MW.

Yingli will supply the 28MW GeckoLogic from January 2009 to December 2009, while the option of the extra 7MW of modules is available for 2009. The modules from this contract are most likely to be installed in PV projects in Germany and other European countries. The delivery details of the 30MW Sinosol contract will be finalised in November 2008.

Italian installer buys 5.5MW from aleo solar

aleo solar AG continues to expand its business in Italy by signing two supply contracts for a total of 5.5MW with Italian project developer ERIC Group S.p.a. Of this total, 500 kiloWatts will be delivered this year, with the remaining 5,000 kiloWatts to follow in 2009.

Italian feed-in laws provide operators of photovoltaic systems with a strong market. This announcement from aleo comes soon after Chinese manufacturer Trina announced significant new orders in the Italian market for 2009.

Polycrystalline module from aleo solar.

SolarPower Restoration Systems signs three-year module supply agreement with SBM Solar

SolarPower Restoration Systems, Inc., the BIPV technology company, has announced that it has signed a non-binding letter of intent with SBM Solar, Inc. for the supply of a minimum of 10MW of solar modules per year for the three years commencing 2009. The modules will incorporate SBM's new polymer surfaced composite panel crystalline module design.

This cooperative agreement is a result of the strategic alliance formed earlier in the year by the two companies with the aim of working together for the development of highly efficient and low cost non-glass, polymer surfaced crystalline PV solar modules for use in the BIPV market.

Schott Solar scores another PV module deal in U.S.

Schott Solar said it has signed a multiyear contract with AEE Solar to supply the company with more than 5MW of multicrystalline photovoltaic modules. The deal marks the third U.S. supply contract announced by Schott in less than a month, following agreements with PermaCity Solar and DC Power. The latest contract brings the total amount of modules to be supplied by Schott under terms of the deals to more than 28MW.

Yingli Green Energy to supply Spanish PV integrator with 16MW of modules in 2009

Fire Energy, S.L. ("Fire Energy"), a Spanish PV system integrator and PV devices distributor is to be supplied 16MW of PV modules by Yingli Green Energy in 2009, according to a new supply contract signed between the two companies. This is the second contract both companies have entered into.

Advent Solar signs 250MW of distribution deals in Europe

Enerpoint, MHH Solartechnik and SunConnex have agreed to purchase and distribute Advent Solar's 'Ventura' solar modules in Europe to the tune of 250MW through 2013. The 'Ventura' technology from Advent was announced at the 2008 European Union Photovoltaic Solar Energy Conference, in Valencia, Spain. The Ventura Solar Technology from Advent Solar is said to combine Emitter-Wrap Through (EWT) back-contact cells with semiconductor device manufacturing methods, deliver high energy output by optimizing silicon light capture, and dramatically improving cell and module-level connectivity to minimize resistive losses, while using thinner silicon wafers to reduce costs.

Schott to supply solar modules to DC Power Systems

Schott Solar, Inc. has signed an agreement with DC Power Systems to supply more than 13 megawatts of photovoltaic modules for distribution in the Americas. California-based DC Power is the largest privately held distributor of renewable energy solutions in the Western Hemisphere. The company works through a network of more than 1,500 qualified dealers and installers to provide photovoltaic systems for commercial, residential and municipal applications in North and South America, said DC Executive Vice President Daniel Marino in a news release.

Module Testing and Certification News Focus

Underwriters Laboratories expands its Photovoltaic Technology Center of Excellence

Underwriters Laboratories (UL) announced its intent to begin expansion immediately of its Photovoltaic Technology Center of Excellence. This is North America's biggest photovoltaic testing and certification facility, which happens to be located in Silicon Valley, CA. The announcement comes only four months after the facility's grand opening in order to meet the increasing demand for solar innovation, testing and certification. UL is the only accredited National Certification Body for PV product testing in North America.

Underwriters Laboratories will add 13,550 square feet to their facility so that they can provide 35 percent more space to UL's current photovoltaic testing operations. The expansion will also include a 31 percent year-over-year increase in project capacity. It will house six more test chambers, bringing the grand total to 20, and include another solar simulation room. An added incentive of the expansion will be the creation of new jobs in order to supply the demand for the increase in technical positions.

TÜV Rheinland joins forces with ASU to form advanced testing and certification facility

TÜV Rheinland Group has entered into a private venture with Arizona State University (ASU) to offer a state-of-the-art testing and certification facility for solar energy equipment. The new venture, entitled TÜV Rheinland PTL, LLC, will be based in Tempe, Arizona and will see the extension of the ASU PTL's testing and certification capabilities, as well as adding the capacity to test and certify PV panels and electrical components for Europe, Asia and North America.

The combination of knowledge and experience of both TÜV and ASU PTL in one facility is good news for the PV industry, as it provides a more accessible, global knowledge base for testing and certification of the equipment used on a daily basis in the industry. ASU PTL has been the only lab in the U.S. accredited for PV design qualification and type approval since its establishment in 1992.

As the main investor in the project, TÜV Rheinland will develop a new facility near ASU's Tempe campus, which will be fitted with the latest testing technology equipment. TÜV Rheinland PTL, LLC will also provide five acres of outdoor


TÜV engineer performing module test.

testing space via its collaboration with Arizona's largest electric provider, Arizona Public Service (APS). The testing space will be located at APS's Solar Test and Research (STAR) Center.

California Energy Commission approves SolFocus CPV panels

SolFocus says that its SF-1000P concentrator photovoltaic panels have met the rigorous reliability and safety standards of the California Energy Commission and been approved by the CEC to be placed on the Eligible California Solar Initiative (CSI) Photovoltaic Modules Renewables Equipment List. The move makes the company the first CPV manufacturer to be listed by the commission and thus eligible for state incentives.

SolFocus' panels, which employ a system of imaging and nonimaging reflective optics to achieve 500X magnification of sunlight onto high-efficiency solar cells, have been integrated with a tracking system and are being deployed at the world's first full-scale CPV power plant at the Institute of Concentration Photovoltaic Systems (ISFOC) in Spain.

VDE and Fraunhofer ISE open new PV module test centre

The VDE Institute and the Fraunhofer Institute for Solar Energy Systems ISE have opened a new PV module testing and certification centre, the VDE-Fraunhofer ISE Test Centre for Photovoltaics (TZPV). The facility will also be used to develop further standards. Fraunhofer ISE is in charge of the relevant performance tests, whereas the VDE Institute is responsible for safety testing and certification according to widely used standards and testing principles.

Testing complies with the type approval requirements specified in IEC and European standards IEC EN 61215 for modules made of crystalline silicon solar cells and IEC EN 61646 for thin-film modules, and safety requirements according to IEC EN 61730-1/2.

Other News

CTDC begins commercial production of tin-oxide baseplates for a-Si solar PV modules

China Technology Development Group (CTDC) has begun commercial production of tin-oxide (SnO_2) solar baseplates, a transparent conductive oxide substrate used as a top electrode for amorphous-silicon thin-film photovoltaic solar cells and modules.

The company's first volume manufacturing line, located in the China Merchants Zhangzhou Development Zone near Xiamen, China, will have an annual run rate of 70,000–80,000 plates when it reaches full capacity. CTDC says it expects to expand its capacity to the equivalent of approximately 20-30MW by 2009.

Hong Kong-based CTDC entered the solar energy sector in September 2007. The company began testing its products in May 2008 at its R&D pilot-line facility in Jiangsu, China, and shipped its first batch of SnO_2 baseplates to China Stream Fund Solar in June.

NanoGram partners with OTB on inkjet printing and other specific processes

In an effort to bring to market NanoGram Corporation's 'SilFoil' technology, the firm has partnered with OTB Group BV, based in Eindhoven, The Netherlands, in relation to its proprietary inkjet printing and laser technologies.

A PV module pilot line is currently under construction in Milpitas, California by NanoGram and is expected to be commissioned in Q2 2009.

Flow simulation software cools Sheuco modules

Schueco announced that it has been working with UK company Flomerics' Flovent computational fluid dynamics (CFD) software to redesign its products to improve their thermal performance so that 15 to 20 percent more modules can be used in a given space. Today's photovoltaic panels present a major thermal design challenge since every degree Centigrade of temperature rise reduces the power produced by 0.5 percent.

Flovent simulates the absorption and reflection of solar energy by the panels, the transfer of heat to aluminum profiles and the surrounding air.

"Examining the flow of air under the photovoltaic panels showed that the size of the passageway was constricting the flow of air," said Hamid Batoul, Technical Director of Solar Department, Schueco International, Paris, France. "We increased the depth of the profile that supports the photovoltaic panels to increase the distance between the panels and the roof. Re-running the simulation demonstrated that this increased the airflow and reduced the temperature of the photovoltaic panels.

Through these studies, we optimized the design of the solar energy systems and also gained an understanding of how temperature is affected by different arrangements of panels and ambient conditions."

Bürkle garners €5 million in new orders from EU PVSEC event in Valencia

Robert Bürkle GmbH has said that it received orders worth €5 million from the 23rd EU Photovoltaic Fair and Conference held in Valencia at the beginning of September. Two new multi-opening, high throughput 'Ypsator' laminators were included in the order take, the company said. By the end of the year, Bürkle said it expects to ship eleven Ypsators, with a planned sales target of €25 million.

BP Solar to close PV module plant in Australia

BP Solar's 50MW photovoltaic cell and module manufacturing plant in Sydney Olympic Park, Australia will close at the end of March 2009, as the company will focus production at larger-scale facilities in other parts of the world. Approximately 200 jobs will be affected by the closure, but BP Solar said it would continue to market and sell its solar systems in the country.

Reyad Fezzani, CEO of BP Solar, commented, "We've looked at all options in our Sydney manufacturing site and the physical location, lack of expansion potential and lease agreements just don't make it competitive: the most modern Solar PV manufacturing plants are up to twenty times larger than our Sydney site and we are competing in this global market." Fezzani also said that the solar market had become increasingly competitive as well as the challenges of the current economic climate. He reiterated that BP continues to invest around US$1.5 billion in alternative energy and low carbon energy businesses annually. BP Solar has been operating in Australia for more than 20 years.

Product Briefings

Pasan SA

Pasan SA's new electronic load enables higher accuracy in testing of solar cells and modules

Product Briefing Outline: Pasan SA has introduced a new electronic load that is more accurate and offers several additional features for the testing of solar cells and modules. This electronic load not only is fitted to module and cell flashers, but can also be combined with continuous light sources. Furthermore, the equipment is suitable for outdoor testing.

Problem: Testing of modules and cells demand higher accuracy and an increasing number of features. This influences the light source as well as the electronic load. Furthermore the line integration and interfacing with control and quality management systems become more and more important.

Solution: First of all, the system acquires and processes data much faster than before. It also provides a higher D/A and A/D resolution of 16 bits instead of 12 bits. The maximum current is increased to 50A in order to enable testing of large panels. For each channel a deviation of +/- 0.1% at 25°C is guaranteed instead of formerly +/- 0.2%. The start of measurement is programmable from the starting point of flash. The new electronic load can also provide up to two different irradiance levels during one flash. By that, series resistance (Rs) on modules can be determined according to IEC standard in one single flash. The new electronic load will be introduced by stages in all Pasan module and cell testers. It also will be available as a stand-alone unit.

Applications: Module and cell flashers, continuous light sources, outdoor applications.

Platform: All Pasan equipments are based on xenon single-flash technology, giving closest approach to spectral irradiance of sun, with negligible heating of module or cell to be tested. The new electronic load will be introduced in stages in all Pasan module and cell testers. It also will be available as a stand alone unit.

Availability: April 2009 onwards.

Reis Robotics

Reis Robotics develops fully automatic laser soldering procedure

Product Briefing Outline: Reis Robotics has now implemented a newly developed laser soldering procedure for practical use with several customers. Photovoltaics manufacturers are increasingly anxious to fully exploit the automation potential of their production capacity in order to deal with the increasing demands for lower prices. Reis Robotics, a system supplier with its subsidiary Reis Lasertec, a laser welding specialist, have combined skill sets to deliver a laser soldering method for higher quality, shortened cycle times and reductions in manual rework.

Problem: Increasing the efficiency of solar cells and solar modules, increasing production throughput and yield and reducing costs requires greater dependence on fully automated and integrated solar cell soldering techniques. In the use of laser-beam soldering and selected solders, the joining temperature can be reduced to a minimum, the solar cells are not subjected to mechanical strain, compared with conventionally used bowtype electrodes.

Solution: A newly developed laser soldering method ensures further increases in quality, shortened cycle times and reductions in manual rework. An integral process controller monitors and documents the production process. In doing this, it is possible to concentrate the heat input such that soldering can be done directly on the EVA foil. With direct soldering on the foil, unnecessary multiple handling of the strings during the pre-process is avoided.

Applications: Fully automated solar cell soldering.

Platform: In one station, two Reis robots perform the soldering. In a separate station, two further robots automatically lay out the interconnection terminal lugs. The lugs are fed directly from a reel using a specially developed system and presented in the correct position for the robot to pick up.

Availability: Currently available.

OCS Energy

OCS Energy launches automated solar panel cleaning system

Product Briefing Outline: OCS Energy has introduced the 'SolarWash' automated photovoltaic panel cleaning system. The system attaches directly to an array of PV panels and is controlled by a microprocessor, providing PV system operators a turnkey cleaning solution without having to manually wash each panel.

Problem: Solar PV is often hyped as requiring virtually no maintenance when, in fact, PV installations need regular cleanings to maintain optimal performance. The accumulation of dirt on solar panels has a significant, detrimental impact, on the performance of solar power systems. Dirt, however, is only part of the problem. PV system operators must also compete with the build-up of dust, tree debris, moss, sap, bugs, bird droppings, water spots, mold and more. To date, most PV systems are cleaned by maintenance personnel of the PV system owner or outsourced to a maintenance/cleaning company. However, allowing employees or an untrained third-party to manually wash an energized high voltage electrical system without following electrical industry standards, puts many owners at risk.

Solution: The patent pending SolarWash system provides a complete solar cleaning solution including maintenance-free nozzles, a web-based interface and a programmable logic controller (PLC). The end-to-end solution allows operators of large PV systems to effectively manage their resources, initiating the washing of panels without the need to schedule a maintenance crew.

Applications: All panel arrays (excluding CPV).

Platform: Unique fanning nozzles secured to the array of panels. Comes with tubing that connect the nozzles to draw water from the most sensible source. Patent pending microprocessor controller cleans only as necessary. Complete system design, engineering, installation and maintenance.

Availability: November 2008 onwards.

Product Briefings

Scapa

Scapa offers specialist product range for solar module framing

Product Briefing Outline: Scapa, a manufacturer of technical, self-adhesive tapes, has launched a range of products for the photovoltaic module manufacturing industry. The high-performance technical products are used in a number of applications including bonding/sealing aluminium framed modules, permanent bonding of the junction box, laminate fabrication, cell positioning and cable management. Scapa offers a wide range of double-sided adhesive coated polyethylene (PE), polyurethane (PUR) and acrylic foams (AFT) that meet specific industry standards and requirements.

Problem: In today's marketplace, there is a need to identify suitable alternative materials that meet the current manufacturing requirements and have the capability to meet the demands of state-of-the-art automated production equipment.

Solution: Scapa's range of double-sided bonding and sealing products for PV module framing include acrylic adhesive systems that offer resistance to moisture and extreme environmental conditions and exhibit excellent Ultra Violet (UV) Light resistance. The adhesives often improve if further UV exposure occurs. The anticipated life expectancy of the Scapa foam products is in excess of 25 years. Utilizing pressure-sensitive adhesives with their initial tack enables the modules to be fabricated and immediately transported without waiting for the adhesive/sealant to cure or dry, thereby improving production flow. The adhesive mounting tapes may be supplied in roll, spool wound and die cut formats, to suit both manual and automated applications.

Applications: Module aluminium frame bonding and sealing.

Platform: Scapa offers a selection of double-sided closed cell foam tapes that will form effective bonding between PV panels and the framing material as an effective seal to both water and moisture ingress.

Availability: Contact the company for information.

Advent Solar

'Ventura' technology from Advent Solar enables multiple cell type usage

Product Briefing Outline: Advent Solar has introduced what it claims to be the solar industry's first cell-to-module solar architecture – 'Ventura Technology.' Ventura Technology provides a platform-level design by combining Emitter-Wrap Through (EWT) back-contact cells with semiconductor device manufacturing methods to create a highly scalable platform for module manufacturing. The architecture provides higher cell-to-module efficiency, while using thinner silicon wafers to reduce costs.

Problem: Conventional photovoltaic manufacturing has nearly exhausted its resources in improving efficiency, cost and reliability, and creative design and technology approaches are needed to make photovoltaic-based solutions a viable and reliable energy alternative.

Solution: By eliminating the front grid, more sunlight becomes available for electrical conversion. EWT provides higher light capture and efficient distribution of energy to the backside contacts. The Ventura architecture combines the EWT back contact cell design with Monolithic Module Assembly (MMA) to deliver a scalable, high output module platform. MMA enables fully automated module assembly, applying proven, high volume, high precision semiconductor-style manufacturing techniques. Using robotic "pick and place" methods, each cell is perfectly arranged onto a monolithic integrated circuit backsheet. Novel bonding techniques form low resistance electrical contacts between the cells and monolithic circuit.

Applications: Designed with building integrated photovoltaic (BIPV) market needs in mind, they feature perfectly aligned, clean, blue silicon squares that customers are proud to showcase.

Platform: The Ventura architecture is versatile enough to accommodate different silicon types: Multi-crystalline, mono-crystalline and Upgraded Metallurgical Silicon (UMG) and scalable in scope to increase value with system level features.

Availability: September 2008 onwards.

Swiss Solar Systems AG

3S XL Laminating Line handles high volume production with 40% cycle-time reduction

Product Briefing Outline: The new 3S Swiss Solar Systems AG XL Laminating Line is designed to provide a fully automated high volume lamination process of solar modules at highest-speed: cycle times can be reduced up to 40%, according to the company. The system has a total capacity of up to 34 modules per hour, which equals an annual capacity of up to 60MWp. It combines two vacuum chambers with the patented hybrid heating plate of the 3S Laminator S3622 with a cooling press. The two vacuum chambers are separately controlled in terms of evacuation, ventilation and heating. The system can handle both c-Si and thin film sizes.

Problem: Lamination is the process that moulds the sandwich of the different photovoltaic-module (PV-module) materials with adhesive foils (encapsulation material) together under heat and pressure-to get it sealed. Conventional heating elements such create a wide range of temperature differences and hot spots that result in inconsistent sealing. High volume applications require greater levels of temperature homogeneity with maximum temperature difference on the heating plate: absolute 2°C.

Solution: The patented Hybrid Heating Plate of 3S Swiss Solar Systems combines the advantages of both electrical and oil heating techniques that generates higher temperature homogeneity, boosting yields and throughput. The heating system has 40 electrical rod elements with 2kW each. Heat carrier oil transmits the heat from the rod elements to the heating plate at high speed allowing very short heating times, however it retains maximum temperature difference of 2°C absolute. After lamination the cooling press permits controlled cooling of the modules. 3S technology shortens the time between lamination and post processing, as well as it reduces interior stress in the module.

Applications: Most common c-Si and thin film module sizes.

Platform: Heating plate with a size of 3.6 to 2.2 meters. Output range up to 60MW.

Availability: Currently available.

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Design criteria for photovoltaic back-sheet and front-sheet materials

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ABSTRACT
The back-sheet materials for photovoltaic (PV) modules serve several purposes such as providing electrical insulation, environmental protection, and structural support. These functions are essential for a module to be safe for people working near them and for the structures they are attached to. To ensure that all modules meet a minimum set of requirement, they must pass qualifications tests such as IEC 61646, 61215, 61730, and 62108 [1,2,3,4,5].

Introduction

For PV modules, ethylene vinyl-acetate (EVA) is the dominant encapsulant not because it has the best properties possible, but because it is a very economical solution [6]. Other materials, such as silicones have better light transmission and UV stability but the improved properties come at a premium. However, EVA by itself does not provide adequate electrical insulation and scratch resistance, Table 1. Because of this, a layer of polyethylene terephthalate (PET) is typically added as a good dielectric and a mechanical barrier. Most PET films are not resistant to UV radiation [7] and must be further protected as is typically accomplished through the use of a layer of poly vinyl fluoride (PVF, or Tedlar®).

For crystalline silicon modules, this trilayer back-sheet laminate of EVA/PET/PVF dominates the industry. Much of this is historical in origin and dates back to work performed at the Jet Propulsion Laboratory (JPL) in the 80s [8,9]. Modules constructed with EVA/PET/PVF back-sheets have demonstrated stability for such a long period of time that it is expected that they are capable of producing significant energy for much longer than 20 years [10].

Fluoropolymer are known to be very UV stable and chemically resistant, but in many ways much more stable than is necessary for PV modules. Unfortunately it is very difficult to get good adhesion of fluoropolymers to other materials. They are also relatively expensive despite the fact that they are used as very thin films (~0.025 mm). Because of this (and supply limitations) there is an opportunity for other materials to enter the market that are less expensive and not so over engineered.

Alternatives

One alternative is to replace all three layers (EVA/PET/PVF) with a single encapsulant. To do so requires an electrically insulative material that is tough, scratch resistant and can maintain good adhesion to module components. One material that shows promise in these respects is ethylene propylene M-class monomer (EPDM) [11]. It is commonly used as wire insulation, roofing material, radiator hoses, and gaskets. This material is still in the experimental stage but because it would replace both the encapsulant and the back-sheet materials, it may provide a cost savings of around US\$6.00/m^2 as compared to typical back-sheet laminates.

Other PVF replacement materials that have already passed the PV qualification tests and achieved significant market penetration are stabilized PET formulations [7]. They are designed to replace both the PET and PVF films. Stabilization is obtained principally through the addition of UV absorbers, UV stabilizers, or inorganic fillers (carbon black, $BaSO_4$, or TiO_2) which can be used to obtain the desired color. Stabilized PET materials can save between US\$3 and US\$5/m^2 depending on the application. This material eliminates the problems associated with adhesion of PET to PVF but still has the more easily managed adhesion of PET to EVA. The cost savings of these alternatives in addition to the supply issues with PVF, provide a strong incentive to change typical manufacturing materials for crystalline silicon modules.

Thin film module requirements

For thin film PV materials there is a much greater concern over moisture ingress. This is especially true of CdTe and Cu(In,Ga)Se (CIGS) technologies but not so much for thin film silicon technologies. Semi-hermetic packages are commonly constructed for CdTe and CIGS based thin film PV through the use of glass front-sheets, aluminum or glass back-sheets, in conjunction with desiccant filled butyl rubber edge seals around the perimeter. However for CIGS materials constructed on metal foils there is a desire to use flexible front- and back-sheet materials to make building integrated products more cost effective and easier to install. For the front-sheet, this presents a unique set of challenges to design a material that is a flexible moisture barrier and still able to transmit light.

The first consideration for such a barrier is how low the water vapor transmission rate (WVTR) must be. If an initially dry module

Back-Sheet Construction	Backsheet Thickness (mm)	Time (hr)	Resistance	Time (hr)	Resistance	Time (hr)	Resistance
EVA	0.5	0	1 MΩ	504	Failed	1032	Failed
EVA/TPE	0.69	0	6.6 GΩ	504	8.5 GΩ	1032	9.1 GΩ
EPDM-C40	0.33	0	8.14 GΩ	528	9.046 GΩ	1824	>10 GΩ
EPDM-C32	0.33	0	8.63 GΩ	192	8.5 GΩ	1488	>10 GΩ

Table 1. Wet High Pot Test: According to IEC 61215 and 61646, after 1000 h of exposure to 85°C/85% RH modules must be immersed in a surfactant containing bath with an applied voltage of 500V and the measured resistance to the bath must be greater than 40MΩ·m^2. To do this test, 0.85 mm thick, 12.7 cm square steel plates were laminated and tested to model a cell. In this configuration, the resistance must be greater than 2.48GΩ to pass. All samples used EVA between the Steel and a piece of glass while the back-sheet was varied. Glass is 2.26 mm, EVA has a nominal 0.46 mm thickness per sheet. "Failed" indicates the ohm meter could not reach 500 V because of high current. >10GW indicates the current was too low to measure.


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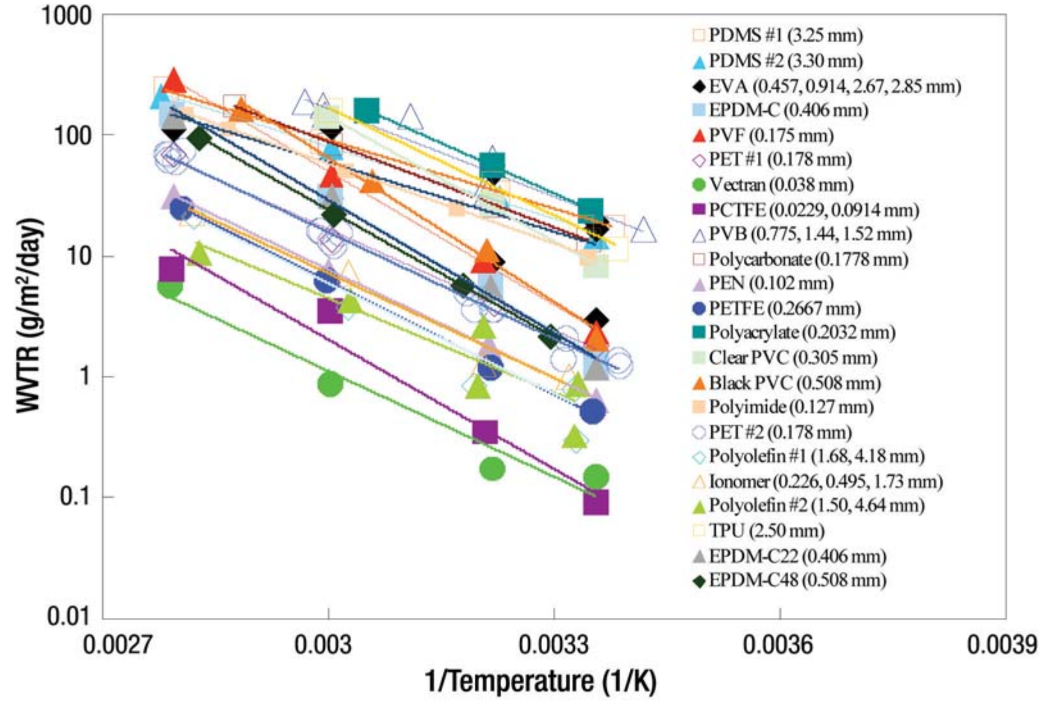

Figure 1. Steady state water vapor transmission rate (WVTR) for various polymeric materials. Polydimethylsiloxane (PDMS), Ethylene Vinyl Acetate (EVA), experimental Ethylene Propylene Diene M-Class Polymers (EPDM), Polyvinylfluoride (PVF), Polyethylene Terepthalate (PET), Poly chloro trifluoro ethylene (PCTFE), Poly vinyl butral (PVB), Poly Ethylene Napthalate (PEN), Polyvinylchloride (PVC), and Thermoplastic Polyurethane (TPU). These measurements were made using a Mocon Permatran-W® 3/31 instrument.

with a moisture permeable front-sheet (or back-sheet) was exposed to constant environmental conditions then the transient water vapor concentration [$C(t)$] in the encapsulant just on the inside of the vapor barrier can be approximated as [12];

$$\frac{C(t)}{C(0)} = 1 - e^{-\frac{WVTR_{B,Sat}\,t}{C_{Sat,E}\,l_E}} \quad (1)$$

Here t is the exposure time $WVTR_{B,Sat}$ is the maximum WVTR for the case with liquid water on one side and dry air on the other side of the back-sheet material, $C_{Sat,E}$ is the concentration of water in the encapsulant at saturation, and l_E is the encapsulant thickness. This yields a half-time for equilibration of [13].

$$\tau_{1/2} = 0.693\,\frac{C_{Sat,E}\,l_E}{WVTR_{B,Sat}} \quad (2)$$

As an example, a module consisting of a back-sheet with a WVTR of 1.13 g/m^2/day at 25°C (e.g., PVF/PET/EVA) laminated to a 0.46-mm-thick layer of EVA (C_{Sat}=0.0021 g/cm^3 at 25°C)

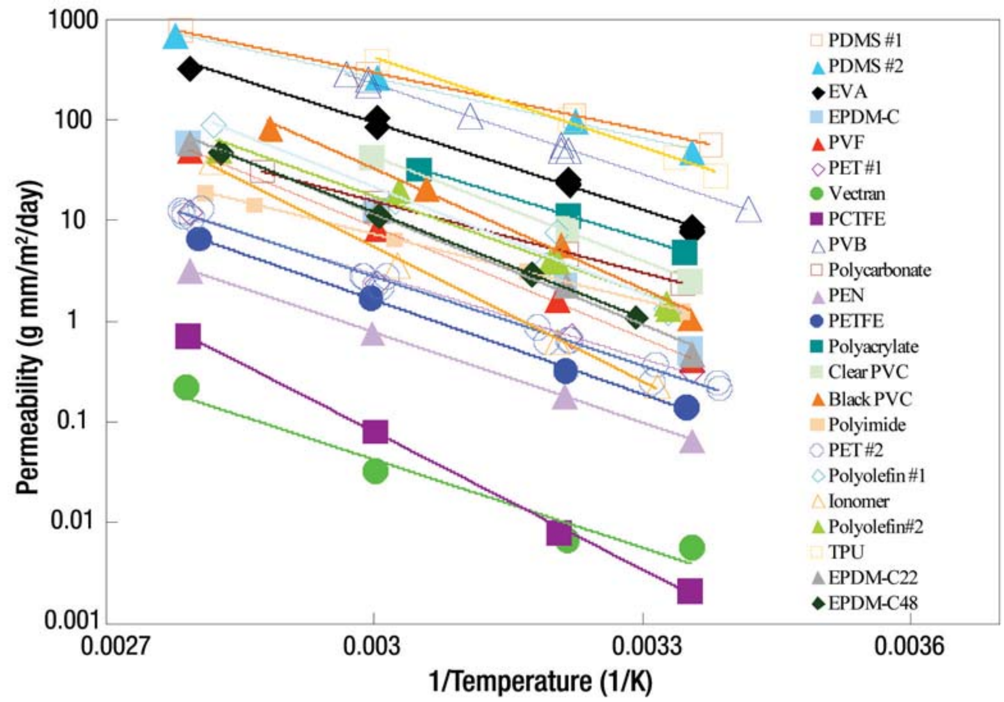

Figure 2. Permeability of various polymeric materials considered for use in PV applications. (Same definitions as in Figure 1).

would have an equilibration half-time of 14 hours. For a front-sheet to have an equilibration half-time on the order of 20 years, it would need a WVTR of about $1 \cdot 10^{-4}$ (g/m^2/day). This value should be thought of as a minimum WVTR that will just begin to make a difference for the moisture content of a PV package over the 20 year lifetime of a module. To really keep a module dry, values in the $1 \cdot 10^{-5}$ (g/m^2/day) to $1 \cdot 10^{-6}$ (g/m^2/day) must be obtained [12].

The WVTR for a number of potential PV packaging materials was measured, (Figure 1). Because the WVTR is dependent on the thickness of the film, it is useful to consider the permeability (P=WVTR·thickness), (Figure 2). In this data set, the lowest permeability materials were the liquid crystal polymer Vectran and poly chloro trifluoro ethylene (PCTFE) with permeabilities around $5 \cdot 10^{-2}$ (g·mm/m^2/day). To achieve a WVTR of $1 \cdot 10^{-4}$ (g/m^2/day) a thickness of 50 cm would be required.

This 50 cm estimate neglects transient effects but indicates the inability of simple polymeric materials to significantly reduce the exposure to moisture. Modules with polymer front- or back-sheets will quickly equilibrate with the environment. Using materials with lower permeation rates will only serve to reduce the time a module is exposed to conditions of supersaturation of moisture [12].

Oxide barriers with extremely low permeation rates are necessary to achieve a low WVTR [14] to prevent moisture ingress. In these systems, the WVTR of $1 \cdot 10^{-4}$ (g/m^2/day) is about 2 orders of magnitude lower than what would be practically achieved by a polymeric only barrier. Application of the ideal laminate theory [15] indicates that contribution to the resistance to permeation from the polymer is insignificant. Therefore, the choice of polymer film for oxide deposition is not directly relevant when trying to achieve a WVTR of $1 \cdot 10^{-4}$ (g/m^2/day).

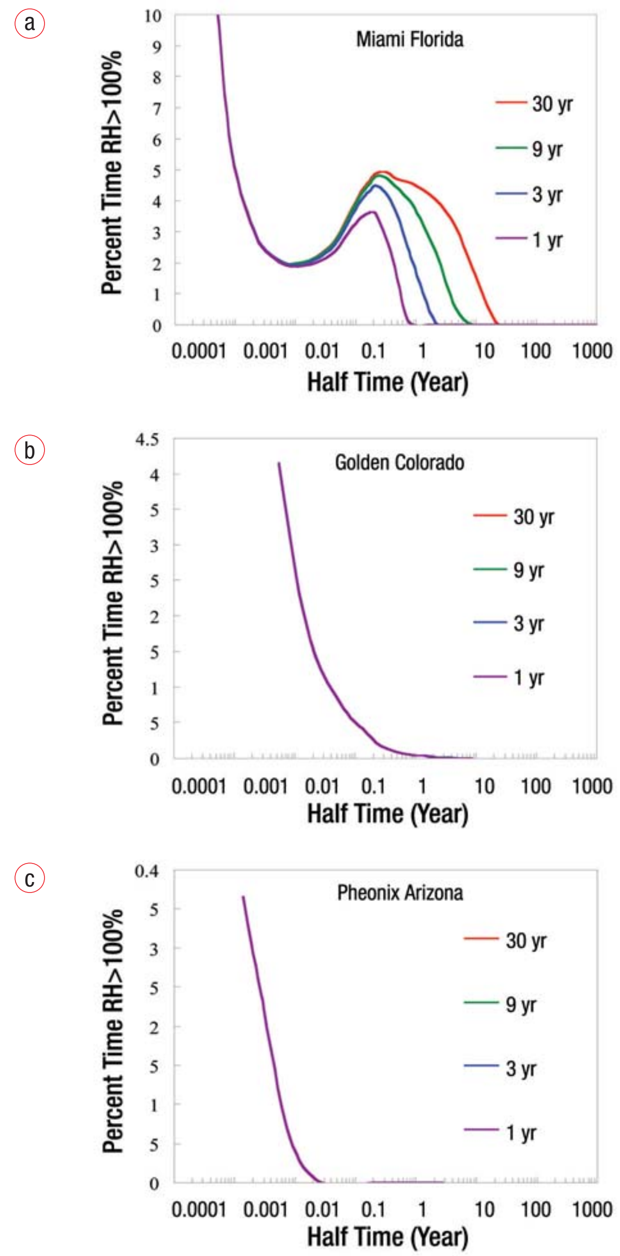

Figure 3. Plots of module exposure starting with an initially dry module and averaging over the first 1 to 30 years. "Percent Time" is the fractional time where the module experiences an RH greater than 100%. The half-times were computed assuming a 0.46-mm-thick EVA encapsulant at 27°C [12].

For PV materials that are less sensitive to moisture, it is the time a module spends at high saturation that is correlated with reliability. Exposure to humidity levels near 100% RH are far more corrosive than low humidity conditions. Because of this, it is useful to consider how much time a module will be exposed to conditions of super saturation.

For typical modules with breathable back-sheets, the moisture will enter at night and then be released during the day when the module is hot and water has a higher vapor pressure. During periods of rain, the module will saturate and if there is then a subsequent drop in temperature with a subsequent reduction in solubility, the concentration of moisture in a module can exceed its saturation limit. This can present a significant problem because water trapped in the module will begin to form small water droplets that may continue to grow under these supersaturation conditions. Water condensing at the interface between the encapsulant and the solar cell materials will create areas of increased corrosion and encapsulant delamination. Because of this, the exposure to supersaturation is important.

The percent of time a module experiences supersaturation was calculated using meteorological data from three different locations (see reference 12). Although the actual water content only varied by a factor of 3 for the three locations, the total time spent above 100% RH varied by 2 or 3 orders of magnitude, Figure 3. In Phoenix Arizona, the environmental humidity is always so low that once a half-time of ~10 days is reached, the module will never be become supersaturated. This is a period of time just long enough to attenuate the effects of a storm system moving through the area. In Golden Colorado, a half-time of one year is necessary to prevent supersaturation. This can be viewed as being long enough to attenuate the effects of seasonal fluctuations.

The exposure of a module in Miami Florida is quite different because the environment exhibits 100% RH almost every night and rain storms occur very frequently. For half-times of less than one day, the total time above 100% RH is very high because the module saturation level is following the environment closely and is reaching saturation almost every night. Then, as the half-time increases (to scales of months or a year), the moisture is trapped in the module on cold nights, enabling higher supersaturation to be achieved. Here, the averages over different timescales produce distinct lines because it takes significant time for the module to approach saturation, leading to lower water contents at smaller timescales. Finally, as the half-time is increased to times approaching the exposure time, moisture is kept out, thus preventing supersaturation.

These calculations and analyses have been conducted for the case of an encapsulant layer between PV cells and a barrier film. The effects of moisture ingress for the case of a barrier deposited directly on the PV cell would be different and characterized by degradation occurring at pinholes in the barrier and spreading out from those points [16]. Because of the ability of moisture barriers deposited directly on materials to limit the extent of degradation, this approach may be more likely to yield environmentally stable flexible PV products.

Back-sheet and front-sheet materials serve many purposes such as providing mechanical integrity, electrical insulation, UV stability, and environmental protection. PV module technology works but there are still many ways to improve designs to make them more economical. Flexible CIGS designs however are in need of the development cost effective and environmentally resilient transparent barriers to achieve large scale production. For crystalline silicon modules new back-sheet materials are beginning to displace more expensive PVF films thus helping to reduce the cost of solar energy.

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About the Author

Dr. Michael Kempe is a Scientist in the PV Module Reliability Group of the National Center for Photovoltaics at the National Renewable Energy Laboratory, where he studies the factors affecting the longevity of photovoltaic cells and modules. His work is concerned primarily with both modeling and measuring moisture ingress into PV modules and studying its effect on polymer adhesion, device performance and component corrosion. Dr. Kempe has formulated polymeric encapsulant materials suitable for 30 years of outdoor exposure in direct sunlight at elevated temperatures. He is also studying the effects of environmental exposure on cell performance. Dr. Kempe graduated from the California Institute of Technology with a Ph.D. in chemical engineering.

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Methodology and systems to ensure reliable amorphous-silicon thin-film photovoltaic modules

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ABSTRACT

The reliability of United Solar Ovonic (Uni-Solar) triple-junction amorphous-silicon thin-film photovoltaic modules is critical to their success in an increasingly competitive PV market. Modules must show useful operating lifetimes of 20 to 30 years, and although module efficiency is very important, the total energy that a module will produce largely depends on its operating lifetime. Thus, module reliability must be evaluated to estimate lifetime and establish customer warranty periods. While real-world outdoor exposure testing is necessary and important, accelerated environmental test methods must also be utilized to provide more rapid feedback regarding failure modes, design flaws and degradation mechanisms. The following paper gives an overview of the methodology used to ensure long-term reliability of Uni-Solar flexible thin-film modules.

Introduction

From initial design and development through manufacturing, methods and systems must be employed to ensure the quality and reliability of Uni-Solar's amorphous-silicon thin-film photovoltaic modules. These methods and systems must also continue to improve and evolve to raise the level of module reliability to assure service lifetimes of 20 to 30 years. (Service lifetime is defined by ASTM as the time at which performance degrades below a predefined level [1].) The process starts at the design and development stage where alternative materials are specified or alternative cell and/or module designs are developed. Once material selection or design is completed, screening tests are conducted to down-select the best material candidate or design. Close collaboration with material suppliers takes place at this stage to ensure a material meets specification requirements. Once screening is done, component level testing is performed, followed by module validation testing. After material and design are approved, quality assurance protocols are initiated to ensure supplier and product quality.

Qualification testing relies heavily on accelerated environmental testing (AET). Since real-time outdoor exposure tests are an impractical method to evaluate 20- to 30-year lifetimes, accelerated lifetime testing must be used under simulated environmental conditions to evaluate and improve PV module reliability. Still, passing all of the required qualification tests defined by IEC-61646 and UL-1703 does not guarantee module reliability and 20- to 30-year service lifetimes. There are several reasons for this. First, IEC-61646 is based largely on the qualification tests and associated degradation mechanisms for crystalline-silicon modules, so a single approach may not apply. For this reason, Uni-Solar has had to develop unique tests for flexible thin-film modules. Second, it is difficult to undertake rigorous studies encompassing all of the interactive effects that may occur in the various environments to which a module may be exposed. Third, supplier quality issues can have an effect on module reliability. Finally, without correlation to long-term outdoor exposure tests, the true reliability or service lifetime of the module design based on simulated environmental tests is very hard to predict.

Relatively few references exist to correlations between AET duration and real outdoor exposure [2,3]. Those correlations are necessary to translate specific AET exposure durations into accelerated lifetime tests (ALT). The dilemma is that one must design for a 20- to 30-year lifetime based on ALT with limited correlations to real-time outdoor exposure. It is more accurate to say that passing qualification tests demonstrates that the module design does not suffer from any serious design flaws that would severely limit the service lifetime.

The central component of the company's flexible PV laminate product consists of a series of multijunction thin-film amorphous silicon-based cells, manufactured via a proprietary chemical vapor deposition approach using a paper-thin metallic substrate [4,5,6] (see Figure 1). Each side of the PV cell has a robust encapsulant material. Covering the encapsulant over the optically active region of the laminate construction, the superstrate provides electrical insulation, cut and impact resistance and unique self-cleaning characteristics because of its hydrophobic properties attributed to having a low surface energy. Directly under the encapsulant on the backside of the multilayer construction, a polymeric film provides additional electrical insulation, creating a product that is safely building integrated, using a high-tack adhesive

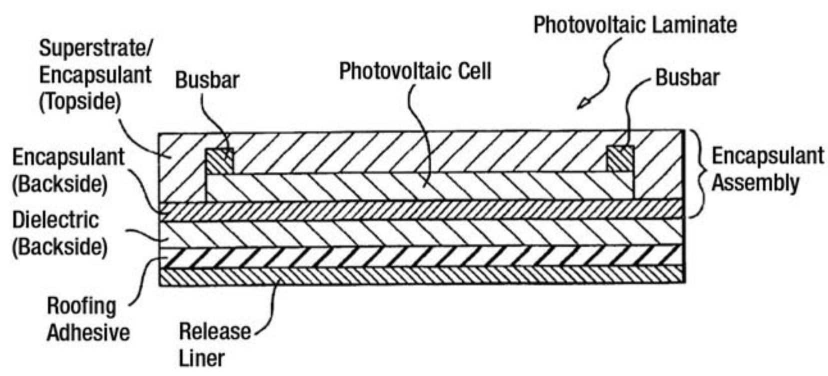

Figure 1. Cross-sectional diagram of Uni-Solar's multilayer flexible photovoltaic laminate construction [7].

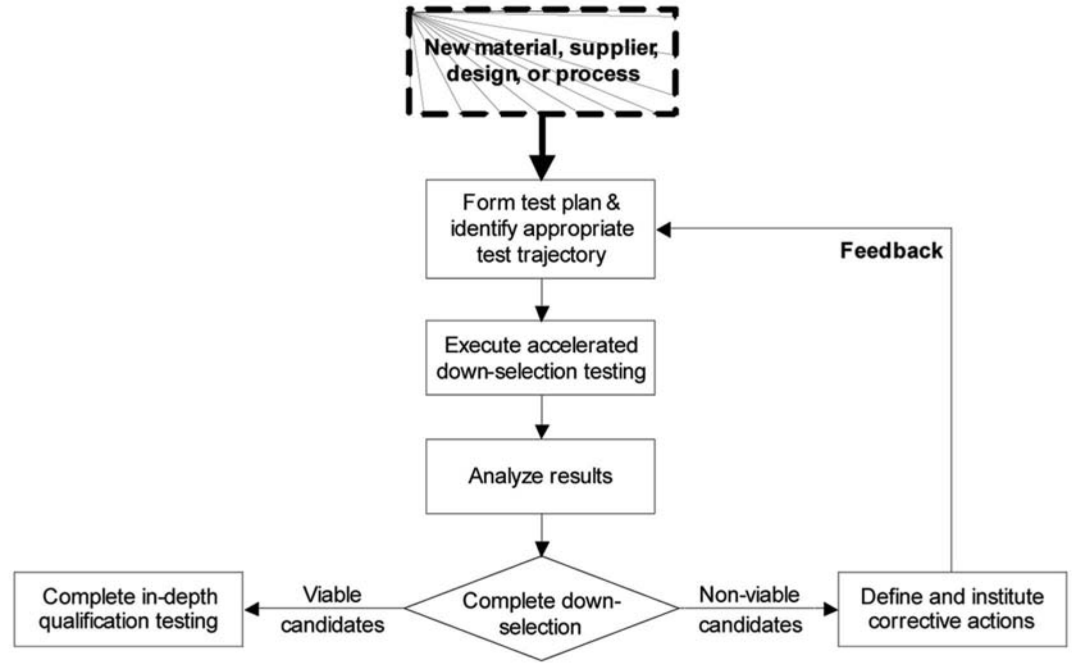

Figure 2. Generic down-selection process flow diagram.

with a removable release liner to provide ease of installation. Enabling a module to maintain a high level of performance, regardless of environmental conditions that may be deleterious to some competitive technologies, the multilayer polymeric system is sealed via a vacuum lamination process and is integral for long-term reliability.

Design and qualification

Design and development process to ensure thin-film module reliability

One primary objective is the design of reliability into material and product specifications. Uni-Solar has developed a four-stage product development process, in which reliability is addressed at each stage. The basic product reliability requirements are defined in the first stage and refined in the second stage. Reliability testing and validation testing occur in the third stage. The fourth stage is authorization to mass produce and can have a subsequent delivery review where reliability is again examined. This process can be iterative at each stage and projects can be sent back for corrective actions for re-entry to earlier stages. After the fourth stage is complete, field monitoring and customer feedback then provide input for continuous improvement.

Material selection and screening process

With a robust material set already in place for the company's commercially produced PV laminate products, the emphasis is on refining existing industry-leading technology so that it is directly competitive with grid-based electricity on a widespread basis without sacrificing performance or durability. While incremental advancements in PV conversion efficiency and improved economies of scale, as operations expand, provide a significant driving force, a considerable effort is also spent on evaluating alternative materials with reduced costs and developing multifunctional materials that have the potential to render a cost reduction by effectively decreasing the part count. An active approach to product development is taken, with material-level reliability at the focal point of the new/alternative material qualification process. Improvements can be made in a controlled manner by becoming technically involved with suppliers to develop and test high-performance, low-cost materials, and by working from a set of detailed specification sheets aimed to accurately define key material properties and create a framework for establishing effective quality control measures.

The development of new/alternative materials often involves the creation of multiple configurations, in an attempt to isolate variables via design of experiment methodologies. With time being a premium commodity, there is substantial motivation to efficiently and effectively down-select among different candidate materials so that resources can be directed toward those with the most promise.

The first layer of analysis used to filter candidate materials involves quantifying fundamental material properties with proven analytical techniques. For instance, measuring the transmission and refractive index of a given superstrate sample is a routine part of the process to ensure proper optical performance. For candidate encapsulant materials, determining rheological properties can yield information relating to the processability under standard production laminating conditions and an indication of structural changes that may occur as a function of time and temperature.

After screening base material properties, a limited number of subscale samples are typically produced for down-selected configurations, with a statistically relevant number of experimental and control samples. If the experimental and control samples perform comparably during initial testing, the subscale samples are then submitted to a brief period of extreme conditions in an attempt to induce a measurable, yet meaningful, separation between the control and experimental samples during postexposure testing. For this purpose, hot-water immersion testing is useful in the rapid evaluation of polymeric materials [8]. Figure 2 shows the generic down-selection process flow diagram being employed.

Component-level qualification testing

The objective of material and cell/module-level qualification testing is to validate the performance and durability of a new or alternative component against that of a known control or benchmark design. Overall, qualification testing is an in-depth extension from the initial down-selection process, while additional testing determines whether a given new/alternative component meets predefined requirements. The inclusion of a combination of recognized AET methods such as humidity-freeze cycling (HF = -40°C to +85°C, 85% RH), thermal cycling (TC = -40°C to +90°C), and damp heat exposure (DH = +85°C, 85% RH) [9] is critical for a complete qualification test plan. Candidate materials entering into the test trajectory should be of production quality to yield results that could be considered representative of full-scale operations and to establish a sound baseline for later quality control mechanisms and reliability studies. In designing the sample

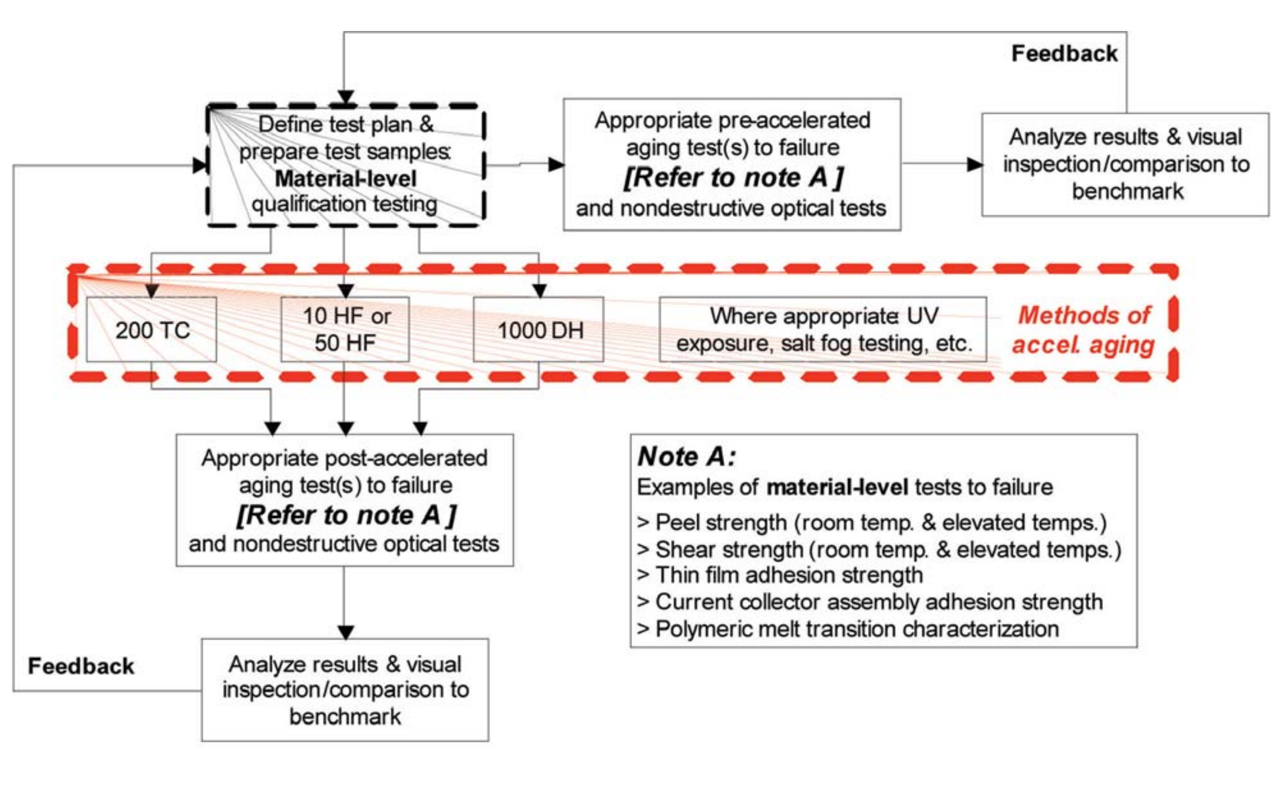

Figure 3. Example of generic material-level qualification testing process flow diagram.

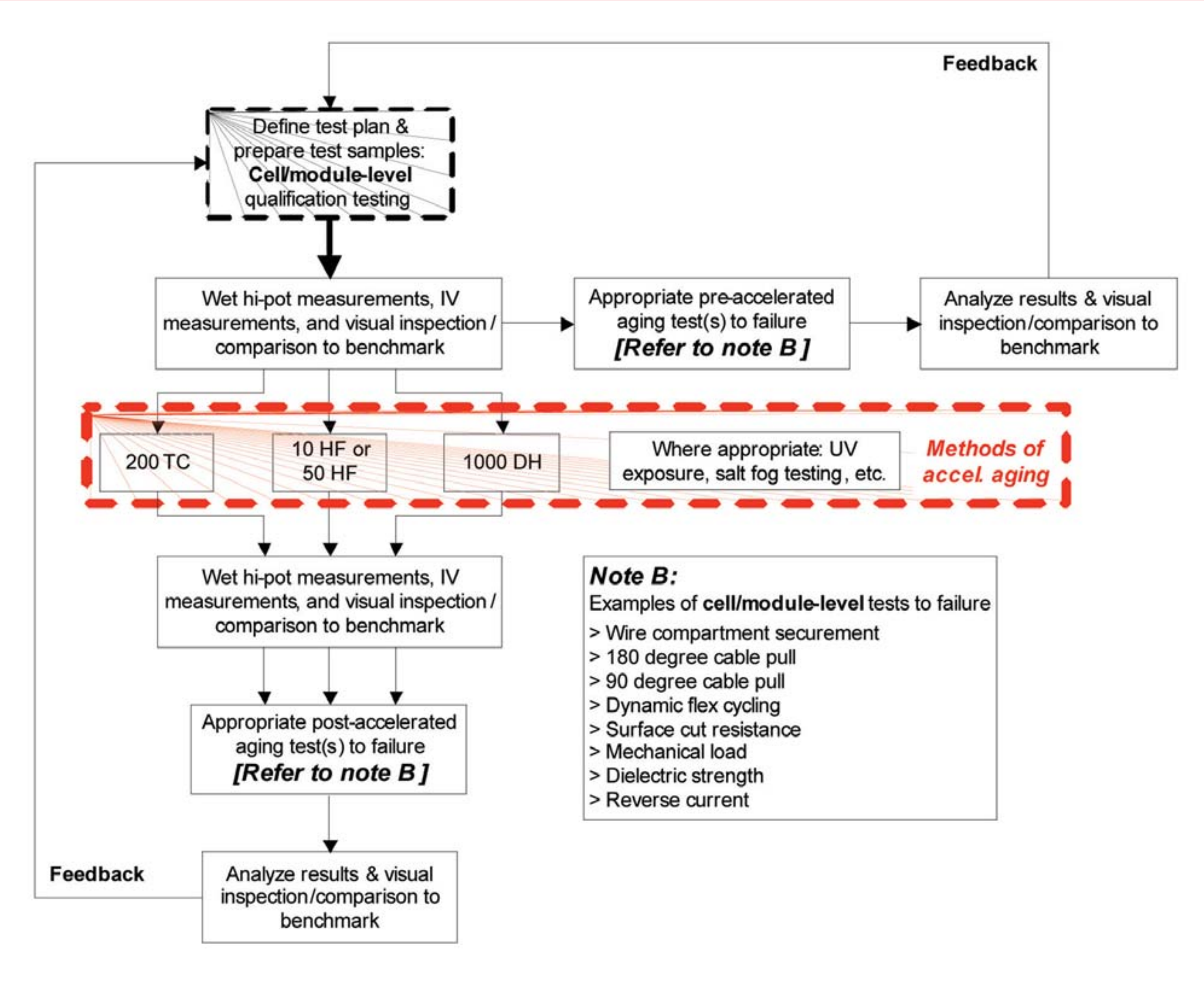

Figure 4. Example of generic cell/module-level qualification testing process flow diagram.

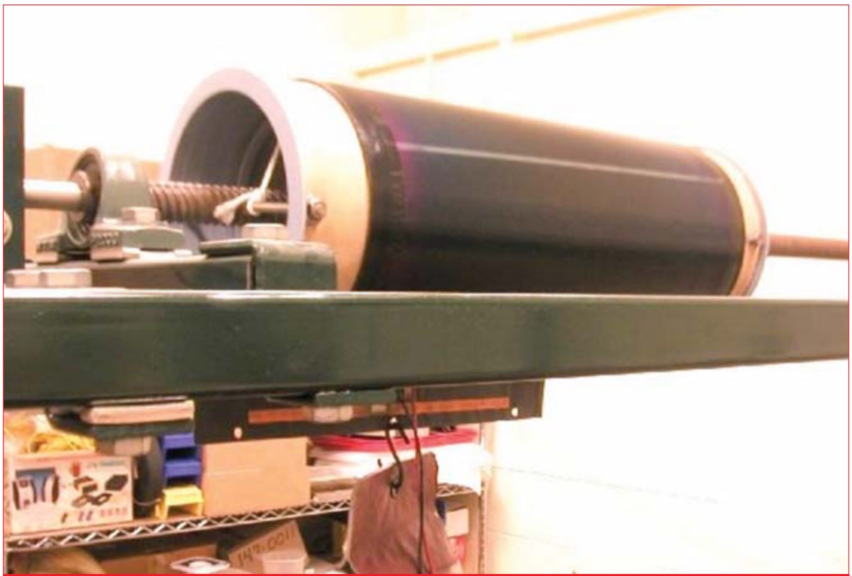

Figure 5. Uni-Solar cyclic flex tester, shown with coiled laminate.

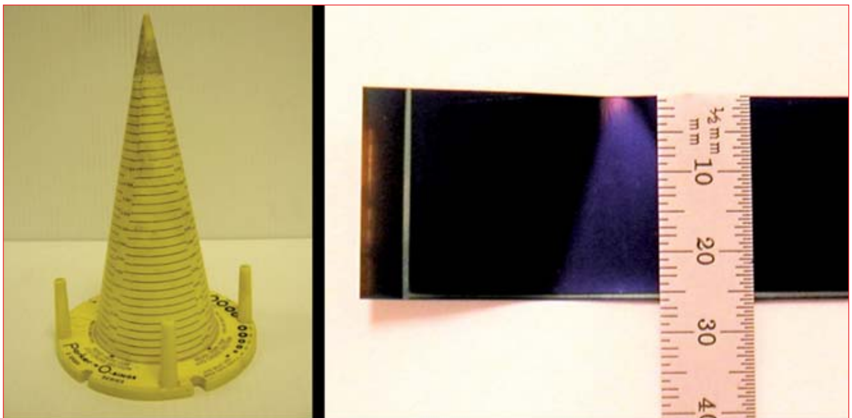

Figure 6. A thin-film adhesion test cone (left) and a formed sample showing thin-film compressive failure (right).

set, accommodations should be made to test all key interactions in an isolated manner, both before and after accelerated aging. For example, evaluating an alternative busbar material would require the creation of a series of peel test samples featuring every relevant interface and a set of electrically active subscale test modules. The scope of a qualification test plan depends on the component in focus and should feature all relevant tests to failure in an attempt to isolate key differences from the performance of the benchmark. Figures 3 and 4 illustrate the test plans for generic material and cell/module-level qualification.

Module and cell components are typically subjected to the AET in a worst-case scenario configuration. For example, when evaluating backsheet designs, the laminate remains completely exposed rather than bonded to a roofing substrate as would occur in a real field application. This not only allows for maximum moisture permeation through the backsheet film, but it enables complete visual inspection after exposure. Individual cells are also routinely tested in an unencapsulated, unprotected state. Current-biasing at rated maximum operating current (I_{mp}) or short-circuit current (I_{sc}) levels is often applied to cells and modules during accelerated tests.

Encapsulant peel and shear tests

Because of the multilayer nature of the encapsulation, a significant amount of effort is dedicated to evaluating interlayer adhesive bond strengths, before and after accelerated aging. Polymeric bond strength is measured via ASTM D903 [10]. By maintaining a standard peel test procedure, quantitative comparisons can be made before and after accelerated aging with statistics applied where appropriate. As each peel test is completed, the failure mode is analyzed and data are recorded. For samples that stretch or break, the maximum force obtained during the peel stroke is recorded. In the event that a sample fails cohesively or adhesively between two specific layers of the multilayered construction, the moving average of the force obtained midpeel is also recorded. Elevated temperature peel tests are also used to down-select and qualify materials where temperature resistance is a required property, such as between the backside encapsulant and the metallic substrate. Lap joint shear tests based on ASTM D1002 [11] are also performed on samples before and after accelerated aging tests and at various temperatures. One material where the test is most applicable is the adhesive component that bonds the PV laminate to the roofing substrate.

Module validation and reliability

Module validation tests

Once material screening and component level tests have been successfully completed, representative module laminates are fabricated for standard validation or qualification tests, with applied test trajectories based on IEC and UL standards. Because of the extensive nature of the complete IEC and UL test trajectories, it is common to perform only the test sequences applicable to the alternative material or design being tested. In other words, the test trajectories for a particular design or material are chosen based on the performance requirements and potential failure modes for the design or material being evaluated. For example, validation of an alternative dielectric backsheet material concentrates on dielectric tests after humidity-freeze and damp-heat exposure, while an alternative front-side encapsulant would require additional optical, electrical performance, UV exposure, and surface cut resistance tests.

Since Uni-Solar module laminates can reach 18 feet in length and the current environmental test chambers are limited in size, smaller representative modules are manufactured for testing. The subscale modules incorporate all elements of a full-size module with only the number of series cells and interconnects reduced. In addition to accelerated testing, full-size modules are subjected to outdoor exposure at company and other sites [12,13]. A recent study shows a 0.6 % per-year degradation rate over a two-year period of outdoor exposure in Florida [14].

Reliability tests

Accelerated tests are occasionally extended to observe longer-term reliability [15]. One example of note consisted of the qualification of a recent design change. The humidity-freeze (HF) cycle test was extended to 150 cycles, or 15 times the IEC-61646 qualification test specification. This duration includes the equivalent of 3000 hours of damp-heat (DH) exposure. A set of nine modules were exposed and removed every 10 cycles for electrical performance measurement. Degradation of the average module maximum power was <5% after 150 cycles. Another positive result from this test revealed the integrity of the encapsulation, since no visual defects were observed.

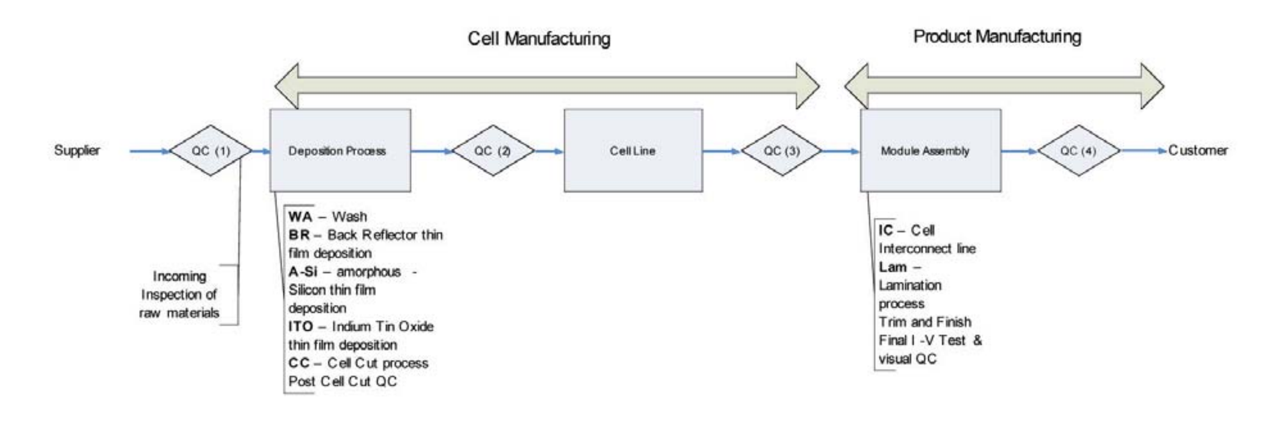

Figure 7. Quality control process flowchart.

A second example consisted of a test sequence which included 50 HF cycles followed by 1000 hours of DH exposure, or the total equivalent of 2000 hours of DH exposure, used to verify module integrity. The laminates were not bonded to a substrate and were fully exposed at both sides during the accelerated tests, allowing maximum moisture permeation. Postexposure visual inspection showed no visible delamination of the front- or backside encapsulants. The laminates also passed postaging wet insulation tests, and electrical performance indicated <1% degradation in maximum power.

Thin-film module tests

Because of the flexible nature of Uni-Solar modules and laminates, a test method was developed to ensure module durability when subjected to coiling and flexing forces during manufacturing, packaging, installation, or the customer application. The cyclic flex test, or fatigue test, is a unique method applicable to flexible modules, one not specifically defined by IEC or UL standards.

A test apparatus was constructed to stress the module by cyclic coiling and uncoiling around a six-inch diameter mandrel. Figure 5 shows a photo of the test apparatus with a module in a coiled state. Each cycle consists of one coiling and one uncoiling every two seconds. The module is coiled in both orientations: front side then back side. Tension is applied to the module to ensure contact with the motor-driven coiling mandrel. The coiling diameter is six inches, which is approximately three times smaller than the maximum recommended coiling diameter of the module. The test is performed on nonaged and aged modules under ambient conditions. The test is instrumental in evaluating interconnect and bus designs. The test also yields information regarding the mechanical integrity of thin-film and encapsulant adhesion.

Another unique test for the modules is the thin-film adhesion test, which is conducted at the cell level on small cut samples. The total cell stack consists of 13 individual layers. The test quantifies the level of compressive or tensile strain at which the thin-film adhesion fails. A conical mandrel is used to form a one-inch-wide cell sample, inducing varying levels of tensile or compressive strain. The percentage of strain is measured at film adhesion failure. The failure mode is a visible separation at one of the film-layer interfaces. This test method is quicker and less subjective than a tape test such as ASTM D3359 for thin, malleable substrates. Figure 6 shows the test device and a tested sample. A criterion has been established to ensure adequate film adhesion.

One direct correlation has been observed between an initial thin-film adhesion test and a field-related failure – in this case, low power resulting from increased series resistance. Subsequent investigation into the failure revealed that the cell material used for the modules suffered from relatively poor adhesion at deposition layer interfaces. Thin-film adhesion test results confirmed a lower level of strain failure after HF test exposure. The cause of the poor interlayer adhesion was traced to organic contamination.

Product quality and process control

The company's quality assurance program exists to maintain high quality and reliability of manufactured modules. The program ensures product conformity and has been developed on systems that can deliver proof of conformance to the customer. It consists of incoming inspections, in-process inspections and final inspections, which are also known as quality control checkpoints, each of which has clearly defined acceptance and rejection criteria. In addition to the QC checkpoints, quality is assured through validation testing, process audits, process failure mode and effects analysis (PFMEA) methodology, analysis of customer feedback, and field performance data (see Figure 7).

Incoming inspection

The incoming inspection process verifies that material from suppliers conforms to specified requirements prior to releasing the material to production. Incoming inspection of raw materials is controlled by utilizing incoming inspection test plans (IITPs). IITPs have been developed for all critical materials used in the manufacturing of Uni-Solar products. Once inspection tests are performed on the incoming material, the records are saved in the manufacturing execution system (MES), a centralized database that stores process parameters of machines used in the manufacturing of the solar laminates as well as the raw material characteristics and in product characteristics. This database provides a link between raw materials properties to process parameters and finished product performance. For material that does not pass inspection, it is classified as nonconforming material and segregated for secondary review between the supplier and management. Corrective actions are also issued to the suppliers if needed.

The incoming inspection process also ensures that records of supplier conformance are retained, such as certificates of compliance. All material requirements are defined for suppliers prior to their shipments. These requirements are documented in the supplier control plans for each critical material. The methods needed for inspection are then determined, such as testing equipment and sampling plans. The incoming inspection process may also call for random audits on supplier compliance per Uni-Solar's request.

In-process inspection

Once material is released to production, in-process quality inspections control the manufacturing of the products. The in-process portion of quality control is the largest of the three QC pieces, since it contains multiple checkpoints throughout the entire solar laminate manufacturing process. These checkpoints include a check before cells are cut to size, after cells are cut, after cells are finished, and after connecting to form solar laminates. In-process quality inspections and tests use clearly defined standards for acceptance and rejection of product.

After the solar cells are cut to their designated size, they are printed with a unique serial number for traceability and put through a series of tests for conformance. One out of every 100 cells is tested for electrical characteristics (I-V curve) film adhesion strength, low light performance, and visual defects. All in-process inspection data are collected and stored in the MES. Again, material that does not pass acceptance criteria at any point is classified as nonconforming material and segregated for secondary review. Corrective actions are also issued to the appropriate department as required.

Final inspection

The last QC checkpoint consists of final production line tests performed on all finished product. Laminates go through a final electrical test, an insulation test (wet hi-pot), and visual inspection for cosmetic defects. Each laminate or module is given a unique serial number and the inspection data are entered automatically in the MES. As in the other major quality checkpoints, if at any point in the final inspection process the laminate does not pass the listed criteria, it is rejected and segregated as nonconforming for secondary review.

Ongoing product/process validation

In addition to verification of product quality characteristics, the company validates that raw materials and finished products meet expected long-term performance through AET. During normal production runs, materials are pulled from inventory and subjected to critical tests performed during the design qualification phase of the product. Samples are made using standard production equipment and production materials, and standard operating procedures. Once samples are manufactured, they are subjected to the cyclic humidity-freeze test, the thermal-cycle test, and the damp-heat test as defined by IEC-61646. Following the accelerated environmental exposure, visual inspections, electrical testing, bond strength, and robustness of terminations are measured to verify product performs within specified limits.

Quality management systems

Although not certified, a quality management system has been implemented that is designed to be compliant with the requirements of the ISO 9001:2000 standard and the needs of customers, with production processes conducted under controlled quality conditions. All critical steps in the process are documented in standard operating procedures within the document control system.

QC audits are also conducted on the entire quality assurance program to ensure conformity. Quality engineers and management perform audits on the incoming inspection process, solar cell cut process, cell lines, final QC process, and calibration systems. The audits verify that sufficient controls are in place to provide a high quality product compliant with specifications.

A PFMEA methodology is used to prevent and predict failures in manufacturing. The process identifies ways in which a process can fail to meet critical customer requirements, and evaluates the current control plan for preventing these failures from occurring and prioritizes actions that should be taken to improve the process. The use of PFMEA is a proactive, rather than reactive, method to improve product quality.

In addition to the internal quality checkpoints and audits, final product quality and reliability are tracked through the external users. All customer feedback and claims are recorded in an electronic customer database. By tracking such customer information, corrective actions can be issued to appropriate departments and improvements can be made to the product designs and processes in place.

Continuous improvement

Hard-lined QC systems have proven highly effective in eliminating time-zero defects and early-stage manufacturing mistakes. Since reliability can be conceptualized as a change in quality over time, reliability testing is integral for ensuring long-term quality. Dynamic screening, qualification and validation processes have been developed, with feedback loops strategically placed, in order to improve product reliability. As a result, ongoing reliability studies have a direct impact on the continual improvement of manufacturing and quality control systems.

As manufacturing and quality control systems evolve, the scope of future work relating to reliability testing must be adjusted to meet the elevated target. The company's future work includes developing additional tests to failure, investigating alternative highly accelerated life test (HALT) and highly accelerated stress screening (HASS) approaches, finding better correlations between time in the field and ALT, and working on improved acceleration models.

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Dr. Subhendu Guha is Senior Vice President of Energy Conversion Devices and chairman of United Solar Ovonic. He is a world-renowned authority in photovoltaic technology, with many years of experience in the development and manufacture of solar panels. He serves on many national and international photovoltaic committees, including the advisory board of National Center for Photovoltaics – the body responsible for directing and implementing the U.S. Department of Energy's strategy in photovoltaic. His work has received recognition from the Department of Energy, *Bright Lights Award*, and the Discovery Magazine, *Environment Category*. Dr. Guha has a PhD in electronics. Before joining United Solar Ovonic in 1990, he served as Vice President of photovoltaics and information at ECD Ovonics.

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Snapshot of spot market for PV modules – quarterly report Q3 2008

Continuous monitoring with pvXchange trade statistics

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.

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Introduction

A spot market always shows the up-to-date prices of solar modules, because it does not consider the long-term delivery contracts of the producers. These days, the spot market for PV modules is global, because the short-term satisfaction of local supply deficits is possible with short transportation times and relatively low logistics costs.

pvXchange provides a closed online trading platform for sellers going 'public' with a short-term offer. Other participants of the market can decide if they want to buy the goods at that price, while potential buyers may post their interest and in turn be contacted by interested sellers.

Each issue of *Photovoltaics International* will enable the tracking of spot prices of modules through statistics provided by the pvXchange trading platform.

Prices remain high due to supply bottlenecks

Module supply shortages continue to lead to increased prices. The high price situation is the result of high demand and short supply, especially for the 'most wanted' module brands, which is expected to persist until the end of the third quarter of 2008. The main driver for this shortage over the third quarter has been high demand from the Spanish market as projects rushed to complete prior to tariff cut-off dates at the end of September.

From September onwards, the first signs of a downward price trend may be expected especially for products at the lower end of the price spectrum, particularly from China. The majority of 'cheap' products on the spot market are offered by manufacturers whose products are not yet certified. It is unlikely that we will see price reductions in the highly efficient premium brands and thin-film modules.

The strongly increasing price trend noticed for less well-reputed modules from China was widely stopped in August 2008, which can be interpreted as a first hint at a slight release of the supply situation in the following month (September). It may be expected that Chinese modules will decrease in value from September onwards. After a temporary shortage in July/August, larger volumes are again available, comprising mostly less well-known brands, such as Galaxy, Luxor, E-Ging or Aide. At the same time, Chaori, Yingli and Suntech Power remain the most in-demand modules from China. However, the available supply volumes are quite limited – maximum available is 100kWp.

At the same time, on the pvXchange trading platform, there were very few offers available from European (German) suppliers in August and September, leading to high prices. The availability of high-quality modules on the spot market is still very low – there are very few brands being traded in Germany other than Solar-Fabrik, Schott Solar and Evergreen. In August, some offers were made by Solarworld and Sunways, but these were for very small volumes – mainly just up to 10kWp. Sharp UK is the only non-German European supplier present on the platform.

Among Japanese brands, Kyocera and Sharp continue to be the most important suppliers, with maximum volumes of 100kWp. As is the case with German brands, there are initial signs of a slight price decline setting in from September onwards.

OEM manufacturers such as Zytech, Powerbags and Schosser played a more important role in the spot market during August than in previous months. This higher presence also had an impact on (high) prices, since the products offered were modules bearing European warranties. It seems evident that OEM manufacturers have been earning quite well this year, an observation manifested by higher prices during July/August than were seen at the beginning of 2008.

Prices for thin-film modules are still increasing broadly, especially among economical a-Si module providers (e.g. Kaneka). There remains a very high demand for thin-film modules, especially for new products from Mitsubishi and Sharp, some of which reach prices of an average 2.60€/Wp. The available volumes are almost sold out until the end of the year. Forecasts show that prices for modules of this type will not fall considerably before the beginning of next year. With the possible exception of First Solar, there are as yet no signs that there will be offers available in the range 2.20 – 2.30€/Wp.

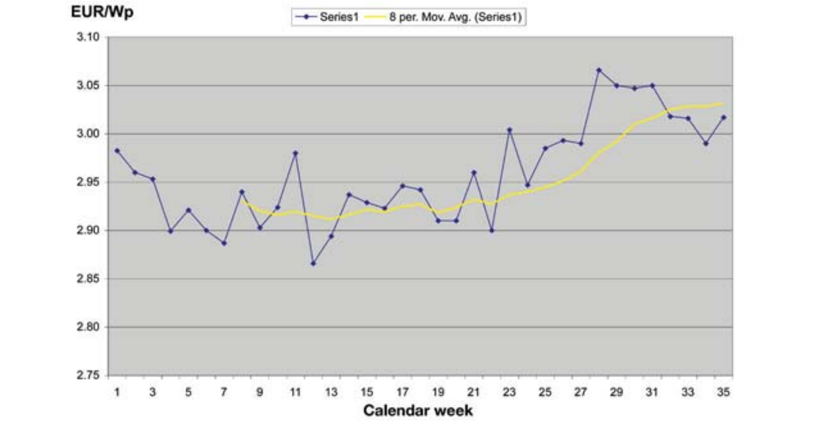

Figure 1. Development of market prices for modules produced by Chinese manufacturers from March – August 2008 (in €/Wp).

First Solar has consolidated its dominant position in the market. Their modules have been reaching new price peaks at the spot market, which in the German context does not enable profitable PV investment terms. It is remarkable to note how much trust lies in this still very new technology.

Leading module manufacturers in the trade period

This section provides an analysis of market shares of the leading module manufacturers, thereby determining those module types that are most popular in today's industry.

Market shares by country of origin

China

Chinese manufacturers like Suntech, Yingli, Chaori and Trina Solar are still gaining ground. Product certification is always a pre-requisite, but new brands like ET Solar, Wuxi Guofei, Solarfun and Jetion are currently gaining traction in the market. Profit pressures in the German PV market and supply shortages make it relatively easy for these new suppliers to place their products. The spot market tracks reductions in products offered by more well-known brands as they lock in longer-term supply contracts. Relatively less-known brands and module types are have been gaining in business since June.

The high return on PV investments in the Spanish boom market in 2008 has enabled very high prices for traditionally cheaper modules from China as supply was stifled and deadlines were imposed. However, a clear distinction must be made between the established Chinese manufacturers with an extended sales structure in Europe on the one hand, and the many newcomers that jumped into the booming PV market only recently. Three groups of Chinese suppliers can be distinguished:

- Manufacturers with an established sales network in Europe and long-term experience in the market achieve the highest price levels up to 3.15€/Wp;
- Manufacturers without well-known brands and international sales structures sell their modules directly from Chinese factories at around 3€/Wp;
- OEM suppliers with European label and warranty terms, that sell modules of the Chinese manufacturers of the second group, reach prices in the middle of the aforementioned prices range of 3-3.15€/Wp.

Japan and USA

Strongly branded modules from Japan, i.e. Sharp and Sanyo, traded at slightly higher volumes than in May or June, while Kyocera and Kaneka showed a lower transaction volume on pvXchange. First Solar has again strengthened its position as the No. 1 product; other US products do not appear on such a large scale.

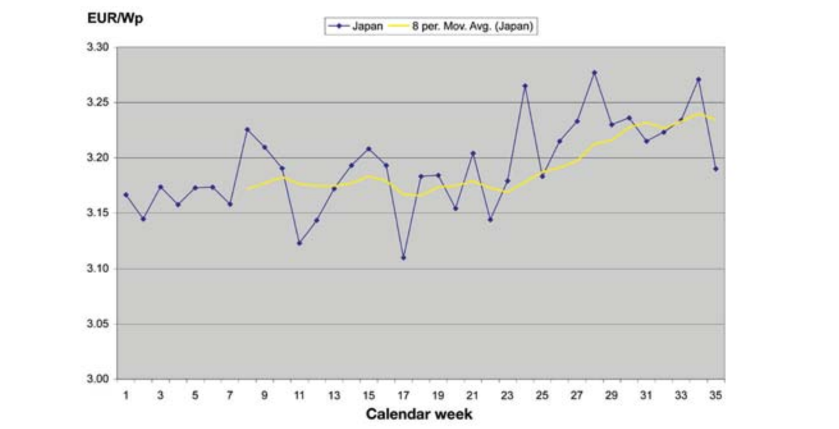

Figure 2. Development of market prices for modules produced by Japanese manufacturers from March – August 2008 (in €/Wp).

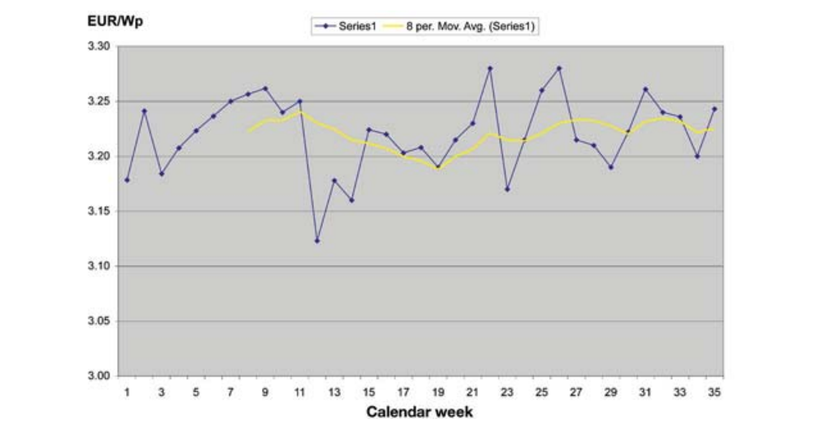

Figure 3. Development of market prices for modules produced by German manufacturers from March – August 2008 (in €/Wp).

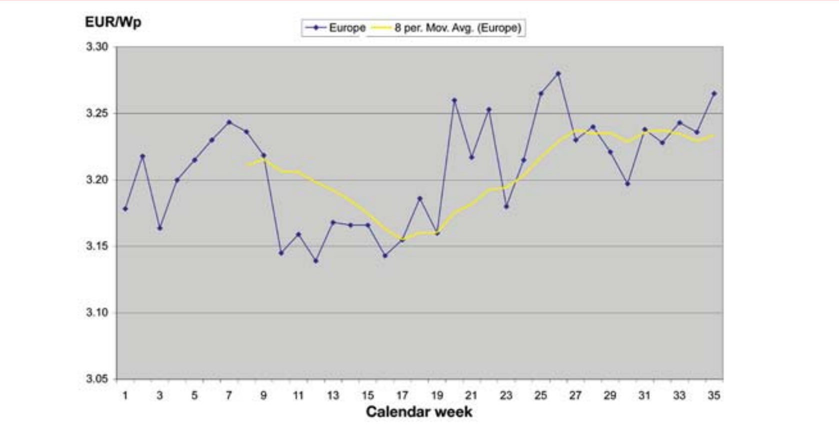

Figure 4. Development of market prices for modules produced by European manufacturers from March – August 2008 (in €/Wp).

Europe

German manufacturers are seldom traded via pvXchange, except for the modules produced by Solar-Fabrik and Schott Solar.

The spot market is less influenced by German manufacturers, as these companies tend to assign large-scale projects to their long-existing customers rather than manufacturers in the Far East. For this reason, German modules often do not even appear on the free market (Solon would be an excellent example).

Optimistic, yet uncertain outlook for 2009

Across the PV industry, there hangs a tentative optimism that in the course of next year the imminent supply shortages on the global silicon market may finally be overcome. Although there are no perfectly reliable figures both for the supply and the demand side available, it seems likely that the massive increase of production capacities will lead to a better coverage of demand than in recent years. The expected ease of current supply bottlenecks will be leveraged not only by c-Si product innovations (reducing the need for silicon) but also by the increasing use of cheaper metallurgical-grade silicon for crystalline modules and a further growth in the production of thin-film technologies. However, despite these developments, short-term silicon supply shortages may still be possible, thereby holding the potential to affect spot market prices.

Many players also hope for a sudden boost of demand in important emerging markets such as Italy or the USA. Currently, it remains unclear whether the demand in these two regions will fully compensate for the sagging demand in the Spanish market. The expectations from German installation companies for 2009 remain rather pessimistic. It is assumed that the price decrease demanded by the feed-in tariff reduction can only be met by sourcing cheaper Asian products. It is not expected that brand goods will reduce in price due to short-term competitive offers. Local producers continue to state that their future pricing structure is unclear, while some installation companies will prefer to take a decline in output rather than carry the risk of using unknown Asian products.

The price peak for PV modules should finally have been reached in August 2008. A reverse trend will be triggered by a cool-down of the currently hectic demand in the Spanish market, in the wake of the announcement of the new feed-in-tariff law. Since many PV investors in Germany have accounted for this decline, a slump in spot market prices is not yet expected until the beginning of 2009.

Information on the data basis – procurement statistics by pvXchange

The current report applies to the six-month period from March to August 2008. Analysed trade volume so far during the entire period has seen more than 60MWp PV modules sold in 757 transactions on the pvXchange trading platform, which are covered by this volume analysis. This figure does not correspond to the entire transaction volume on the platform, but represents the revenues actually realised by the end of the month.

A complete analysis of the transaction volume is only possible after a certain period of time. Usually, it is undertaken for the year after completion of the first quarter of the following year. Given the current growth trend, we forecast that total trading volume realized on the platform will exceed 100MWp in 2008. Of this, roughly 65MWp will be allotted within the German and Spanish markets. Current issues regarding transactions between Spanish clients and German/international suppliers exist mainly in both parties frequently failing to honour signed contracts. As the current Spanish Real Decreto nears conclusion, it is not uncommon for multiple orders to be placed by various vendors. Many vendors (distributors and manufacturers) are left with undelivered orders, a level of supply and demand unreliability that has caused the market to take large swings between available stock and demanded stock. These irregularities are relieved by the intensive brokerage of pvXchange.

About the Authors

With the idea of an independent procuration of photovoltaic products, pvXchange has gained the market-leading position in the business customer segment. The customer base of pvXchange currently includes more than 2,400 companies from the solar industry. pvXchange offers also a wide range of customized consulting and market research services. This market report is a quarterly synopsis of a monthly updated analysis, made in co-operation by pvXchange and eclareon. The monthly report is available; for details contact the authors.

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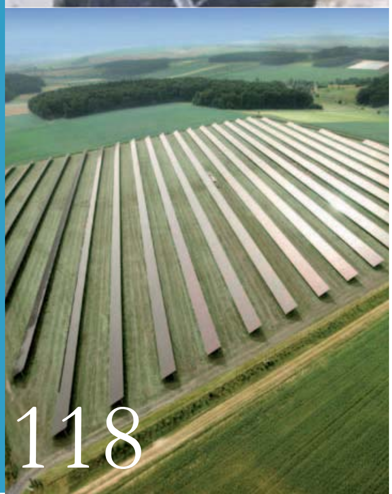

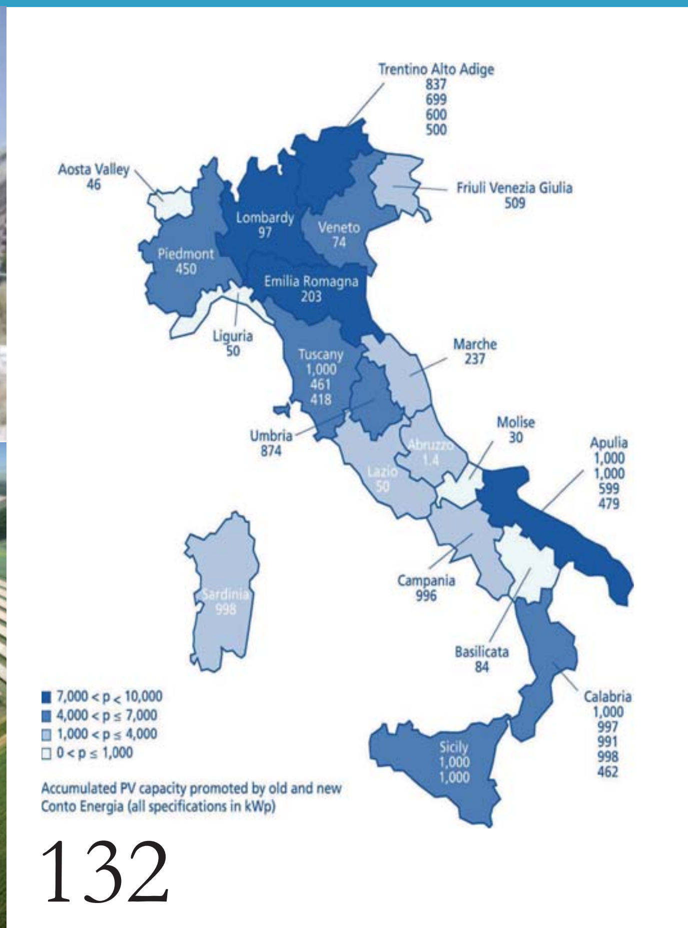

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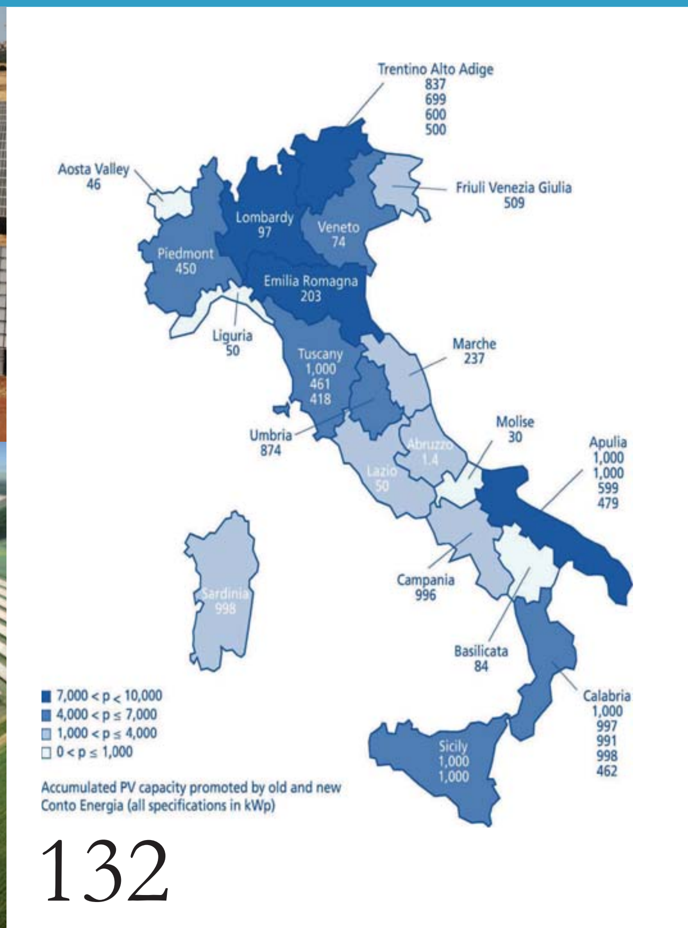

News

Suntech is coming to America and targets large-scale installations

In an effort to capture a share of the state subsidised utility PV market in the USA Suntech Power Holdings, the world's largest PV module manufacturer, has announced significant developments.

A joint venture with MMA Renewable Ventures to form the Gemini Solar Development Company, LLC will take aim at Sunpower and First Solar who currently rule the USA power utility market. The JV company will seek to develop, finance, own and operate large-scale PV projects (greater than 10MW). The JV will also seek third-party investors to help fund new power stations.

The acquisition of EI Solutions, the company responsible for the 1.9MW Google HQ installation, gives Suntech the immediate sales infrastructure to develop a strong market share in the commercial and industrial roof markets.

Large Scale Utility Project News Focus

Lakeland Electric and SunEdison sign agreement to deploy 24MW in public-private partnership

Lakeland Electric and SunEdison revealed their public-private partnership to embark upon the largest utility-sponsored photovoltaic solar program per customer in the United States. The project's capacity will create 24MW of solar energy, giving an average of 214W per meter for approximately 112,000 of Lakeland Electric's customers. The 24MW of solar capacity will incorporate ground-mount and rooftop systems throughout Lakeland's service area.

SunEdison will finance, build, own, operate, monitor and maintain photovoltaic solar energy systems for Lakeland as well as supply utility-scale solar energy service to the company.

SOLARIG beats funding clock in Spain with 22MW connected

Independent photovoltaic power producer, SOLARIG recently completed all of its PV power plant projects in Spain, ahead of the expiration of the current Royal Decree. A total power capacity of 22MW of planned energy production at a cost of €132 million has been successfully connected.

In August 2008, SOLARIG completed photovoltaic energy parks in Alfaro and San Clemente, Spain with a total capacity of 5MW. SOLARIG has a 750MW portfolio of photovoltaic solar projects under construction or under development, inclusing BIPV projects, which include projects in Greece and Italy.

Gestamp Asetym opens 26MW Spanish solar PV plant powered by Trina Solar

Gestamp Asetym has inaugurated a 26MW solar plant in southeast Spain – one of the largest in Europe – featuring photovoltaic modules manufactured and supplied by Trina Solar. An opening celebration was held August 7th at the site in Fuente Alamo, Murcia.

Trina Solar supplied 20 of the 26MW mono- and multicrystalline solar modules required for the project as part of the long-term arrangement between both companies. The PV plant consists of three phases: Fuente Alamo I (8MW), Fuente Alamo II (8MW) and Fuente Alamo III (10MW), which are deployed on 62 square hectares of rural land.

DER lab formed to tackle distributed energy for renewables

A new association has been formed by eleven European research institutes to harmonise standards for both solar and wind grid based distributed power generation. The new association, DERlab, which stands for European Distributed Energy Resources Laboratories, is to be based at the Institute for Solar Energy Supply Technology (ISET) in Kassel, Germany.

The European Commission supports the DERlab and the research institutes have been developing joint requirements, and quality criteria, for the interconnection and operation of distributed energy resources since the end of 2005.

Fotowatio acquires four PV plants; adds 32MW output to power portfolio

Major Spanish solar company Fotowatio has announced its purchase of four PV power plants in Murcia, in the southeast of Spain. The purchase comes less than two months after a €225 million investment in the company by GE Energy Financial Services and Grupo Corporativo Landon, and brings the company's power output portfolio to 90MW.

Abengoa's Solana plant in Arizona gets green light

The proposed 280MW Solana solar power plant in Arizona has been approved by the state utility regulators, giving the go-ahead for the facility's construction. The new venture will be located at Gila Bend, Arizona, and is being commissioned by Arizona Public Service Co. It is expected to come into operation in 2011 and provide power for close to 70,000 homes in Arizona at its peak output.

Ausra seeks expansion, secures US$60.6 million in funding

Ausra, Inc., provider of large-scale solar thermal energy systems for industrial processes and utility electricity generation,

DERlab, Kassel, Germany.

has secured US$60.6 million in its latest preferred equity financing. Proceeds from Ausra's financing will fund the company's research and product development and commercial activities, including the completion of its 5MW Kimberlina solar thermal power project near Bakersfield, California – the first power plant in North America to incorporate Ausra's core technology, the Compact Linear Fresnel Reflector (CLFR) solar collector and steam generation system.

Scaled Solar snags two HCPV power systems deals in California

News

Scaled Solar said that it entered into two definitive supply agreements for its SS1-CPV systems in July 2008. The company's high-concentrating photovoltaic (HCPV) systems will power solar farms with a total combined output of 75MW in the San Francisco Bay Area and California's Central Valley, beginning in 2009 and running through 2013.

GreenVolts lands US$30 million in funding for solar CPV project

Concentrating photovoltaic technology firm GreenVolts has landed US$30 million in Series B funding from Oak Investment Partners. The San Francisco-based company says it will use the funding to continue to build out its organization, speed up its advanced R&D efforts and scale capacity for anticipated 2009 deployments. A portion of the funds will also be used for its GV1 project in Byron, CA, built as part of its 20-year power purchase agreement with Pacific Gas & Electric. The first of GV1's planned two megawatts, generated by GreenVolts' CarouSol CPV tracking system, will be delivered later this year.

SolFocus completes CPV installation at 3MW ISFOC facility

SolFocus has announced its completion of the installation of its CPV system at the Institute of Concentration Photovoltaic Systems' (ISFOC) 3MW municipal power production facility. Of the three companies involved in contracts with ISFOC in this phase of the project, SolFocus is the first to complete installation and have its CPV panels tested for quality of performance. The two SolFocus-installed power plants are 200kW at Puertollano and 300kW at Almoguera, Spain.

The ISFOC, a power-producing test facility for CPV technology, was established in 2006, with the first of its contracts awarded to SolFocus soon afterwards. SolFocus' SF-1000P CPV panel has recently been approved for listing for commercial deployment in California by the California Energy Commission (CEC).

ET Solar signs 1MW dual-axis tracking system contract with Premier Power

Nanjing, China-based ET Solar Group Corp. has entered into a 1MW dual-axis tracking system contract with Premier Power Renewable Energy, Inc. The tracking systems, which were jointly developed by ET Solar Group and Meca Solar, each boast a peak power of more than 11kW and will be installed at a location close to San Francisco.

ET Solar will send 97 of the systems to Premier Power for completion of the project by the end of 2008. The annual power output is estimated at more than 2 million kWh, which, according to the company, is close to 40 percent higher than other fixed array installations in the same area.

Premier Power installs solar trackers for utility-grade projects in USA

Premier Power has completed installation of its phase of the USA's largest "Bi-Directional Solar Trackers". The solar installation uses over 50 solar planes on a single solar array. Each solar array spans approximately 45 feet, with 915 square feet of solar panels and sits on one tracker that is designed to follow the sunlight and thereby maximise the amount of light that hits the solar panels.

Premier claims that their dual-axis solar trackers permit increasing photovoltaic solar energy production by more than 35 percent when compared to fixed installations.

The Delano Irrigation district project announced on September 25th was the first of two installations in a series of large-scale trackers being engineered and integrated by Premier Power by year-end.

Commercial Project News Focus

SunPower solar PV system switched on at HP facility in San Diego

Officials from Hewlett-Packard, SunPower, GE Energy Financial Services and local and state government dedicated a new 1.1MW solar photovoltaic rooftop power system at HP's imaging and printing R&D facility in Rancho Bernardo.

Image courtesy of Tom Cheyney

HP's rooftop system, Rancho Bernardo, San Diego.

The SunPower T10 solar roof tile commercial roof system is installed on five different HP rooftops, covering approximately 200,000 square feet of space, according to HP's project manager, Kevin Cowen.

With a rated capacity of 1172kWpeak and an expected annual energy production of 1,651,000 kWhr, the nonpenetrating rooftop system will provide 10% of the facility's power load, Cowen said. The installation team chose four Xantrex 250 inverters to help run the system.

SunPower cells play their part in California Academy of Sciences' 'Living Roof'

The California Academy of Sciences (Academy) in Golden Gate Park, San Francisco, California is to reopen following a closure for establishment of the new facility. An interesting aspect of this new construct is the 'Living Roof', an architecturally designed display roof that features 60,000 SunPower solar cells incorporated in 720 custom-built glass panels. The panels form a 172kW BIPV electric system that will generate up to 10 percent of the Academy's energy needs.

SunPower completes 2.3MW roof installation for Toyota

The largest single-roof solar power installation in North America reached completion at Toyota's North America Parts Center California (NAPCC) in Ontario, California. The 2.3MW project was carried out by SunPower Corporation, and will begin operating in early October.

Covering more than 242,000 square feet of the NAPCC's roof, the project consists of 10,417 SunPower solar modules. Toyota will purchase the generated electricity from GE Energy Financial under the SunPower Access power purchase agreement program, and foresees close to 60 percent of the company's energy needs being supplied by the project.

Suntech to supply 1.6MW of panels to run building-mounted PV project at ASU

Suntech will supply 1.6MW of solar panels to Sun Devil Solar LLC, a wholly owned subsidiary of Integrys Energy Services, for its PV project with Arizona State University (ASU). The panels will be installed on top of two elevated parking structures in the centre of ASU's main campus using a tracking system. The project will be the state's largest building-mounted project when it reaches completion at the end of 2008.

ASU has received multiple awards and grants from the US Department of Energy's Solar America Initiative to further encourage development and uptake of solar technologies. Long-term plans include the establishment of a 7MW installation at the University's Tempe campus.

Applied Materials completes first corporate solar power system with SunPower

Sunnyvale, California is the location of the U.S.'s first corporate campus-based solar power system, where Applied Materials has had installed two SunPower technology-based facilities totalling 2.1MW. The two systems comprise a 950KW SunPower PowerGuard installation and a 1.2MW SunPower Tracker installation. SunPower in turn uses Applied Materials' Baccini Technology in its cell manufacturing process.

Aerial view from south of Applied Materials Sunnyvale campus.

Mitsubishi Electric enters 1.2MW solar panel contract for California winery

Constellation Wines U.S. has announced its plan to power its Gonzales Winery in Monterey County, California with the help of a 1.2MW solar power installation. The project will see the installation of 6,358 Mitsubishi Electric 185W solar panels on approximately 170,000 square feet of the winery's warehouse roof.

The project is being financed and built by Pacific Power Management and is expected to be completed by the end of the year. The installation is projected to provide around 60 percent of the total energy requirement of the winery.

Other News

Abengoa Solar signs two CSP and thermal R&D contracts for U.S. Department of Energy

Building on the company's three existing R&D contracts with the U.S. Department of Energy, Abengoa Solar has announced that it has been awarded a further two contracts by the Department worth US$14.4 million. The first contract is for development of technology to reduce the cost of thermal energy storage for trough-based CSP systems by 20 to 25 percent, while the second contract will aim to develop new technologies for integrating thermal energy storage with power tower CSP systems.

The Department of Energy's aim in this research funding is to develop CSP technologies to rival conventional energy sources by the year 2015. Abengoa's previous three contracts with the D.O.E., awarded in December 2007, were based on parabolic trough technology development.

Solel and Glaston Open US$9M Solar Reflector manufacturing facility

Solel Solar Systems announced recently the opening of a US$9 million factory in Finland in partnership with Glaston, a glass processing technologies company, for the production of parabolic solar reflectors for Solel's solar field projects. Operations began in September. The facility is located in Akaa, about 200 kilometers north of Helsinki. It has the capacity to produce 240,000 parabolic solar reflectors a year, enough to power a 50MW power plant.

Solel has already announced a number of contracts to supply solar thermal technology to Spanish developers and has recently completed the re-supply of most of the solar receivers for the solar power plants under commercial operation in California's Mojave Desert. Solel's American division, Solel USA, has a signed agreement with Pacific Gas and Electric Company to deliver 553MW of solar power from the Mojave Desert by 2012.

WS Energia enters US market with Solar Monkey partnership

Solar Monkey and Portuguese company, WS Energia, announced an agreement to establish a new generation of high precision, reliable and affordable solar tracking systems in North America based on WS Energia's tracker design.

Product Briefings

First Solar

First Solar's FS Series 2 PV modules are specifically designed for power plants

Product Briefing Outline: First Solar's FS Series 2 PV Modules are designed for use in grid-connected, commercial power plants. They are CdTe thin film in construction that will generally produce more electricity under real-world conditions than conventional solar modules with similar power ratings and the lowest cost per watt overall.

Problem: Cadmium telluride is a direct bandgap semiconductor, which enables it to convert solar energy into electricity more efficiently (i.e., more watts per kg of material) than the indirect bandgap semiconductor materials used historically. As a result, it is capable of converting solar energy into electricity at an efficiency level comparable to historical technologies, but uses only about 1% of the semiconductor material required by traditional PV technologies.

Solution: The efficiency of cadmium telluride is less susceptible to cell temperature increases than traditional semiconductors, enabling First Solar thin film modules to generate relatively more electricity under high ambient (and therefore high cell) temperatures. The semiconductor material also converts low and diffuse light to electricity more efficiently than conventional cells under cloudy weather and dawn and dusk conditions. CdTe permits simple device structures and manufacturing processes, leading to low cost production.

Applications: Free field power plants: Multi-megawatt grid-tied free field applications commercial rooftop systems: large grid-tied, commercial rooftop applications

Platform: Front (substrate) and back (cover) laminated glass sheets are heat-strengthened to withstand handling and thermally induced stresses, while avoiding breakage over the 25+ year module life. Manufactured in highly automated state-of-the-art facilities certified to ISO9001:2000 quality and ISO14001:2004 environmental management standards.

Availability: Currently available – contact First Solar for further information.

GreenMountain Engineering

GreenMountain Engineering's Trac-Stat SL1 measures tracker performance

Product Briefing Outline: GreenMountain Engineering has launched its new diagnostic instrument for measuring tracker performance, the Trac-Stat SL1. The SL1 is a high-resolution datalogging sensor that mounts on a solar tracker. It records the angle of error between the sun and the tracker for use in the development of tracking, concentrating photovoltaic (CPV) and solar thermal systems.

Problem: There are many possible sources of error in a solar tracking system, from tracker installation and wind loading, to thermal expansion and subtle algorithm errors. Identifying and mitigating these issues is key to maximizing system performance and driving the cost-competitiveness of technologies like CPV that rely on accurate tracking.

Solution: The SL1 is a high-resolution datalogging sensor that mounts on a solar tracker. It records the angle of error between the sun and the tracker for use in the development of tracking, concentrating photovoltaics and solar thermal systems. With a resolution of +/-0.02°, the SL1 meets the precision requirements of CPV tracking systems. The data collected can be used to characterize the error in a tracking system, log controller performance over time and calibrate and align trackers. This information is essential for the development of the high-accuracy tracking systems required for CPV.

Applications: Provides consistent and accurate information about the pointing error of solar trackers.

Platform: The SL1 offers the flexibility of analog or USB output with both interactive and stand-alone operation modes. In interactive mode, the operator can read current sun position data over a USB connection for tracker calibration and monitoring. In stand-alone mode, the SL1 can log data to internal memory over extended periods of operation for later download and analysis.

Availability: July 2008 onwards.

Global Solar Energy

Global Solar Energy's flexible CIGS cells are BIPV compliant

Product Briefing Outline: Global Solar Energy's flexible Copper Indium Gallium diSelenide (CIGS) solar modules have been awarded the Electrochemical Commission (IEC) certification. The IEC 61646 certification carried out at the Arizona State University Photovoltaic Testing Laboratory (ASU-PTL), enables the flexible CIGS product to be used in a wide variety BIPV solar products.

Problem: Unlike traditional solar panels that are rigid, heavy and fragile, Global Solar's thin-film solar modules are lightweight, flexible and durable. While other companies produce CIGS on glass, Global Solar claims to be the only company with CIGS on flexible materials.

Solution: Global Solar has developed a proprietary process for manufacturing thin-film CIGS photovoltaic cells and modules. Global Solar is the only company reliably producing CIGS that can be encapsulated in traditional glass modules or in a flexible substrate. CIGS create more electricity from the same amount of sunlight than does other thin-film PV and therefore has a higher "conversion efficiency". CIGS conversion efficiency is also very stable over time, meaning its performance continues unabated for many years. The performance of many other PV materials can rapidly decline with use. Customers are well aware that Global Solar's CIGS does not suffer the degradation in cell efficiency associated with other thin-film PV.

Applications: Its thin-film CIGS strings are not dependent on silicon and instead use highly-available raw materials that are easily integrated into a wide range of applications for use in commercial, residential, utility-scale and government products.

Platform: CIGS is deposited on a flexible stainless steel backing. Cells are supplied in strings to make power sets that can be dropped into solar glass products using virtually the same process that is used to manufacture silicon glass modules. The solar cell strings come in varying power sets and can be used for glass modules from 6W to over 100W.

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Availability: Currently available.

Product Briefings

SOLON AG

SOLON Single Axis tracker comes as complete module system

Product Briefing Outline: SOLON AG is introducing the SOLON Single Axis tracking system as part of a newly developed complete photovoltaic system for large-scale projects. SOLON Single Axis tracks the sun`s position on a single axis and is claimed to achieve up to 25 percent more output than a comparable fixed tilt solar system. Cost-efficient installation and low maintenance expense are its key attributes. SOLON will offer the system starting in early 2009.

Problem: The use of top-quality COR-TEN steel or hot-dipped galvanized steel in the manufacture of the SOLON Single Axis ensures that it is capable of withstanding extreme weather conditions for decades. The system is designed for wind speeds of up to 80km/hr in operating position and up to 130km/hr in storm position. The large modules used and the time-tested SOLON connecting technology also give the SOLON Single Axis improved security against theft.

Solution: The SOLON Single Axis standard unit consists of 12 module rows containing 32 large SOLON modules each. The system is tracked hydraulically along the horizontal axis. In addition, automatic backtracking corrects the position of the units as needed to prevent the modules from shading one another. Depending on latitude, the SOLON Single Axis can increase output by up to 25 percent. The preassembled installation system makes it possible to set up the system rapidly, with efficient use of resources and low inputs of time and material.

Applications: Large-scale projects.

Platform: The market launch of the SOLON Single Axis represents an expansion of SOLON AG`s product portfolio in the field of solar power plant technology. SOLON has already demonstrated well-engineered power plant technology with the SOLON Mover, a complete dual axis PV tracking system. Since its market launch in 2005, more than 10,000 SOLON Movers have been installed worldwide.

Availability: Early 2009 onwards.

Advanced Energy Industries

AE's 'Solaron' PV transformerless inverter targets commercial applications

Product Briefing Outline: Advanced Energy Industries has introduced its 'Solaron' PV inverter – the first high-power, transformerless, grid-tie inverter for commercial system installations that are designed to convert raw, solar DC power to high-quality, North-American AC grid electricity.

Problem: Producing solar-generated electricity on a commercial scale can require large, up-front capital investments. In addition, commercially viable PV systems must be designed for easy integration, unmonitored operation and minimal maintenance over years of service.

Solution: AE's PV inverter technology converts raw DC power from solar-cell arrays to high-quality AC-grid electricity, enabling commercial installations to produce targeted output power levels with fewer solar modules and potentially lower balance-of-system (BoS) costs than was previously possible. With 97 percent CEC-weighted efficiency, the new Solaron platform enables integrators and independent power producers to realize a substantial return on their inverter investment alone. Designed for the North American market, the first model of the Solaron platform offers a durable, transformerless, grid-tie design. With its robust controls and patented, soft-switching technology, the Solaron inverter achieves breakthrough 97 percent CEC efficiency and is NRTL-certified to UL 1741. A wide MPP (maximum power point) tracking window ensures maximum, day-long processing power. Both local and remote data access enables operators to monitor the system's performance and reliability.

Applications: 333kW grid-tied commercial applications.

Platform: bipolar architecture and patented, soft-switching technology, the Solaron inverter achieves breakthrough 97% CEC efficiency and is NRTL certified to UL 1741-2005 by CSA International. A wide MPPT window ensures maximum, day-long processing power.

Availability: July 2008 onwards.

TITAN TRACKER

TITAN TRACKER designed for high-accuracy zenithal tracking

Product Briefing Outline: The TITAN TRACKER 122-219 ATR PRECISION is a new concept in solar trackers and has been developed for flat-plate and high concentrating photovoltaics (CPV). It breaks with the usual trend, based on mounted-pole systems, and is claimed to offer improved benefits during the whole life-cycle of the installation

Problem: Accuracy is a critical parameter for high concentrating photovoltaics, but also reliability and cost-effective. Many two-axis sun trackers do not cover the whole angular field in the zenithal tracking properly and therefore they do not get the maximum performance with double-axis tracking.

Solution: TITAN TRACKER provides adjustable accuracy, better than 0.01 degrees, thanks to the stiffness and rigidity of its 3D structure, geometry based on five supports and the location of the motor gears in the outer sides (with a long lever). TITAN TRACKER is claimed to be the only tracker that makes a continuous tracking in azimuth for CPV applications.

Applications: Flat-plate and high concentrating photovoltaics.

Platform: The foundations are minimal due to there being not bending moments (such as in mounted-pole systems) and hence important savings in materials (up to 35% less concrete and 85% less steel) can be achieved. Formwork is not needed, thereby reducing the need of specialized staff. Wind speed up to 125Km/h at any position. The tracker has a patented mechanism, which allows for adaptation to possible irregularities in the track, thereby avoiding any possible errors due to uneven surface. The structure is composed of cold-formed sections of steel using screws and galvanized in continuous process. All components have been designed and tested according the most demanding international standards.

Availability: April 2008 onwards.

Concentrated photovoltaics: the path to high efficiency

Francisca Rubio & **Pedro Banda**, ISFOC, Puertollano, Spain

ABSTRACT

The costs of a photovoltaic installation are driving the market and the need for subsidized schemes, such as feed-in tariffs. Concentrated photovoltaics (CPV) is leading the development of future lowcost renewable energy sources in two ways: on one hand offering high efficiency systems, and on the other, being most capable of reducing manufacturing costs. The idea to decrease the cost of the photovoltaic system using optical elements to focus the radiation into the cell to reduce the size of the cells has been in the mind of the scientists since the 1970s [1]. But, apart from a reduced market, there were several issues that did not allow CPV success at that time. This paper puts forth the proposition that the key is to replace the area of active material, which is the most expensive, with optic elements, which are well known and cheaper.

Introduction

In order to optimize the performance under concentrated light, the cells should be very efficient – more efficient than the 20% record lab efficiency reached in the initial days of research [2]. Cell technology did not permit very high concentration levels; the maximum concentration ratio was 40% and therefore the optical elements were very simple. Cell technology based on Si and its low efficiency did not allow a large reduction of the cell size and therefore, the temperature budget was low, creating degradation problems in the system. For example, in the SOLERAS project in Saudi Arabia, installed by Sandia Labs in the 1980s, the systems degraded by up to 20% in six years, mainly due to delamination issues at high temperature. A further issue resulted from the use of outdated tracker technology, creating problems with the algorithms and control systems. Despite these hurdles, this project continued in operation for 18 years [3].

CPV technology relies particularly on these three areas: high efficiency cells, optics and sun tracking. In each of these areas there have been significant developments in the last five years, leading to current commercial systems already competitive in the current market.

Cells

Cell technology has been greatly improved and the efficiency consequently increased. Si-based solar cells with back point contact [4] reached an efficiency record of 27.6% and some manufacturers like Amonix or Guascor Foton use this type of cell under more than 400X concentration [5]. However, the best improvement in cell technology lies in the use of compound III-V semiconductors. Ternary alloys of III-V elements like GaAs together with In, Al and P allow a better temperature behaviour of the cell. GaAs' thermal coefficient is $1.76*10^{-3}$ °C^{-1}, compared to $3.21*10^{-3}$ °C^{-1} for Si. Also, III-V technology allowed the development of multijunction solar cells. Two or more p-n junctions are monolithically integrated into a single device. The use of these cells allows a better use of the solar spectrum as each of the junctions is optimized to capture the radiation of a different part of the spectrum. Based on the spectral response, the theoretical limit efficiency of silicon cells is 40%, whereas multijunction cells could potentially reach 86% [6]. Current records for laboratory multijunction cell are Spectrolab's 40.7% record [7] and 40.8% from NREL [8]. These very high efficiencies would allow the reduction of the cell size down to 1cm^2 or even 1mm^2, like in Isofotón or Concentrix systems [9]. This decreasing area also allows the improvement of the thermal behavior and the reduction of the serial resistance [10]. Currently, almost all systems using multijunction cells have concentration ratios of more than 350X, while the majority feature more than 450X (Concentrix, Solfocus, Arima...), with some using ratios of up to even 1000X (Isofotón). The way is paved to proceed to higher concentrations.

Thermal management

Thermal management continues to be a challenge for CPV systems. Most of them use some type of heatsink or thermal dissipater as passive cooling. In most of the designs an alumina plate is used to mount the cell die as it is a good electrical insulator and a good thermal conductor. In order to improve the thermal behavior, there are designs which use a very simple and small Cu or Al plate [11]; others link directly to the metal housing of the module, whereas others use intermediate thermal systems. In large parabolic mirror dish systems, such as those from Solar Systems (Australia) [12], an active cooling system is needed due to the fact that all the cells are together and the thermal dissipation area is lower.

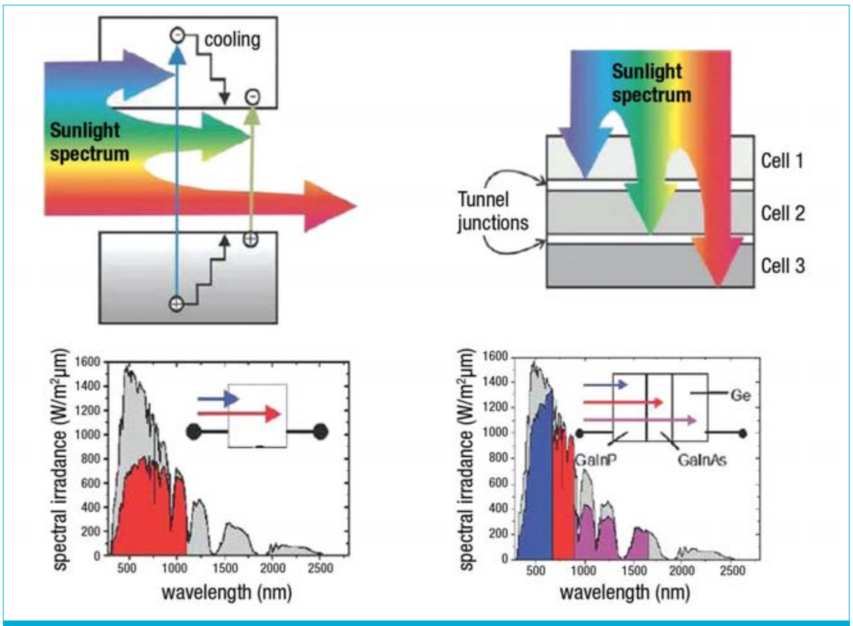


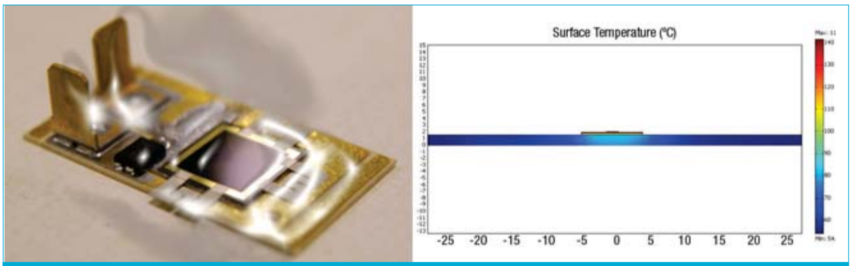
Figure 1. Solar spectrum in Si and multijunction cells.

Courtesy of A. Luque, CONSOLIDER project.

Optics

Optical designs that meet the strict criteria for high concentration systems are key to new CPV concepts. Traditionally, flat Fresnel lenses or mirrors have been used, such as those in Sandia, Ramon Areces, and Euclides systems [13]. In current systems, the Fresnel lens is still the optical element of choice for companies such as Concentrix, Amonix, Guascor, Emcore, Arima ECO, Renovalia CPV, Sol 3G and Entech, among others. Ease of design and simulation, as well as reduced cost, are the contributing factors for this being considered a lead component. Nevertheless, its manufacture meets a number of challenges under the requirements for high concentration CPV. There are various technological approaches to the manufacture of Fresnel lenses, from injection or compression molding, with very difficult tuning, to silicone films, which do not always allow good prices. In order to improve the acceptance angle of the system, a secondary element can be used. This element is normally made of a solid glass or hollow metal prism, both of which allow a better light distribution on the cell and improve the collection of the light [14]; optical systems without a secondary element can also provide very high efficiencies [15].

Reflective optics are an alternative method, capable of being used in several ways, such as in a large parabolic mirror dish, using a parquet of cells, like Solar Systems' technology [16], or as compact mirror systems, with one parabolic mirror per cell, which can incorporate additional reflection steps like Solfocus' system [17].



Courtesy of Renovalia CPV.

Figure 2. Cell featuring alumina and thermal simulation.

Additionally, other non-imaging optical concepts like the Total Internal Reflexion (TIR) system [18] are used by companies such as Isofotón. In recent years, new optical concepts such as XR [19] or RXI [20,21] have been developed, concepts that combine reflection and refraction and have the potential to achieve very high concentration with a wide acceptance angle.

Tracking systems

Depending of the acceptance angle of the optics, tracking systems should be more or less accurate and should be adapted for every module technology. Up to a concentration ratio of 2.5X, there is no need for sun tracking. For mid concentration (up to 40X), the tracker can be lineal, like the Euclides system, with elevation movement in a polar axis or east-west movement in a north-south axis. However, for high concentration systems, two-axis sun tracking with a very high accuracy is mandatory [22].

The control of the tracking system can be carried out in open loops (sun movement equations) or closed loops (light sensor). Use of a single control method can pinpoint tracking errors, while tracking accuracy can be reduced by using an open loop control on a system that has not been precisely installed and positioned. A closed loop system will not work properly if there are clouds shadowing the light sensor. Current systems use hybrid control, which include both sun movement algorithms and radiation or power output sensors [23].

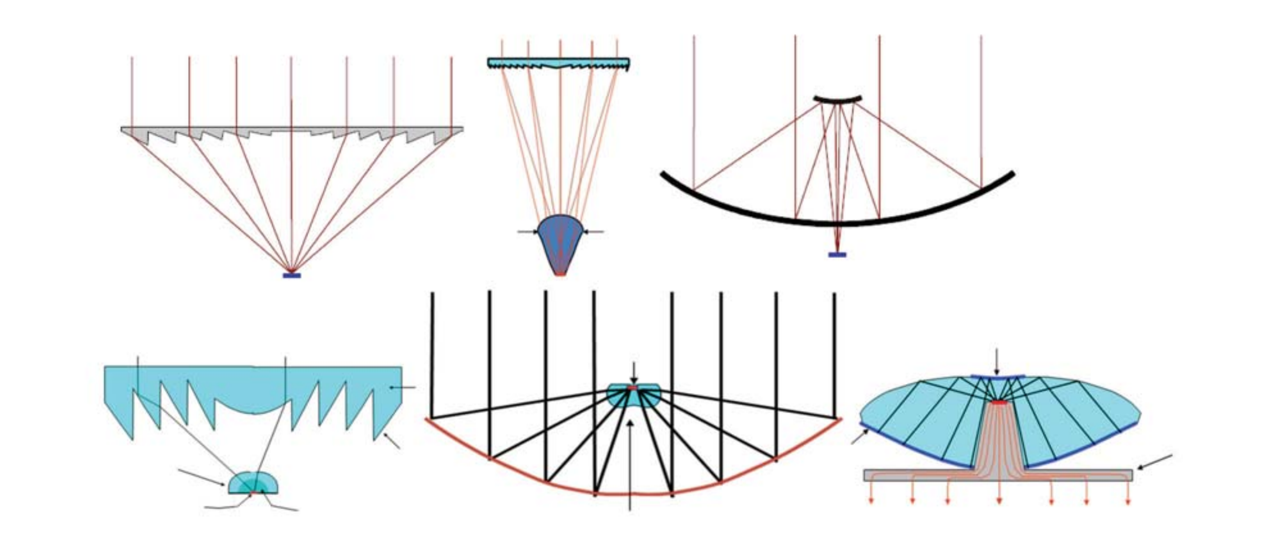


Figure 3. Different optics layouts: Fresnel without secondary, Fresnel with secondary, mirror, TIR, XR optic and RXI optic.

Institute for Concentration Photovoltaics Systems – ISFOC

Technology developments and a buoyant PV market have made it possible for CPV to be deployed. High efficiency cell technology is already available for terrestrial applications; new optical concepts or processes have also been developed and, finally, tracker systems and controls are being developed and validated. With proven technology and manufacturing processes available, manufacturing lines and utility-sized CPV power plants are ready for deployment.

Armed with the objective of making this a reality, ISFOC, formed in September 2006, is the result of the R&D plan promoted by the Spanish Department of Education and Science from the Castilla La Mancha Government and the IES-UPM (Institute of Solar Energy from the Universidad Politécnica de Madrid). The project is financed by the Spanish Ministry of Education and Science [24].

In order to generate key knowledge on this technology, ISFOC is executing a number of power plants (up to 3MW in total) incorporating different concentrator technologies. Companies featuring in the first phase include Isofotón (ES), Solfocus (US) and Concentrix (DE). The second phase includes Emcore (US), Sol 3G (ES), Arima Eco (TW) and Renovalia CPV (ES).

Currently, there are 1.1MW already installed and connected to the grid from the first phase. The objective of these pilot plants is to assist the industries in the setting up of pilot fabrication lines. There will also be valuable information obtained from the process such as reliability, suitability and production from each technology [25].

Standards

In December 2007, the first standard for CPV (IEC 62108) was approved. This standard establishes the reliability tests for the CPV modules. The tests to be carried out are:

- Electrical tests: electrical performance measurement, ground path continuity test, electrical insulation test, wet insulation test, bypass/blocking diode thermal test and hot-spot endurance tests).
- Climatical tests: thermal cycling test, damp heat test and humidity freeze test.
- Mechanical tests: hail impact test, robustness of terminations test and mechanical load test.
- Ambient conditions: water spray test, off-axis beam damage test, ultraviolet conditioning and outdoor exposure test.

There are a number of laboratories that are now in the process gaining of

Figure 4. Euclides system.

Figure 5. Two-axis tracker.

Courtesy of Denis Lenardic, www.pvresources.com.

Figure 6. ISFOC HCPV power plants in Puertollano.

Manufacturers	Company	Today on sun (MW)	Plant location	Manufacturing capacity (MW/year)
Abengoa Solar	Spain	1.2	Spain	
Guascor foton	Spain	10.275	Spain	15
Isofotón	Spain	0.4	Spain	5
Renovalia CPV CS La Mancha	Spain	0	Spain	11
Sol 3G	Spain	1.4	Spain	12
Concentrix	Germany	0.3	Spain	25
Solfocus	USA	0.5	Spain	50
EMCORE	USA	0.35	Spain	10
AMONIX	USA	0.61	USA	
Arima ECO	Taiwan	0.05	Spain	7.5
Solar Systems	Australia	1.2	Australia	5
Total		**16,285**		**140.5**

Table 1. Main CPV manufacturers showing total installed power versus actual manufacturing capacity.

accreditation for performing these tests. All companies under ISFOC's project must pass the most important tests of this standard before installation. During performance of the standard procedures, designs were improved and modifications were added to comply with the IEC tests. The isolation test and the damp heat test are among the most difficult trials, as the modules need to show they are watertight while maintaining electrical isolation.

Other standards under development include CPV modules power rating, CPV system energy rating (with ISFOC participation) as well as tracker requirements and safety.

At ISFOC, power and energy rating of CPV systems and concentrator characterization is being carried out using the methodology described in [26]. ISFOC's experience is aiding in the improvement of the procedures outlined in this publication.

The standard conditions for concentrator characterisation are defined at 850W/m^2 and a cell temperature of 60ºC. The possibility and potential benefits of changing this temperature value to 25ºC is currently being researched in order to be comparable with flat panel conditions and indoor characterisation.

The measurement conditions are established as:

- Clear sky conditions.
- The direct radiation should be higher than 700 W/m^2.
- The wind speed should be lower than 3.33m/s.

In order to determine the DC Power of the concentrator, the following variables are monitored during the measurements:

- The I/V curve of the system is measured with a capacitive charge. This equipment incorporates a discharged capacitor, which is charged during the measurement until the system reaches the open circuit condition. This tracer is capable of carrying out very fast measurements over long periods of time automatically, for a range of different concentrator systems.
- Direct radiation is measured in real time by two pyrheliometers.
- Cell temperature is measured with several thermal sensors on the back part of the module behind the cell. The V_{oc} value of either the complete system or an independent and calibrated cell in open circuit could also be used for temperature measurement.
- Wind conditions (speed and direction) are also measured in order to determine their effect on the final rating in the cooling mechanisms.
- Additionally, the spectrum of the sun could also be measured in order to determine its deviations from the spectrum to which cells are characterised.
- The ambient temperature is also measured in order to study the relation between all the parameters and conditions.

Current and voltage values are then translated to as-defined standard conditions following the equations, deduced from the Shockley equation model:

$$I_2 = I_1 \cdot \frac{B_{oper}}{B_{mea}} \qquad (1)$$

Other Companies	Company location
Boeing	USA
Concentrating Technologies	USA
Cool earth	USA
Energy Innovations	USA
Enfocus Engineering	USA
Entech	USA
GreenVolts	USA
JX Crystal	USA
Opel International	USA
Pyron Solar	USA
Semprius	USA
Skyline	USA
SolarTech	USA
Soliant Energy	USA
Menova	Canada
Morgan Solar	Canada
ENEA	Italy
Magpower	Portugal
Solar Tec AG	Germany
Whitfield Solar	UK
Daido Steel	Japan
Sharp Solar	Japan
Everphoton Energy	Taiwan
Green and Gold Energy	Australia

Table 2. Other CPV manufacturers.

where I_2 is the current under standard conditions; I_1 is the measured current; B_{mea} is the measured direct beam radiation and B_{oper} is the direct beam radiation under standard conditions;

$$\Delta V_i = N\frac{0.0257\times(T_{oper}-T_{cel})}{297}\left[\ln\left(\frac{(I_{Lmea1}-I_i)(I_{Lmea2}-I_i)(I_{Lmea3}-I_i)}{I_{Lmea1}I_{Lmea2}I_{Lmea3}}\right)\right] + \left[N(E_{g1}+E_{g2}+E_{g3})-V_{ocmed}\right]\left(1-\frac{T_{oper}}{T_{cel}}\right) \quad (2)$$

and

$$T_{cell} = T_{h-s} + B_{mea}\cdot R_{th,sys} \quad (3)$$

where N is the number of cells in series connection; I_{Lmeaj} is the photocurrent of each junction; E_{gj} is the band gap of each junction; V_{oc} is the system open circuit voltage; T_{oper} is the standard temperature; T_{cell} is the cell temperature; V_{oc} is the system open-circuit voltage and $R_{th,sys}$ is the thermal resistance of the system.

This method allows the calculation of DC power of the concentrator using only a few representative measurements. ISFOC has already validated this procedure using data from the first installation, the results of which are publicly available [27].

Conclusion

With the available technology, approved standards, installation of the first demonstration plants and the availability of their results, the CPV industry is experiencing extraordinary progress. The number of CPV and cell manufacturers has increased in the last two years and the number of CPV installations has become considerable.

CPV is in the early developmental stages of deployment, and holds great potential for rapid growth. With a global PV market driven by government subsidies, CPV will rely on special measures that will allow its growth, independent of other renewable energy sources. We expect that early deployment will be sufficient to show the capabilities of this technology in fulfilling the needs of cost and productivity to reach grid parity in the short term.

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Value of PV energy in Germany

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ABSTRACT

This paper presents a detailed assessment of the value of photovoltaic energy within the German energy supply structure, taking into account the correlation between actual consumption and local power generation. Contrary to previous statistical approaches, this paper takes a new dynamic approach, modelling the dynamic behaviour of the PV power generation as a one-year time series. A comparison with the time series of the power demand allows assessment of the value of PV energy. The value of PV energy mainly results from its ability to substitute conventional power generation and the benefit of this kind of decentralized power generation for network stability and quality. An evaluation of these aspects is carried out for the year 2005 and a likely scenario in 2015.

Introduction

Power generation using PV power plants has achieved an order of magnitude in Germany that has become relevant for energy supply within a short period of time. Assuming a continuation of the enormous growth rates of previous years, PV will have a secure place in power supply. Its role must therefore be more carefully assessed from the point of view of energy provision, especially considering its correlation with actual consumption and local power generation. In order to give a detailed evaluation of PV supply, its temporal and spatial variations have to be considered.

This new approach was developed in a recent study entitled 'Rolle der Solarstromerzeugung in zukünftigen Energieversorgungsstrukturen – Welche Wertigkeit hat Solarstrom?' ('The Role of Solar Power Generation in Future Energy Supply Structures – What Value Has PV Energy?'). The study was supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the German Solar Industry Association (BSW) and the European Photovoltaic Industry Association (EPIA) and includes contributions from Fraunhofer Institute for Solar Energy Systems (FhG-ISE) and meteocontrol GmbH.

Appropriate evaluation of PV energy

The differential costs of EEG [1], calculated as the feed-in tariff reimbursements minus costs of alternative power generation, were examined in a BMU Report [2]. This report established that detailed analyses of the most appropriate sources of electricity from renewable energy are urgently required in order to draw conclusions about further development of the EEG. Based on this recommendation, investigations into the value of PV energy were carried out in the actual study in order to make the requested proper assessment.

Two important points have to be considered:

- The potential of PV to substitute conventional electricity production and power plant capacity where not only base load, but medium and peak load can be supplied through correlation with actual consumption; and
- The potential of decentralised energy generation to save costs in grid operation, by avoiding losses in transmission, and to allow a more secure and efficient operation of the distribution network.

This approach allows a more detailed description of the use of power generation by PV systems than was possible in [2] for pragmatic reasons. This newly developed procedure correlates the dynamic of PV power generation and the dynamic of electricity consumption allowing for a better quality assessment for the value of PV energy than has so far been possible using statistical approaches. To represent the development of the value of PV energy, a scenario for 2015 was developed along with the reference scenario for 2005.

Modelling Germany's PV power generation

In order to account for dynamic effects, a high-resolution model capable of computing the supply of PV throughout the year with a temporal resolution of 15 minutes was developed. Figure 1 shows the procedure schematically. Based on irradiation and temperature data for 120 locations in Germany (from the University of Oldenburg and the German Meteorological Service DWD), time series of standardized PV power generation were computed for every location and for different installation types. In regards to installation, two different technologies (crystalline and non-crystalline), 17 different orientations and five different installation environments (ground-based, flat-roof, on-roof, integrated in-roof, façade) were examined and weighted statistically according to surveys of the German Solar Industry Association (BSW).

A parameterized transforming algorithm is used to extrapolate the PV power generation of several representative sites to PV power generation in grid regions as well as throughout Germany. This algorithm uses two types of entry parameters:

- the standardized PV power generation for the representative sites (result of the first step); and
- the spatial distribution of installed PV capacity.

In 2005 a PV capacity of 1,893MWp was installed. According to statistics published by Photon, the spatial distribution is connected to 875 distribution networks. An installed PV capacity of 12GWp is assumed for 2015. As no forecast on spatial distribution adjusted to distribution networks is available, a distribution adjusted to federal states is chosen, using the scenario assumptions of the BSW for this study.

The calculated time series of power generation were compared to data of PV installations measured by meteocontrol in 2005. The analysis of different sites reveals only low differences between computed and measured data (difference in whole energy generation 1-10% and root mean square error (RMSE) 23-25W/kWp). For this reason, the computing method and the models were assumed to be appropriate for this study and the following analyses.

Substitution of conventional power generation

The assessment of the substitution of conventional power generation requires more than solely taking an average price at the European Energy Exchange (EEX) for comparison or the costs of base load power plants. A new approach was developed to ameliorate the value of comparison. It allows the electricity generation to be classed by power plant type (base, medium and peak load power plants). In this way, the saved generation costs for the different types of power plants can be individually determined.

For such a detailed approach, a one-year time series with a temporal resolution of 15 minutes of PV supply were taken for the year 2005 (2GWp installed PV capacity) and for the projected scenario of 2015 (12GWp installed PV capacity) and contrasted with the load curve. The load curve data for 2005 can be collected from public information on grid load provided by the four transmission network operators.

To assess the time series of load in 2015, it is assumed that the following two parameters cause a variation from the load curve in 2005:

- the increase of electrical power used for air conditioning (summer peak load increases by approximately 3.5GWp between 2005 and 2015); and
- the increase of wind power generation from 17 to 30GW [3].

Using this dynamic approach, the effects of the substitution of conventional power generation were investigated. The benefit of this substitution consists of four different components:

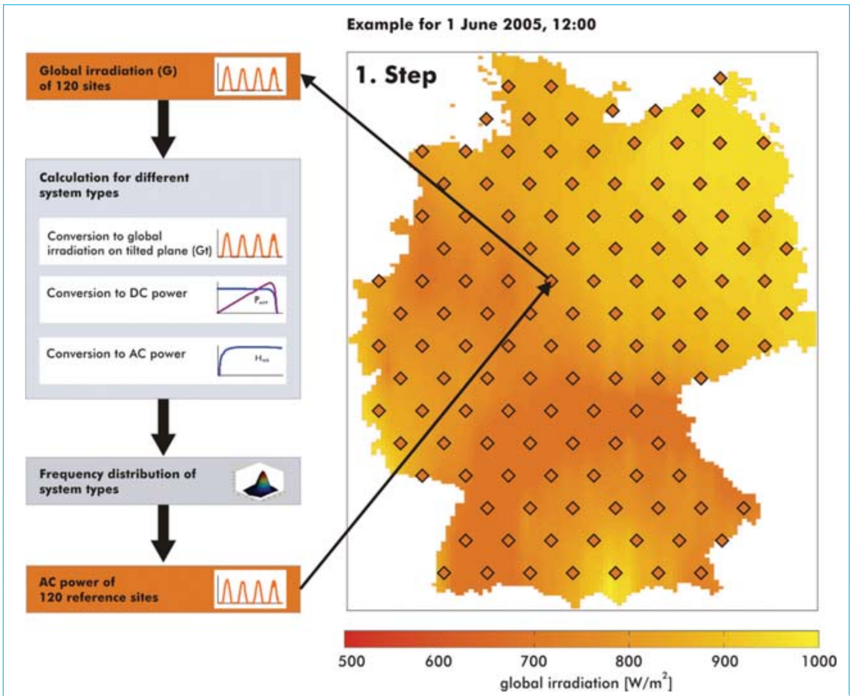
1. Avoided variable power generation costs of the conventional base, medium and peak load power plants;
2. Avoided damage costs of CO_2 emissions by substitution of fossil fuels;
3. Avoided fixed power generation costs of the conventional power plants (power plant capacity effect); and
4. Additional balancing costs caused by the variations of PV power generation.

Avoided variable power generation costs

The dynamic approach for the investigation of avoided variable power generation costs demands that power generation be classed by power plant type. According to the different types of power plants (base, medium and peak load) and the different types of fuel used to supply the electric power in the different load sectors, the savings differ.

Coal-fired and gas-steam power plants are both used to supply medium and peak load. The study does not attempt to form a detailed distinction between medium and peak load power plants, thus allowing a clear view of the substitution effect in summation. Further, it is assumed that base load is constant during working days within one season. The capacity results from the minimum of the weekly averaged hourly profile; accordant assumptions are made for the weekend base load.

Two cases are taken into consideration in the examination of savings accrued by use of PV power generation: a reference case without PV power generation and a scenario with a distinguished installed PV capacity. For these two cases, the consumption is classed in base, medium, and peak load and accumulated over the year. The contrast between the consumption in the two scenarios classed



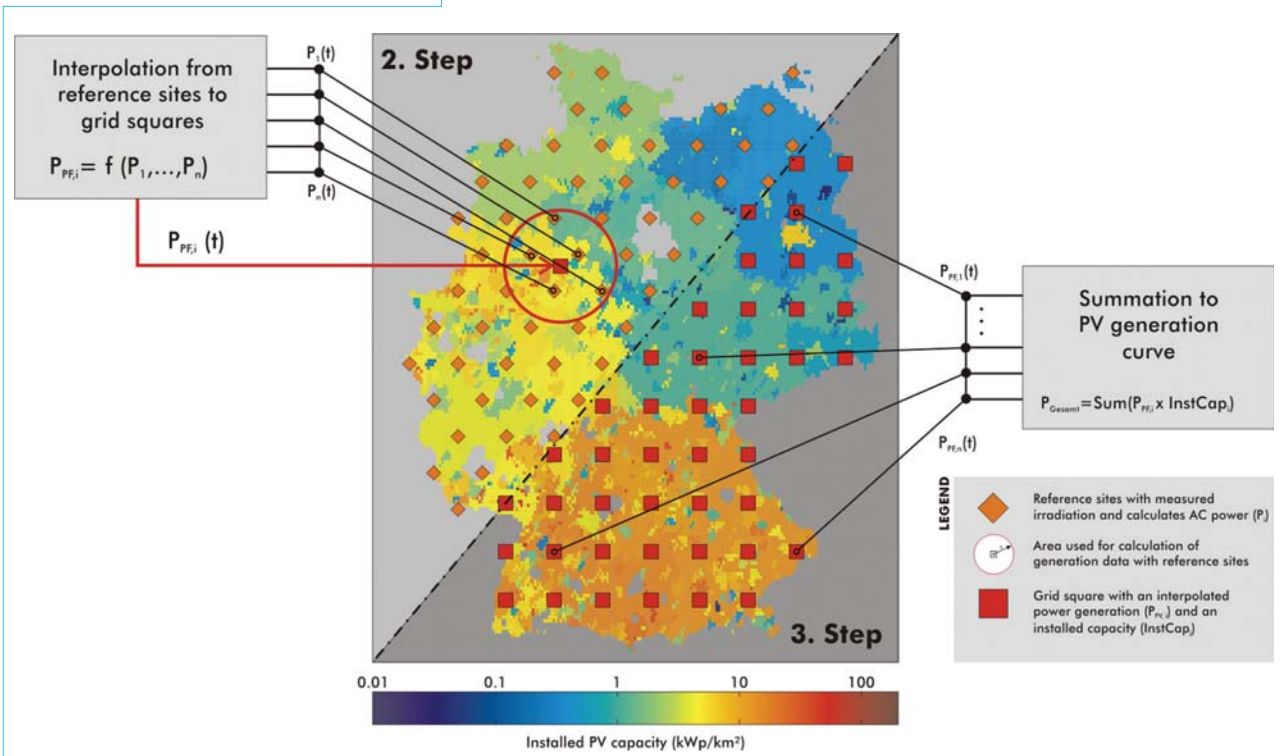


Figure 1. Calculation approach for time-series generation of PV energy in Germany.

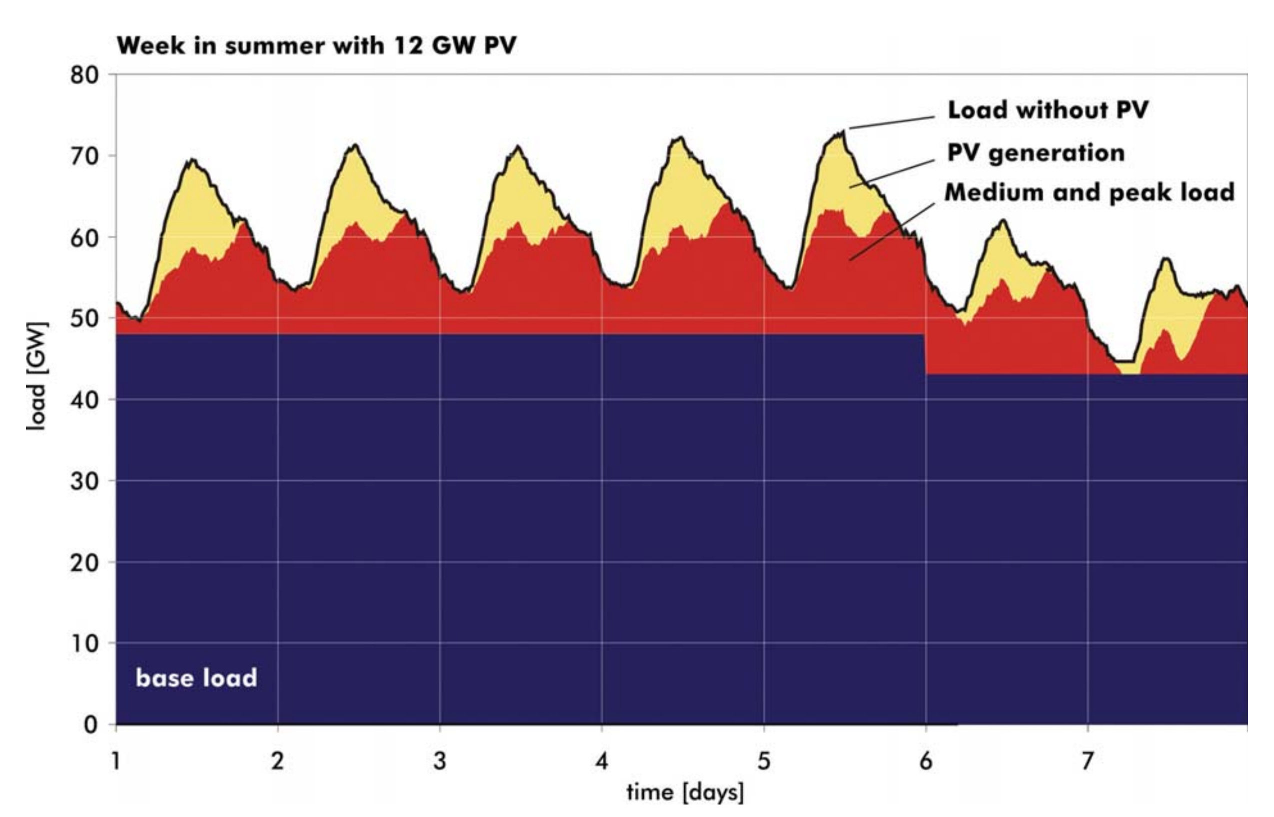


Figure 2. PV generation substitutes highlighting medium and peak load.

by load sectors represents the avoided power generation from conventional power plants caused by PV power generation.

Figure 2 gives an example of the distribution of the total load to base load (blue) and medium/peak load (red) in a summer week assuming an installed PV capacity of 12GWp. The reduction of consumption of medium/peak load due to PV power generation is evident. In the years 2005 and 2015, annual PV power generation is split into 7% base load energy and 93% medium/peak load energy.

The predominant part of PV energy is used to supply medium/peak load. For this reason, solar energy will contribute to a large extent in supplying the variable part of the load, which is conventionally supplied by coal-fired and gas-steam power plants. The power generation costs of these technologies range from 30% (coal-fired power plants) to 50% (gas-steam power plants) higher than the costs of base load power generation.

A range of fuel costs (only lignite/coal-energy-mix – lignite/coal/natural gas-energy-mix 2005 – lignite/natural gas-energy-mix) is taken into consideration to allow differentiation between coal-fired and gas-steam power plants. These three energy mixes allow calculation of the real substitution effect. Three different rates of price trends are considered for the scenario of 2015 [4]. With these basic assumptions, avoided variable power generation costs (respective to energy mix used) amount to approximately 2.5; 3.7; 5.1c€$_{2005}$/kWh$_{PV}$ (2005) and approximately 2.5; 4.4; 6.8c€$_{2005}$/kWh$_{PV}$ (2015) (excluding external costs).

In this context it must not be ignored that avoided fuel costs are minimal at a 100% level of coal use, but saved damage costs of CO_2 emissions are at the maximum. Accordingly, at a 100% level of use of natural gas, the saved fuel costs are maximal but avoided damage costs of CO_2 emissions are minimal. This trade-off has to be taken into consideration to allow a proper assessment of cumulated benefits later in this study. Therefore, saved CO_2 emission costs and avoided variable power generation costs cannot be considered independently. Both cost components were added for each technology, resulting in a combined range. Therein, the range of avoided variable power generation costs is 2.5; 3.1; 4.4c€$_{2005}$/kWh$_{PV}$ (2005) and 2.7; 3.6; 5.9c€$_{2005}$/kWh$_{PV}$ (2015).

Avoided damage costs of CO_2 emissions by substitution of fossil fuels

The most important factor regarding the avoided power generation costs using PV power generation is the saving of external costs. It is assumed that the damage costs resulting from CO_2 emissions comprise the biggest part of external costs. Using the damage cost range of 15; 70; 280€$_{2005}$/t$_{CO_2}$ [5] and assuming avoided CO_2 emissions from conventional medium load power plants of 323; 622; 783g$_{CO_2}$/kWh$_{PV}$, the result is 0.5; 4.4; 21.9c€$_{2005}$/kWh$_{PV}$ avoided damage costs of CO_2 emissions in 2005 and 2015. This calculation also includes CO_2 emissions with a range of 30; 65; 100g$_{CO_2}$/kWh$_{PV}$ during the life cycle of the PV plant.

Avoided fixed power generation costs (power plant capacity effect)

The power plant capacity effect of PV describes the capacity of conventional power plants that can be substituted by the installation of PV systems. Different approaches allow an investigation of the influence of PV energy on the necessary installed power plant capacity. By noting the PV power generation at the moment of annual peak load (1995-2005), it is ascertained that the effect of power plant capacity of PV is insignificant, as no PV system could supply power at the moment of annual peak load.

An alternative method to investigate the effect of power plant capacity is the so-called 'Effective Load Carrying Capability' (ELCC) [6]. The ELCC of a power plant is defined as the rise of load without further decrease of security of supply (here assumed to be 99%), which is made possible by this power plant. Applying the ELCC method, the power plant capacity effect amounts to 230MW in 2005 (11.5% of installed PV capacity) and 3,600MW in 2015 (30% of installed PV capacity) through the use of PV.

The use of wind energy mostly reduces load in winter and decreases the difference

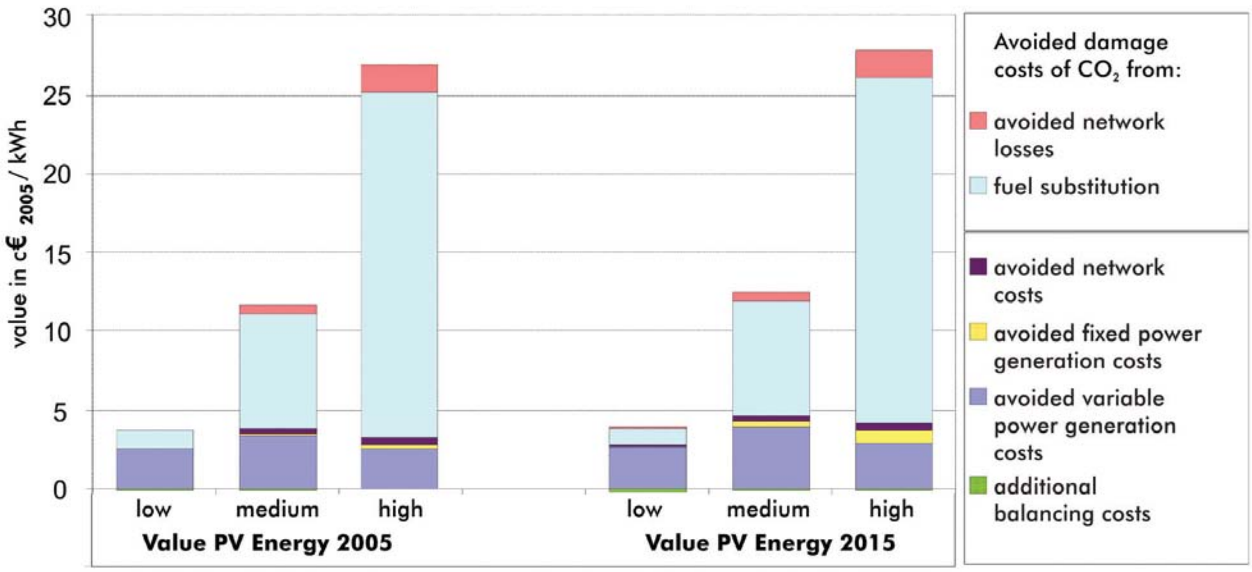


Figure 3. Value of PV energy split into the different value components.

between summer and winter peak load. This leads to a higher effect of power plant capacity of PV in 2015 (30GW wind) than in 2005 (17GW wind). Assuming the same boundary conditions, an effect of wind energy on power plant capacity of 6% in 2005 and 11% in 2015 is identified.

In evaluating the power plant capacity effect of PV, it is assumed that PV systems substitute gas-steam and coal-fired power plants, which are typically used to provide medium/peak load. They have investment costs of 550; 800; 1300€/kW. Assuming a lifecycle of 40 years, a discount rate of 5% and an average annual PV energy production of 900kWh$_{PV}$/kWp, the resulting benefits of substituted power plant capacity lie in the range of 0.0; 0.15; 0.3c€$_{2005}$/kWh$_{PV}$ in 2005 and 0.0; 0.4; 0.8c€$_{2005}$/kWh$_{PV}$ in 2015.

Additional balancing costs

As balancing group management does not have the ability to track the actual load exactly, balancing capacity is required. The available balancing capacity can be positive (increase of power generation) as well as negative (reduction of power generation). Three sources of error are known: errors in load forecasts, unplanned outages of power plants and errors in forecasts of wind power generation. In the course of the increasing relevance of PV power generation, the accuracy of its forecasts becomes equally important.

The examination of actual and future costs of errors in forecasts of PV power generation led to the determination of the balancing capacity range based on the approach and assumptions that were used in the German DENA study [3]. The statistical approach is based on an interaction of the probability functions of the different forecast errors. A forecast error of 10% of normalized root mean square error (NRMSE) was assumed for 2005 and 6% of NRMSE for 2015. This corresponds to the predicted improvement of wind forecasts [7].

Assuming a deficit level of 0.01%, the additional range of balancing capacity due to PV power generation is determined to be +19MW and -20MW (-1.0%/+1.2% of installed PV capacity) in 2005 and +280MW and -220 MW (-1.8%/+2.3% of installed PV capacity) in 2015. Under the assumptions of an average tariff for positive reserves of 65€$_{2005}$/(kW year) and for negative reserves of 25€$_{2005}$/(kW year) [8], the additional balancing costs are approximately 0.1c€$_{2005}$/kWh$_{PV}$ in 2005 and 0.2c€$_{2005}$/kWh$_{PV}$ in 2015.

Potential benefits for network operation

Due to their local/decentralized power generation, PV systems have the potential to generate benefits for network operation in three ways:

1. Reduction of network losses: power losses can be reduced as locally generated power substitutes power generated by more distant producers. Saved damage costs of CO_2 emissions caused by reduced power losses are closely linked to this.
2. Network capacity effect: local generation reduces the network's loading and releases additional transmission capacities. This allows a delay or even avoidance of grid extensions.
3. Benefit from the active provision of local ancillary services for network operation to improve its quality, security and efficiency.

Reduction of network losses

The analysis of transmission losses of German network operators shows that an upper limit of 10% in all layers of network and in annual average can be assessed. In the actual study, a lower range of avoided power losses of 2-8% is assumed due to PV power generation. This lower range is caused by the topological distribution of installed PV capacity that constrains the achievable reduction of network losses compared to an ideal topological distribution. Assuming costs of 6c€$_{2005}$/kWh$_{PV}$ for network losses (according to internet publications of network operators), the result is avoided network losses in the range of 0.1; 0.3; 0.5c€$_{2005}$/kWh$_{PV}$ (excluding avoided external costs).

Network capacity effect

A comparison to standard VDEW load curves (for households and for agriculture) shows that there is no PV power generation at the moments of annual peak load (typically in winter evenings). Data from enterprises with peak load during the day yields a different situation. However, a reduction of annual peak load cannot be guaranteed in this case because PV power generation can be near to zero at the moment of annual peak load.

An approach with the ELCC also shows that the network capacity effect can be neglected in this study. In future, different behaviour of use (e.g. air-conditioning and energy management) could lead to more correlation with PV power generation and the benefit of the network capacity effect could increase. Distribution networks are usually not fully loaded.

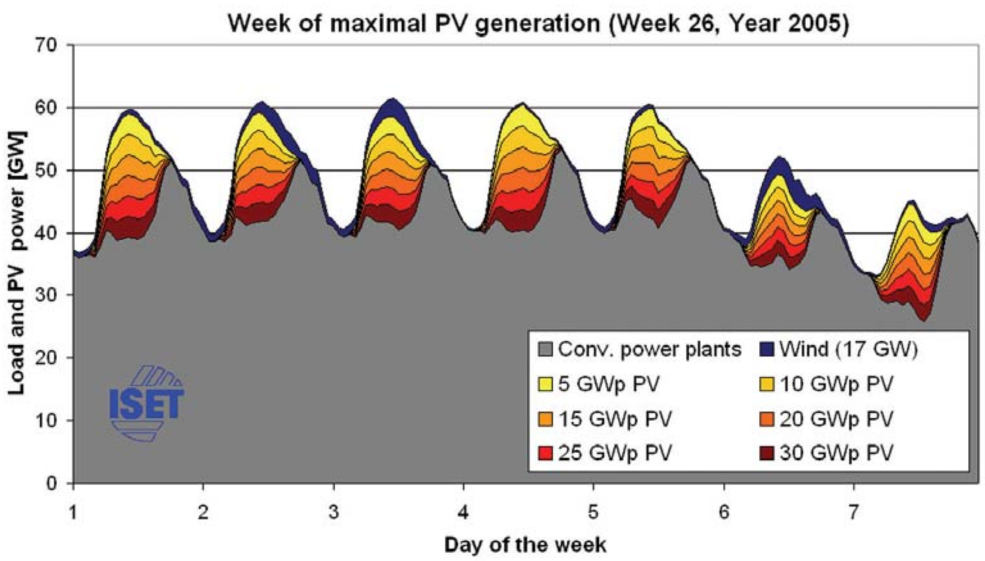


Figure 4. Influence of PV energy production to the load curve dependent on installed PV capacity. The load curve is shown for the week of maximal PV energy production (database: 2005, 17GW installed wind capacity).

This means that there is no benefit from any network capacity effect; this may change considerably with an increasing load in the future.

Benefit of active provision of ancillary services for network operation

Possible ancillary services as well as the economic attractiveness of their provision were examined in the course of this study. With the exception of primary control and positive balancing capacity [8], PV systems are suited to the provision of ancillary services due to their decentralized installation. In many cases, a quantification of the benefit is difficult to achieve because the possibilities of contribution and respective reimbursements are absent. In the overall result of this study, the benefit from providing ancillary services is currently assumed to be insignificant. In the future, an enormous increase of this benefit value is possible, especially with regard to active distribution network management. Power quality and reliability can be improved by the use of PV systems and reactive power can be provided very cost-efficiently [9].

Avoided costs of network operation

The avoided costs of network operation result mainly from the avoided costs of network losses in the range of 0.1; 0.3; 0.5c$€_{2005}$/kWh$_{PV}$. The other two factors are considered to be insignificant to the actual study. As with the substitution of conventional power generation, the avoided damage costs of CO_2 emissions from the avoided network losses must also be taken into consideration. This leads to avoided damage costs of CO_2 emissions from avoided network losses in the range of 0.0; 0.2; 1.8c$€_{2005}$/kWh$_{PV}$.

In this context, it must be emphasised that the investigations in this report are targeted at average benefits in Germany, though case studies with considerably

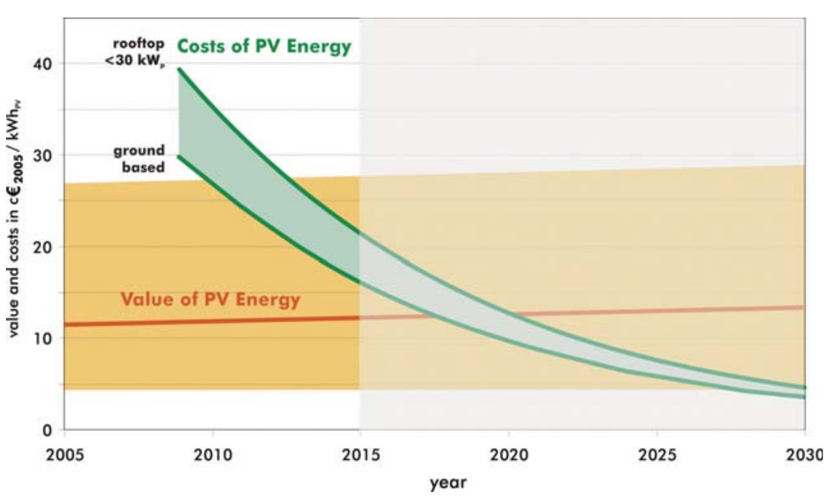


Figure 5. Comparison of costs (reference: EEG feed-in tariffs according to the blueprint for EEG 2009, including 2% inflation) and the range of value of PV energy determined in this study (in $€_{2005}$).

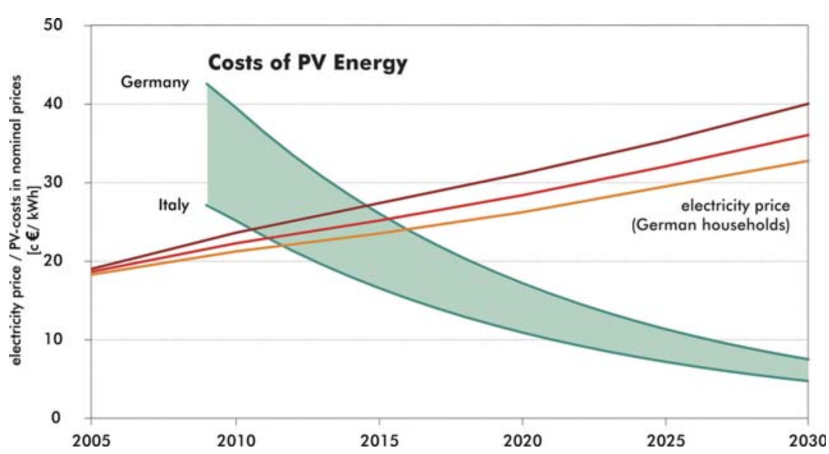


Figure 6. Comparison of the value of PV energy and the electricity tariffs for households in determination of grid parity.

higher benefits are possible. It is assumed that the results of the presented approach can be applied for 2005 and 2015.

Conclusion

The result of the study with the given scenarios for 2005 and 2015 is shown in Figure 3. A total value of PV energy in a range of 3.5; 11.5; 26.9c€$_{2005}$/kWh$_{PV}$ in 2005 and 3.6; 12.3; 27.7c€$_{2005}$/kWh$_{PV}$ in 2015 is identified. (Value given in 2005 prices.)

The effect of avoided damage costs of CO_2 emissions is evident. The underlying assumptions for these values are associated with great uncertainties and are not further examined in this study. An alternative approach of these costs using the avoidance costs of CO_2 emissions may show an increase of these costs in the future.

A number of factors of the value of PV energy were not considered in this study. Among these are hedging of price fluctuations, taxes and duties, and external economic influences such as the labour market. A combined investigation that includes wind energy and other renewable energies is recommended. It can reveal further synergy effects that can increase the total value significantly.

An important finding of this study is the high correlation with the demand curve that allows integrating PV into the existing power supply structure up to an installed capacity of 30GWp without important structural changes in the portfolio of power plants (Figure 4) because of the predominant replacement of controllable medium/peak load power plants. Poorly controllable base load power plants, on the other hand, are affected in their operation at low rates. Therefore, any additional storage capacity is not necessary.

Furthermore, a predominant decentralized and local PV power generation reduces costs for the network operation, especially with regard to the transmission network. An additional advantage of PV power generation is the cost-efficient possibility of providing ancillary services. They can be integrated effectively in network management systems and can contribute to an improvement of network stability and quality.

In conclusion, Figure 5 compares the assessed value of PV energy with the feed-in tariff reimbursements. The feed-in tariffs according to the blueprint of the new EEG of December 5th, 2005 are used as reference. Viewed in relation to PV energy costs for 2009, the range is between 32c€/kWh$_{PV}$ for ground-based PV installations and 42.48c€/kWh$_{PV}$ for rooftop installations <30kWp. This blueprint envisages a reduction of 7% for 2010 and 8% starting from 2011. An inflation rate of 2% is assumed and calculated at 2005 prices in an attempt to represent the actual remuneration. Depending on the assumptions made, especially regarding avoided damage costs of CO_2 emissions, the value of PV energy will reach the costs according to the feed-in tariff between 2011 and 2030 as shown in Figure 5. The ascertained values for 2005 and the scenario in 2015 are therefore continued proportionally until 2030. The medium value intersects during the years 2017 and 2020.

Alternative approach: grid parity

This newly developed approach for the determination of the value of PV energy complements other existing and commonly-used approaches. One approach takes the point of view of a household and calculates the so-called grid parity (in relation to date) when generation costs or feed-in tariffs are below private power purchase tariffs. From the date of grid parity, the use of generated PV energy will be more economic than its feed-in. For this reason, this date also represents the point at which the EEG-reimbursement could be replaced by other types such as Net-Metering.

For example, a household with an annual electricity consumption of 3500kWh and power purchase costs according to Eurostat, with three different inflation scenarios [4]. The expected feed-in tariff of PV energy generation according to the blueprint of EEG of December 5th, 2007 is taken for reference for the costs of German PV feed-in. In Italy, where higher irradiation would lead to an additional energy production of approximately 57%, the costs of PV feed-in are considerably lower.

Figure 6 shows the comparison between Germany and Italy. In Germany, grid-parity will be reached in 2014-2016. Assuming the same acquisition tariffs, but taking into account the Italian irradiation levels, grid parity would already be reached in 2010-2011.

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Climbing the ladder to the top: Italian photovoltaic market report

Daniel Pohl, EuPD Research, Bonn, Germany

ABSTRACT

Apart from some obstacles and bureaucratic hindrances, the Italian PV market has recently joined the upper echelons of the solar industry. Along with small and medium-sized systems, the commercial and large-scale segment in particular has a great deal of promise. Even though the local industry is still trying to block the domestic market from international competitors, increasing numbers of foreign investors are entering the market. In this close-up of the Italian PV market, the country's participation in the solar energy industry is reviewed and a projection to 2010 is given, with particular emphasis on the country's potential to be a major player in the large-scale installation sector.

Introduction

Companies from all along the value chain are currently looking at the Italian PV market with great interest. These are not just European enterprises; companies from the U.S., China and the Far East are beginning to sit up and take notice in the southern European market. "The main reason why interest has grown so enormously in the recent months is that Italy's photovoltaic installation capacities, promoted by the Conto Energia, are increasing so rapidly. From only 9.4MW at the end of 2006 they surpassed the 100MW-milestone in mid-April 2008 and by mid-June, 145MW had been notched up," explains Gianni Chianetta, President of the Italian solar industry association Assosolare. Currently, Italy is only the third largest country market in Europe, gaining ground on PV 'world champion' Germany and the top market Spain.

However, both of these competitors are expecting stormy weather in the near future. "The German PV market for instance, known for years as a very stable and fast-growing sales market, is likely to experience some cutbacks in the face of the upcoming degression in 2009. For one, feed-in tariffs will be reduced and in addition to that a dynamic growth corridor for the installation of PV systems has been set. If the limit is exceeded, the degression will be raised even further," says Markus A. W. Hoehner, Chief Executive Officer of EuPD Research. The story in Spain is quite similar. Although the Spanish solar promotion law was replaced by the long-awaited Royal Decree RD 1578/2008 in late September 2008, there remain uncertainties. Given this situation, many investors are pinning their hopes on the further development of the Italian market.

System size (kWp)	Non-integrated systems	Partially integrated systems	Integrated systems
1≤p≤3	0.40 EUR/kWh	0.44 EUR/kWh	0.49 EUR/kWh
3≤p≤20	0.38 EUR/kWh	0.42 EUR/kWh	0.46 EUR/kWh
p>20	0.36 EUR/kWh	0.40 EUR/kWh	0.44 EUR/kWh

Source: EuPD Research 2008.

Table 1. Feed-in tariffs according to the Conto Energia (February 19th, 2007).

Figure 1. Enerco rooftop installation.

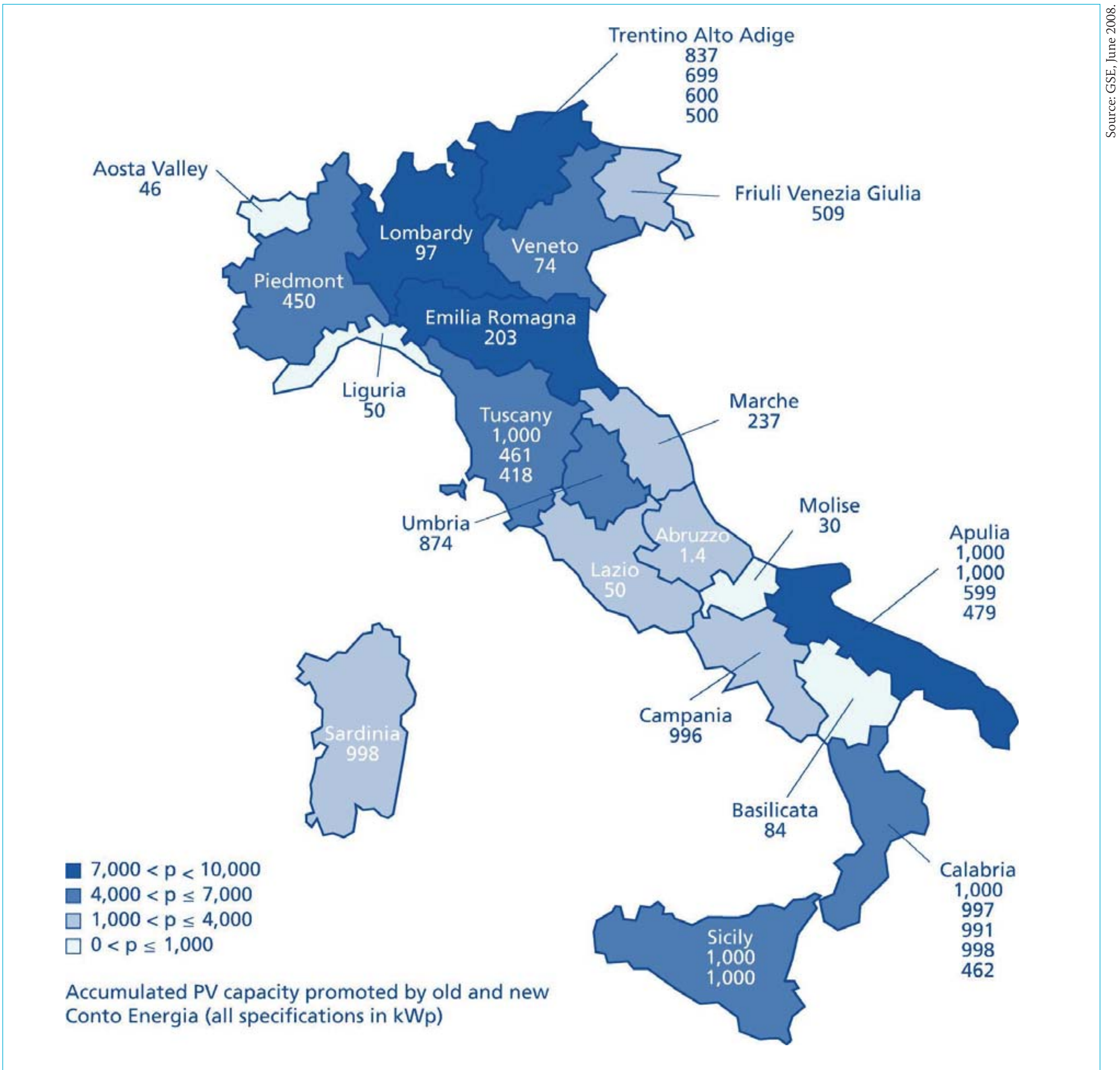

Figure 2. Largest installed systems per region (source: GSE, EuPD Research 2008).

Large-scale rooftop PV is catching up

Within the next few years, Italy is expected to become a sales market for commercial and large-scale systems in addition to the small and medium-sized systems for which it has previously been known. While the proportion of mid-sized installations of between four and 20kW was in the lead in 2007, the segment of rooftop systems of 100kW up to one GW is catching up fast. According to a market survey recently published by EuPD Research, large-scale systems contributed a total of 17MW in 2007.

By 2010, this is expected to increase by six, and probably even by seven times, and achieve a volume of more than 110MW total. This is a belief that market players like Maurizio Battistella from the Italian PV company Enereco corroborate: "In 2010, the most important system segment will be PV plants of between 100 and 500kW, installed mainly on factory roofs and shopping centers," Battistella claims. The reason for this is that due to high electricity prices in Italy, the use of electricity generated by company-owned PV systems increases the efficiency of industry activities.

> "Within the next few years, Italy is expected to become a sales market for commercial and large-scale systems in addition to the small and medium-sized systems for which it has previously been known."

'Closed-shop mentality'

Nevertheless, Anne Gassen, Research Analyst with responsibility for the Italian PV market at EuPD Research, quashes expectations that she considers too optimistic, especially for open-space systems. "It is still to be expected that the large-scale ground-mounted system segment will be prevented from progressing as much as it could due to the complex bureaucracy, lack of knowledge and experience in handling such large projects and the overburdened administrative departments. This market segment has to overcome these difficulties first," Gassen sums up. According to the expert, it is mainly local stakeholders who oppose these large MW plants. They fear that public incentives largely go in the hand of foreign investors mounting primarily imported modules, while a solid local industry, that might create employment and long-term development of the solar industry, is neglected. An argument that even Romano Prodi, former President of the Italian government, brought into the discussion at 22nd

Source: EuPD Research 2008.

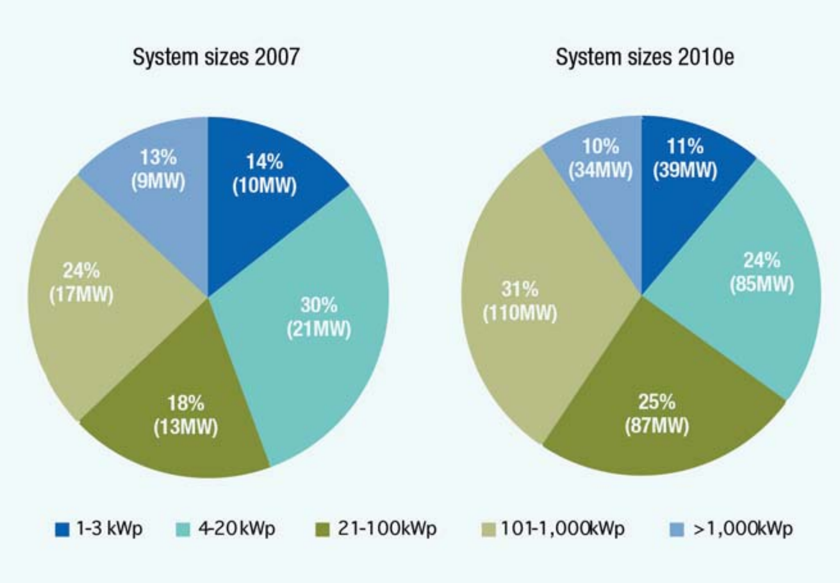

Figure 3. PV system sizes in 2007 and expectations for 2010.

EU PVSEC in Milan one year ago. This 'closed-shop mentality' accounts for the rather marginal role of large-scale systems with multiple MW sizes so far, representing not more than 13 percent of the total installed capacity until now.

Despite this, investment plans for the future – especially from foreign companies – are ambitious. The German company Solon AG, for example, announced its plans to install five PV plants of 10MW each until 2009 and possibly further plants through its Italian affiliate Solon Spa, totaling another 100MW up to 2010. Another example is the recent agreement between Enel and Sharp to install a total capacity of 161MW by end of 2011. Such emerging demand from foreign companies displays the attractiveness of the Italian market. Hence Salvatore Cristofori, a representative of the Italian project planning company Sorgenia Solar reports a remarkably "high interest from international investors, in particular from Europe and the USA."

Local industry has to overcome obstacles

Besides these positive aspects, there are diverse factors that might slow down or even put question marks on the further development of MW projects in Italy. "On the one hand, the duration of the authorization procedures can take a long time, as they are complex due to the many stakeholders involved and plethora of technical questions that have to be cleared before the installation can proceed", says Research Analyst Anne Gassen. On the other hand, Gassen continues, the heavy criticism for ground-mounted systems from the local industry or individual interests may prevent development. Lawyer Jürgen Reiß, a specialist for such authorization procedures affirms: "Everything here depends on the individual situation. Sometimes there are really very small issues that cause difficulties. For example, if the person in the office responsible is not interested in PV technology, this could influence your case." Q-Cells' General Manager for Italian operations Matthias Altieri counters with pragmatism and states that only a broad and "professional preparation of the documentation required for the authorization procedures can make things easier." Jürgen Reiß mentions one further factor that he claims is very characteristic for business in Italy, especially in the southern regions. "There are those organizations that you cannot avoid when planning large projects", Reiß said, meaning for example the Mafia in Sicily and the 'Ndrangheta in Calabria.

'Cathedrals in the desert': Where the large-scale segment is heading

Despite vehement criticism against intensified implementation of large-scale PV plants in the regions, the main argument in support of such installations is that large solar power fields enable PV technology to contribute relevant capacities to meet EU climate targets. According to the targets, by 2010, 25 percent of the electricity generated in Italy must stem from renewables. But even Leonard Berlen, Editor of the renewable energies internet portal Qualenergia, advises against the excessive use of open-space PV plants. "The installation of large-scale PV fields is not advantageous for Italy, at least today. It would be preferable for Italian operators to acquire special expertise in building integrated plants. And I am sure that the big figures will arrive anyway," Berlen states. He even stresses the Italian image of 'cathedrals in the desert,' a figurative picture that is very familiar in Italy. It stands for large projects in southern regions (see Figure 2), which were implemented with the aim of promoting the economically-underdeveloped south, but did not stimulate any positive development, effectively only enriching some commissioned companies.

Conclusion

The destiny of this market segment depends more on local bureaucratic procedures and politics than on market dynamics. It is not very likely that the 'nodo burocratico,' the bureaucratic bottleneck, will dissolve in one fell swoop as the situation in Italy is highly heterogeneous due to the lack of national guidelines for PV and the fact that individual regions, provinces and even municipalities are responsible for the authorization procedures. "Especially in the field of large-scale PV plants, it can be observed that there are many investors that underestimate costs and expenditures, trying to install a PV field with a minimal financial investment," EuPD CEO Markus A. W. Hoehner states. Lawyer Jürgen Reiß comments: "Somebody even compared the PV boom in Italy with the gold rush in Alaska. But this initial euphoria has already begun to evaporate. It requires effort and perseverance to implement large-scale plants in Italy. In the end, only serious investors will succeed in realizing those projects."

But Reiß is optimistic regarding the facilitation of the authorization procedures: "During the last three, four years, the situation of authorization procedures has significantly improved. I assume that by 2010, the large-scale segment will grow slowly, but continuously. The largest size I can imagine succeeding is 10MW, as local interest conflicts are likely to become too difficult for larger projects. I think that the majority of large installations will be around one MW."

About the Author

Daniel Pohl, graduated with an M.A. in North American studies, literature and political science from the University of Bonn and the University Paris-Sorbonne. He has been working as an editor and media consultant in the field of economics and renewable energies and is now heading the corporate communications department at EuPD Research in Bonn. Throughout his career he has published numerous articles on diverse energy topics in national and international special-interest magazines. He has also worked for national newspapers as well as broadcasting stations and a TV production company.

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Maximizing PV solar project production over system lifetime

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ABSTRACT
Anyone familiar with the PV industry can attest to the remarkably accelerated pace of innovation aimed towards generating solar power more cost effectively relative to conventional means. Many of high-technology's best minds are bringing expertise in materials, manufacturing process, and electronics to tackle the challenge. The resultant gains in cost effective manufacturing, silicon availability and greater irradiance conversion efficiency will make continuous and sustainable impact to cost per kW generated. These advances are akin to the predicable improvements in transistors per mm^2 that have fuelled the semiconductor industry for the past 25 years (although we are not yet so bold as to devise the PV version on Moore's Law). As today, less than 0.01% of electricity generated comes from PV installations [1], demand will materialize and the need for public subsidies will decline as the economics improve. This first in a series of papers, we will investigate the steps required to optimize every solar project by presenting parameters for evaluating solutions for the problem areas.

Introduction

As we architect today's installations and compute incentive rebates or project returns for power production agreements, the industry is accepting of a remarkably universal system derating factor that hovers around 22%. On closer examination of how this number is computed, one can find contributing factors such as PV module nameplate DC rating, MPPT efficiency, mismatch, diodes and connections, soiling, inverter conversion efficiency, system availability and shading [2]. To provide an immediate and sustainable benefit to the workings of the PV market, considering the breadth of contributing factors, the answer should be systematic in approach and span the lifecycle of the installation. We began this effort by taking a detailed look at what are considered to be "perfect" installations; commercial scale, flat roof, abundance of sun, no obstructions or shade, architected by installers with impeccable reputation.

Module mismatch

Today's PV systems are typically comprised of modules (panels) serially connected to one another in strings until the voltage maximum is met (600V or 1kV as mandated by the US and Europe respectively). For example, a multi-crystalline silicon module in the US with V_{oc} of 35V will usually find itself connected in series with up to 17 others. For larger installations, several of these strings are connected in parallel to form the array. Because of the serial and parallel interconnection, power output of the each module in the array will be affected by the weakest modules (Figure 1).

Therefore, it is important that the modules in the installation are well matched in power rating and come from the same manufacturer. Most module manufacturers meticulously flash-test the product after assembly and provide IV curves for each, allowing an installer to greatly reduce the variance between the modules. But is this enough to avoid mismatch losses? Our findings suggest that at solar noon on the first few weeks after installation, this is probably sufficient. However, environmental effects such as uneven soiling, temperature variations, slight differences in orientation and property migration of silicon become evident within weeks, leading to significant losses due to mismatch. The graph in Figure 2 depicts a representative example of voltage distribution of a silicon PV string installation in Northern California on a sunny midday in June 2008 [3]. The graph plots voltage of each module in a string, one data point per second.

> "As we architect today's installations and compute incentive rebates or project returns for power production agreements, the industry is accepting of a remarkably universal system derating factor that hovers around 22%."

Each of these 170W multi-crystalline modules would be operating near their V_{mp} of 24.6V if this system were operating at peak efficiency. We would hope to see a thick straight line above 24 volts – clearly this is not the case. The lower voltage output and high module distribution (up to 15%) represents lost power output. This also illustrates that it is rare for a module to be working at the maximum power point of the system. Those operating below system V_{mp} see large voltage swings as the inverter adjusts system current while those operating above system are less impacted.

The inverter effect

By observing the topology of most installations today, the most widely accepted approach for cost and reliability is to have a central inverter with a variable DC input from the array. The inverter performs the DC to AC conversion necessary to deposit energy production onto the grid. These single or multi-stage conversion processes (DC/DC step-up for isolation and DC/AC) have been optimized over 50+ years, are highly efficient and well accepted by global regulatory bodies and power companies.

The inverter also attempts to keep the array (or string) at the highest power output possible. To find the point at which the entire system can produce the maximum power at the current solar irradiance point, the inverter usually applies a "trial and error" algorithm, which adjusts its current draw on the system. By measuring the new DC power input, the inverter will determine whether to continue the adjustment in the same direction or reverse course. This process is constantly looking for the peak power point but rarely finds the system working at this point (only instantaneously during transitions). There are many variants of the algorithm but with input data limited to system DC voltage and current, all have limited accuracy. The task becomes significantly more complex during times of changing irradiance (e.g. cloud cover, shading), as each module's maximum power point is dynamically moving. System stabilization may take several minutes after a cloud has passed. Because each module has a series of by-pass diodes, a significantly under-performing module can be "turned off" when the current drawn from the inverter exceeds its ability to provide power.

The graph shown in Figure 3 is taken from another commercial installation on the California coast on a sunny day in June 2008 with high clouds (using a string inverter). It is clear from the graph that there are extreme swings in module voltage exceeding the period of cloud cover, causing the array to spend the next few minutes trying to stabilise. A look at the IV curves for these 125W multi-crystalline modules reveals that there is almost no variance between V_{mp} as irradiance varies. As a cloud passes through the array, there should be negligible changes in voltage with a corresponding reduction in current. The wild voltage swings that are present exacerbate module mismatch, create strain on the module diodes and represent enormous inefficiencies (often in excess of 50%) across the array. In climates such as Eastern US, Germany and Japan where frequent changes in irradiation levels (e.g. clouds) are normal, the inability to maintain V_{mp} and quickly stabilize the system can greatly compound the energy losses.

System visibility

Much of the production losses occur as environmental factors and system wear take their toll on the PV array. Understanding the time-based degradation of the system requires an ability to measure the power output over long periods of time and correlate this data to expectations from seasonal irradiance and weather conditions. There are many system monitoring solutions available today, including instruments to read the DC input and AC output of the inverter, and a gateway to send this information via the internet to the consumer. The data is useful in understanding how much power is being generated by the system and how much money is being saved on the power bill. However, from this information it is extremely difficult to detect reoccurring power losses caused by gradual soiling, shading, heat patterns, or module defects. Pinpointing the offending modules so that proactive maintenance can be performed requires more granular solutions, which could possibly add cost to the system, thus outweighing the utility. Figure 4 shows a string in which one of the modules had a permanently active bypass diode, thus halving its power production. The installation had been active for almost one year and the installer and consumer believed the system was running at peak efficiency based on the data read at the inverter.

Addressing BOS inefficiency

Our research on real-world system characteristics, and efforts to solve some of the fundamental problems by modifying the PV system architecture lead us to the assertion that there is anywhere between 6% and 20% performance improvements readily available. Through deploying a combination of new technologies, more granular system monitoring and event-based system maintenance, these improvements can be attained in new installations. Determining which technologies and the granularity/frequency of monitoring and maintenance will depend on an economic metric that balances front-end capex, cost of ownership (risk and reliability), and incremental energy production. The ideal scenario is one that does not impact costs (either capital or operating), but which returns this upside power generation.

A more efficient production scenario could be attained with "perfect" site selection, advanced tracking systems to ensure optimal orientation, daily module cleaning to eliminate soiling, and regular proactive tree trimming. However, it is likely that the cost of such measures outweighs the value of the incremental production and severely limits many potential installation sites in

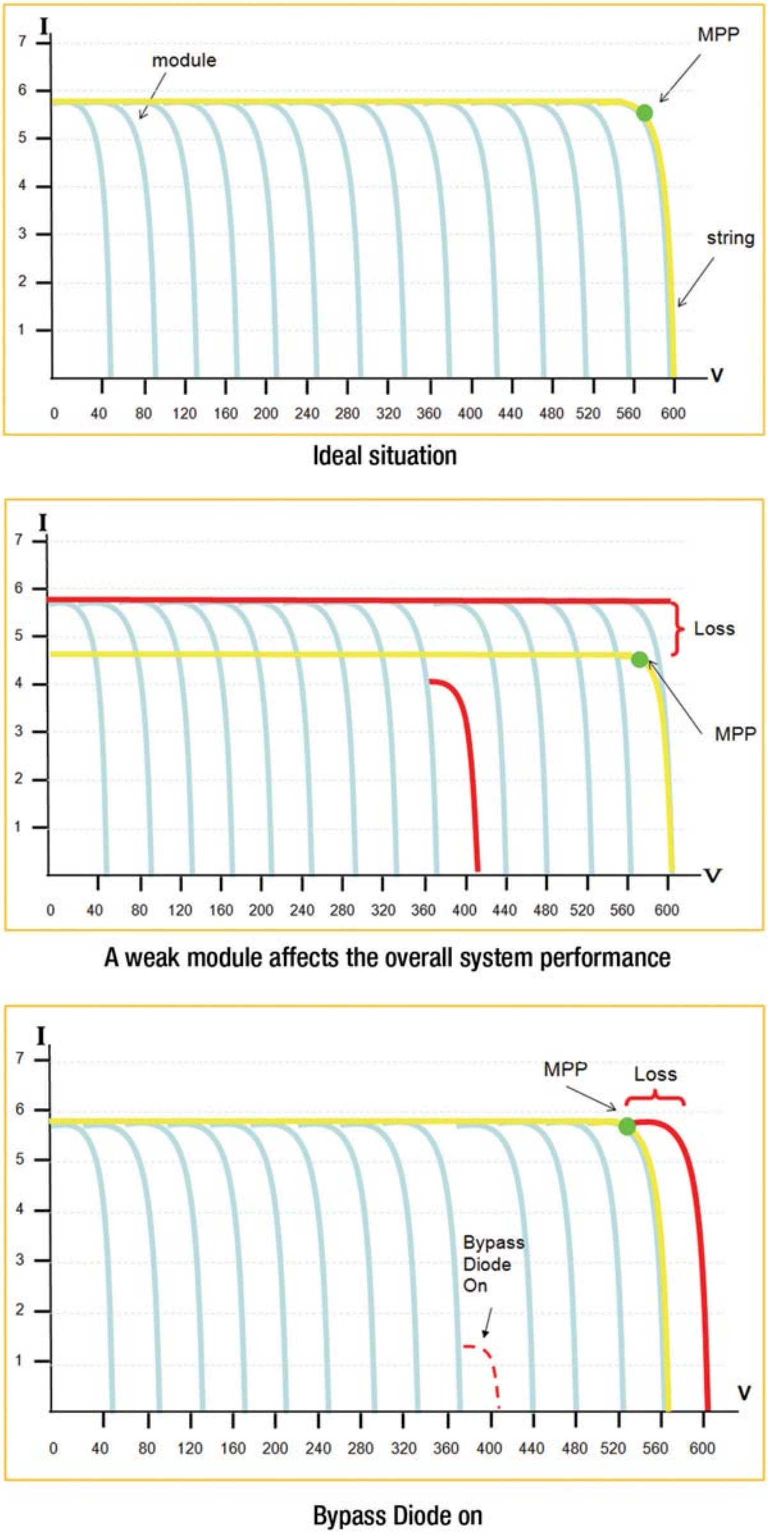

Figure 1. Effect on power output in presence of weak module.

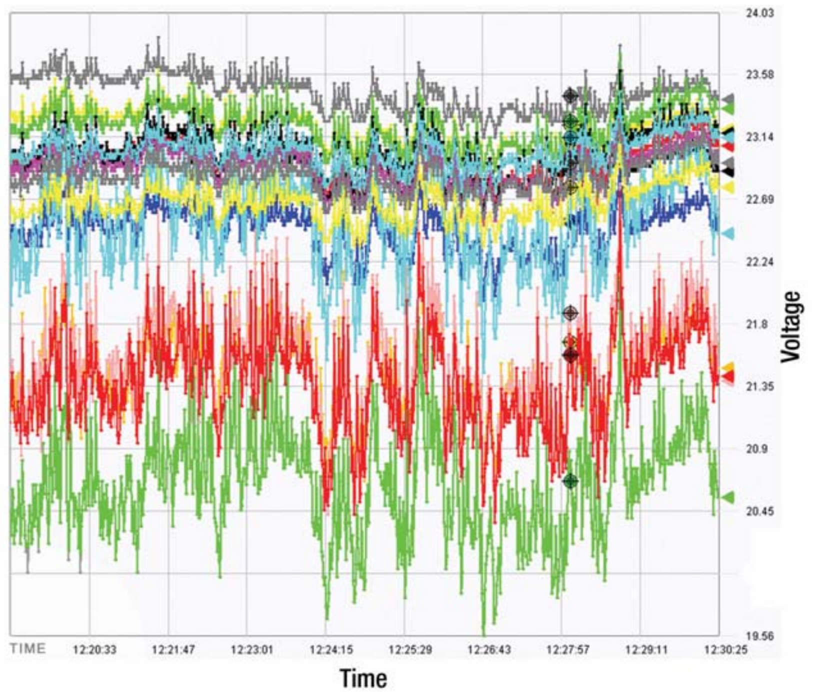

Figure 2. Voltage distribution of a typical silicon PV string.

close proximity to the existing grid. If we are able to architect a low-cost dynamic system that extracts maximum power from each module, we can greatly reduce the system drain from weak modules and ensure a stable array during shading and cloud cover. Strong modules will provide power above their rating while weaker panels will contribute what they are able and will be not be disconnected via the bypass diode. The effort and expense in matching the modules (both in orientation and in manufacturer model number) can be practically eliminated.

This effort must start with greater granularity in addressing maximum power point tracking (MPPT). Methods have been devised to narrow the scope of the tracking algorithm from the array (central inverters), to a single string (string inverters), to the module (micro inverters). These solutions reduce the complexity of the task by addressing fewer modules, or even a single module (an array of cells), which can incrementally improve tracking performance. However, these solutions equate to more inverters in the system, as the entire inverter architecture (including the DC/AC conversion function) is replicated to achieve greater MPPT granularity. System architects continue to struggle with the cost and reliability implications of such approaches relative to the incremental returns.

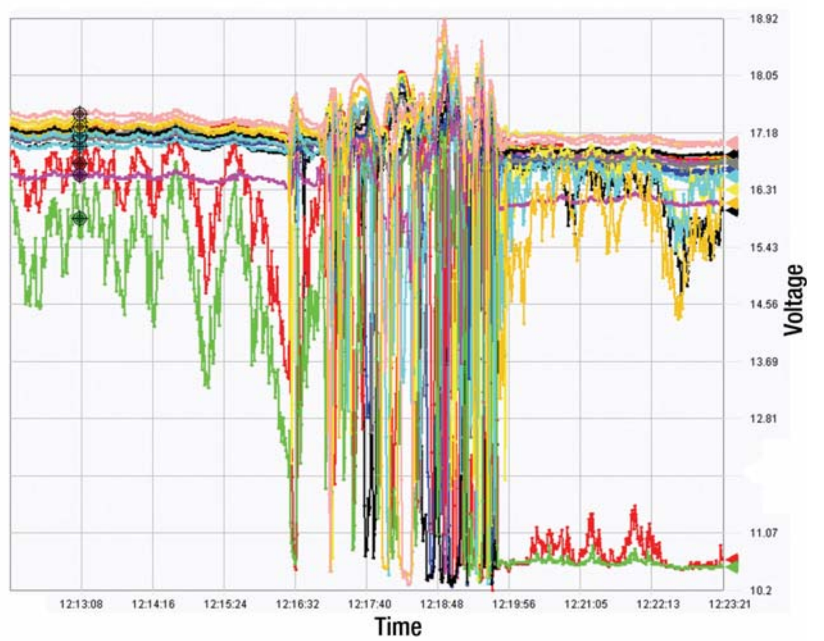

Figure 3. System impact of a change in irradiance (a cloud).

Monitoring module performance

Other more selectively distributed solutions are emerging, designed to address these cost and reliability concerns. They are based on the theory that finding the optimal operating point for a given module (or even cell) can be attained quickly with access to a wider range of tracking data. With system knowledge of real-time module performance data (IV), performance data of adjacent modules and system heuristics computed over previous days and weeks to understand recurring shading events, more accurate tracking algorithms can be developed that communicate an operating point directly to the module.

"When planning a system, it is not necessary to limit BOS enhancements to one area. For many installations, the combination of tracking, distributed MPPT, monitoring and manual processes will result in the highest kW/h generated for the investment."

Understanding this system data also facilitates a monitoring solution that moves far beyond today's products. If the collection mechanism is already in the system for MPPT, the same data can be provided to the installer or consumer without additional cost. The system owner or integrator could not only see how much power is being generated, but how each module in the system is functioning. Simple applications could be developed to create alerts and dynamic system maps to recommend when service such as cleaning, tree trimming or warranty replacement should be performed on unusually weak modules. This level of visibility and related maintenance procedures can assist with more targeted manual system adjustment and warrantee work to reduce annual performance degradation factors.

When planning a system, it is not necessary to limit BOS enhancements to one area. For many installations, the combination of tracking, distributed MPPT, monitoring and manual processes will result in the highest kW/h generated for the investment.

Loss limitation

When considering which BOS system or enhancement to deploy, the system architect will initially consider power output gains from greater efficiencies.

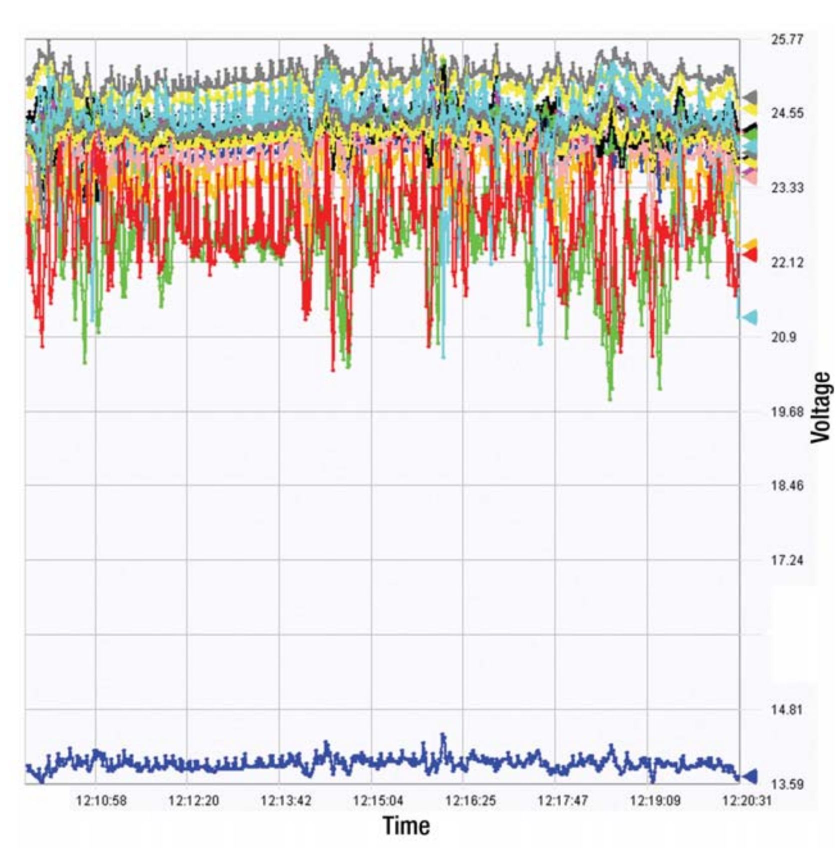

Figure 4. A disconnected module.

"We are seeing the emergence of new approaches that should be carefully considered with tangible data and side-by-side comparison in a variety of environments."

Upside potential will vary considerably based on location/orientation, weather patterns, potential obstructions, tendency for module soiling, and site security. However, it is also important to observe potential impacts to conversion efficiencies that may result from any repartitioning of the inverter functions. Today's central inverter implementations utilize extremely efficient conversion techniques limiting losses to below 5%. Any reduction as a result of additional conversion stages or cost tradeoffs will offset the production gains and must be considered. Clearly, the most effective way of determining the overall system gain is with a side-by-side comparison within the same installation environment relative to a conventional system over a statistically relevant period of time. Partitioning a larger installation to evaluate several combinations over a portion of the lifecycle can result in long-term data collection benefitting this and future projects.

Risk and reliability

Diligent evaluation of risk and reliability of new BOS solutions will also be a key determinant of which solutions are deployed. While today's system reliability has yet to be field tested over the ten to twenty-five year warranty periods, it is critical that any new system components meet or exceed the reliability standards of today's solar modules and inverters. Any incremental per-module electronics should be minimized to reduce reliability, physical stress, thermal impact and the incidence of failure. Particular attention should be paid when devices inherently susceptible to failure (such as DSPs, microcontrollers, motors and moving parts) are introduced into the system. While these devices need not be completely avoided, the costs of redundancy, failure, repair and replacement must be factored into the project's rate of return. Effective deployment of a monitoring system with visibility to the device could serve to immediately identify the cases of failure, ensure that immediate warranty work is performed, and return the system to its optimal production levels.

BOS cost considerations

Last (but certainly not least) are the cost implications of new BOS components. An increase in capital or operational expense must be accompanied by a 1 to 1 ratio of production returns to maintain the project rate of return. At or below this ratio, the BOS element will likely never gain critical mass as it also poses the inherent risk of an unproven solution. As new technologies re-partition the traditional solution and eliminate unnecessary redundancy, new installations will potentially reap incremental power production with very little additional up-front capital expense relative to today's installations. Further integration work across the system by existing industry leaders can continue to improve the initial costs over time.

Conclusion

The system approach to maximizing power output is gaining with several new entrants in the PV market. We are seeing the emergence of new approaches that should be carefully considered with tangible data and side-by-side comparison in a variety of environments. Combined with the advances in module costs and efficiencies, we see another opportunity for innovative project managers to quickly reduce the cost of solar power production, approach grid parity, and continue the demand for PV deployment that will fuel continuous growth for the industry.

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Acknowledgements

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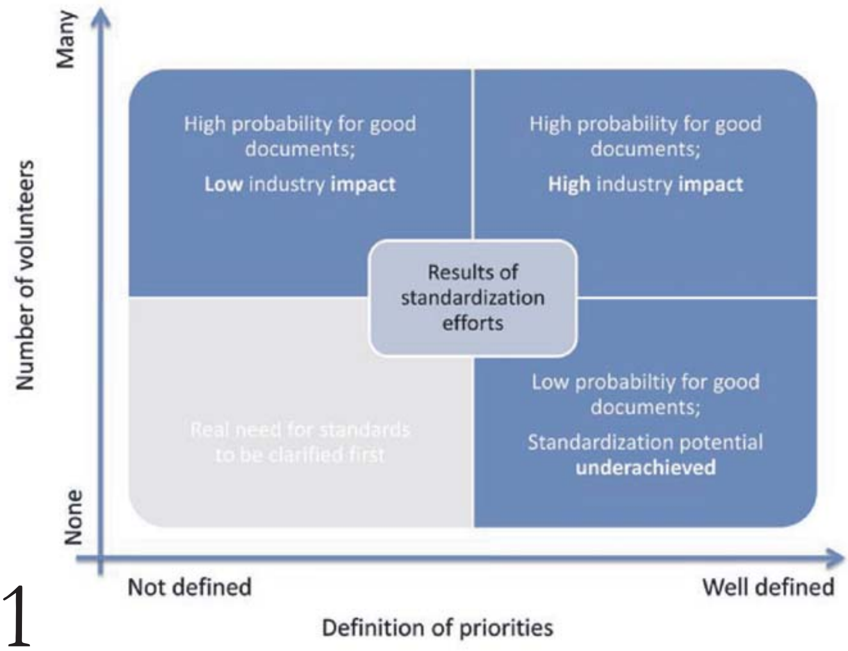

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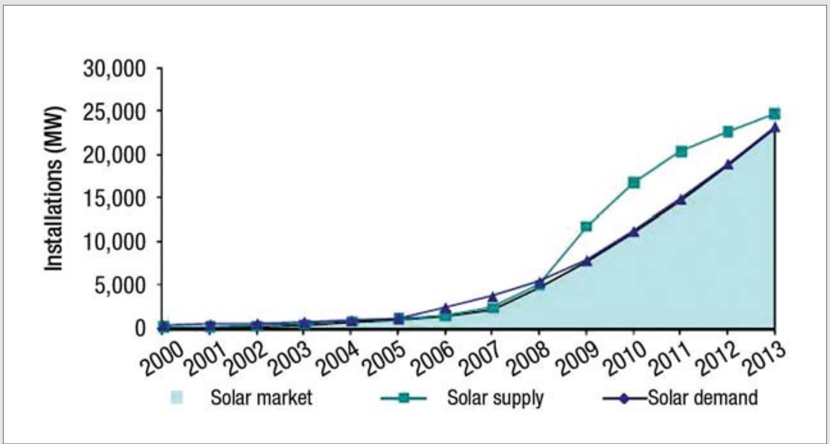
Solar module price erosion to cause industry fall-out



The solar market moves into oversupply in 2009.

In its latest solar market report, Lux Research paints a gloomy picture of a looming overcapacity in photovoltaic module production as the demand for solar is impacted by caps on installations in Spain and the continued uncertainties of the market in the U.S. When coupled to slower than expected adoption levels in the new emerging markets of France and Italy, the industry is heading for module over-supply in the fourth quarter of 2008 of approximately 400MW, which will significantly increase in 2009 to 3.9GW.

In Lux Research's latest report, 'Solar State of the Market Q3 2008: The Rocky Road to US$100 Billion,' the solar market is expected to grow 48 percent per annum through 2013, reaching 23GW compared to its forecast of 4.9GW for 2008.

The reduction in government subsidies that take effect in 2009 will be compounded by the growing pace of PV production capacity ramps, resulting in 7.9GW of installed modules but with an over-supply of 3.9GW.

The result will be significant module price erosion impacting profits and revenue, which will grow at a slower average rate of 33 percent, according to the market research firm. With that expected growth rate, the PV industry is projected to reach revenues of US$100.4 billion in 2013. Lux Research estimates the PV industry will have revenue of US$33.4 billion in 2008.

Global Trends News Focus

Thin-film industry could reach 40 percent of the PV market by 2012

The rapid expansion of thin-film manufacturing, headed by First Solar, could make up over 40 percent of worldwide photovoltaic production by 2012, according to a new report from Greentech Media and the Prometheus Institute for Sustainable Development. Thin-film PV production could also reach a capacity of 10GW in the same timeframe, the report stated.

The new report, entitled 'Thin-Film PV 2.0: Market Outlook Through 2012,' notes that in the first half of 2008 alone, over US$200 Million in venture capital was poured into the thin-film market, adding to the total of nearly US$1 billion invested in the market since 2007.

Thin-film manufacturing equipment sales to reach US$4.8 billion in 2015

A new NanoMarkets report covering the manufacturing of thin-film and organic photovoltaics projects that sales of equipment in this sector will reach annual revenues of US$4.8 billion in 2015, compared to US$450 million being projected for 2008.

The market research firm said that equipment sales would reach over US$1 billion in 2009, more than double this year. NanoMarkets projects that the market figure for TFPV/OPV equipment will flatten in 2010, due to crystalline silicon cell makers been able to secure sufficient polysilicon supplies to obtain high utilization rates in existing manufacturing facilities, enabling a greater level of competition with thin-film alternatives.

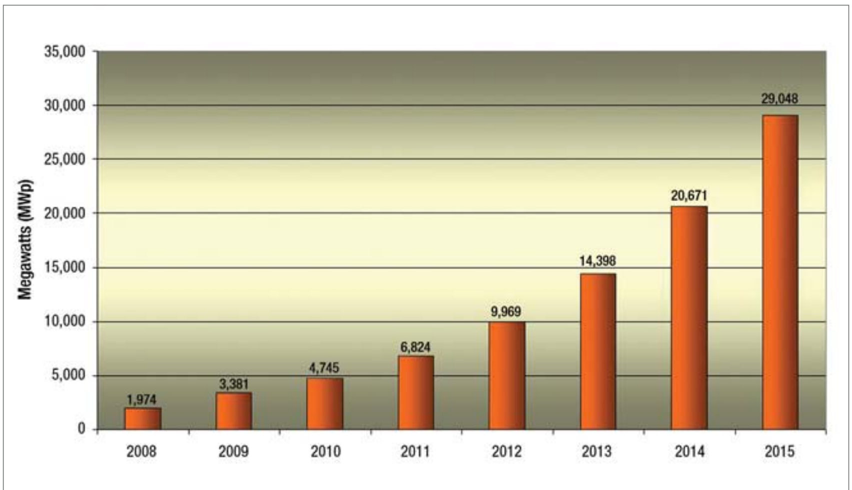
NanoMarkets is also projecting that the market for printing equipment used in the manufacture of TFPV cells will grow from around US$40 million in 2008 to over US$750 million in 2015.

Current thin-film leader First Solar should continue to be a major player and dominate the cadmium telluride (CdTe) sector. However, the market share race for CIGS and OPV sectors has barely started. By 2015, these two sectors combined will account for 19 percent and 10 percent of aggregate MW capacity.

Cleantech investments on the rise

A combination of climate change concern, return on investment and rising energy costs has led to increased interest in cleantech investment, according to Ernst & Young. The U.S. in particular has 301 venture-backed cleantech companies involved in the solar or biofuel industry that have received cumulative investments of US$7.29 billion. Following a few steps behind are solar investments in Europe (203 companies), China (25) and Israel (16). Investment in four solar companies in China amounted to US$56 million.

A study by Ernst & Young found that of the 150 global companies surveyed, 90% were undertaking some form of climate



Source: Photovoltaics International

Total installed thin-film and organic PV capacity (MWp).

change initiative, with disclosed financial commitments totalling US$276 billion for the next ten years.

A second study found that the cleantech investment market is set to flourish even further, with 35% of corporate venture capital programs planning to increase their investments in cleantech companies next year, and 44% planning an increase over the next five years.

Overall investment in the cleantech industry as a proportion of global venture capital investment as a whole is up from 1.6% of total investment in 2003 to 11% in 2008.

EU News Focus

BIPV in Europe growing at 43.8 percent

According to market research firm Frost & Sullivan, the building integrated photovoltaic (BIPV) market in Europe is growing at 43.8 percent per annum and was worth €142.6 million in 2007. Germany, France and Italy are viewed as the key markets for BIPV in Europe, with demand higher than module availability due to polysilicon shortages, the market research firm said.

"It is expected that most companies will not be able to cope with the sudden rise in demand for PV modules," noted Akhil Sivanandan, research analyst with the Environment and Building Technologies unit at Frost & Sullivan. "This shortage means that the potential of the market is not being fully realized. After 2009 however, most companies should have secured their silicon supply. With new and emerging markets like France and Italy providing increased support to BIPV, the market is poised to continue its explosive growth rate in the next few years. More countries are expected to follow suit as BIPV gains further acceptance among consumers in the coming years."

Frost & Sullivan expects more PV manufacturers to focus on the BIPV market as demand grows.

centrotherm photovoltaics gains €70 million in orders from EU PVSEC event

centrotherm photovoltaics AG has said that at this year's European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC), held in Valencia at the beginning of September, the company secured orders worth €70 million. €50 million came from traditional crystalline solar sell manufacturing equipment, while €20 million came from engineering projects. Strong demand came from India in particular as well as from Eastern Europe, China, Taiwan, and Malaysia.

The company also noted that it received strong demand for fully integrated solar factories and is focusing efforts to be able to offer complete technology and plant engineering services under one roof.

Schott Solar calls off IPO again

Reuters reports that Schott Solar has decided to call off its initial public offering, pointing to the "dramatic deterioration in international capital market conditions in the past days." The company had postponed the IPO in September because of market woes, but revived the offering afterwards. Schott Solar, a unit of German technology firm Schott that makes solar wafers, cells, modules and CSP systems, previously said it was trying to raise as much as €656.6 million (US$894.7 million) through the IPO, whose subscription period was originally planned to end on Oct. 1, but then extended to Oct 8, according to Reuters.

UK's Centrica acquires London City Hall solar installer

British Gas is to enter the photovoltaics market in the UK after its owner, Centrica PLC said it had acquired Solar Technologies Group Limited, an installer of PV and BIPV systems in the country, including the BIPV solar system for the London City Hall, designed by Fosters and using E-Ton Solar Tech's crystalline PV modules. Solar Technologies was acquired for £2.8 million by Centrica.

Semilab buys SOPRA

In its continued efforts to become a major force in the materials metrology markets for both semiconductor and photovoltaics industries, Semilab Co. Ltd. has acquired French metrology equipment specialist SOPRA SA. The all-cash transaction was closed on 17th September, 2008. Details of the deal were not announced.

SOPRA will become a new division of Semilab known as SOPRALAB and will continue as a French registered legal entity based in Paris, France. Worldwide sales and support organizations will be integrated, and Semilab will retain key executives of SOPRA within the new organization, the company said.

Japan's Itochu forays into European solar market; acquires stake in Italy's GAPS

Italian solar power system marketer Greenvision ambiente Photo-Solar, or GAPS, has sold a 43 percent stake in its company to Japanese M&A company Itochu. Recent start-up GAPS will receive approximately ¥1.2 billion (US$11.5 million) from the deal, which will also see collaboration between the two companies on marketing strategies, and the supply of Japanese-, U.S.- and Asian-made solar power modules to the company's portfolio.

This stake in GAPS is one of several of its kind carried out by Itochu in recent times. With governmental incentives encouraging the investment of M&A companies in the solar industry, Itochu's investment in Norwegian company NorSun AS and in a U.S.-based marketer of solar power systems in 2007 are likely to be the start of a number of investments in the industry by the Japanese company.

Spain sets 500MW cap for 2009

The Spanish Cabinet agreed to a revised cap on installed megawatts of photovoltaics modules planned for 2009 and beyond. The new cap has now been set at 500MW for 2009 only as part of a plan to ease the transition away from the previous subsidy package that is expected to see approximately 1200MW installed in 2008 and a total installed base of approximately 1800MW.

Spain still expects to meet its 10,000MW goal by 2020, to meet EU directives for 20 percent of energy derived from renewable sources. The total cap for 2010 will be 460MW.

A key aspect of the new deal is that greater emphasis will be placed on rooftop installations with two-thirds of the cap being allocated for this over ground-based systems mainly used for large-scale utility plants.

UK set to approve feed-in tariff for renewables micro-generation

The UK parliament published amendments to the Energy Bill, which provide more information on the potential feed-in tariff for renewable energies. Ed Miliband, Secretary of State for the Department of Energy and Climate Change in the UK, said in a presentation to the House of Lords that he intends to amend the current energy bill that goes before the Houses of Parliament.

A timeframe of one year has been put on implementation from the passing of the bill. The document stipulates that The Secretary of State within three months of the passing of the bill must make regulations "for the purpose of granting permitted development status (developments that do not require planning permission) to specified micro-generation installations". Importantly these clauses relate directly to small wind turbines and air source heat pumps but include "any such further technologies The Secretary of State may consider appropriate."

The amendment should see the inclusion of a feed-in tariff for the micro-generation of renewable energies.

U.S. News Focus

Solar investment tax credit extension will benefit U.S. utilities

The U.S. Congress' passage of the Emergency Economic Stabilization Act of 2008 and the subsequent signing into law of the bill by President Bush not only provides government bailout options for the country's troubled financial sector, but also includes a strong package of investment tax credits for solar and other renewable energy developers. Because of the removal of a prohibition that prevented regulated utility companies from taking advantage of the credit, the Solar Electric Power Association (SEPA) predicts a major increase in large-scale solar photovoltaic and thermal projects.

Based on announcements and discussions with utility executives this year, SEPA believes that utilities will quickly become the largest and one of the most important customers for the solar industry, expanding solar markets beyond analysts' expectations. The association predicts that access to the federal tax credit will expedite the time frame and scale to which this happens.

"U.S. electric utilities' engagement with grid-connected solar electricity has increased significantly in 2008, with major photovoltaic and concentrating solar thermal project announcements totaling more than 5000MW," said Julia Hamm, SEPA Executive Director. "Without the ability to take direct advantage of the ITC, the only viable financial option was to have these plants be owned and operated by independent power producers which then in turn sell the electricity to the utility. The change to the tax credit facilitates utility ownership as another option, which will result in additional projects and innovations."

Pacific Gas and Electric's long-term contracts, announced in August, with thin-film PV company OptiSolar and crystalline-silicon firm SunPower to build 550MW and 250MW solar-power plants, respectively, in the Central California county of San Luis Obispo. Both deals, scheduled to be built in phases between 2010 and 2013, were contingent on the extension of the federal credits, the utility said at the time of the original announcement.

The complete list of the solar investment tax credit provisions in the newly passed legislation include:

- Extension for eight years of the 30% tax credit for both residential and commercial solar installations.
- Elimination of the US$2,000 monetary cap for residential solar electric installations, creating a true 30% tax credit (effective for property placed in service after Dec. 31, 2008).
- Elimination of the prohibition on utilities from benefiting from the credit.
- Allowance for alternative minimum tax (AMT) filers, both businesses and individuals, to take the credit.
- Authorization of US$800 million for clean energy bonds for renewable energy generating facilities, including solar.

U.S. Energy Dept. doles out US$17.6 million to six companies for advanced solar PV development

Six early-stage and established photovoltaic companies based in California and New England have been awarded up to US$17.6 million to develop advanced solar PV manufacturing technologies as part of the Solar America Initiative, the U.S. Department of Energy announced. The DOE says that, including the cost share from industry – which will be at least 20% – the total research investment is expected to reach up to US$35.4 million. The projects are part of the initiative's goal of making solar energy cost-competitive with conventional electricity sources by 2015.

After their subcontracts are negotiated through DOE's National Renewable Energy Laboratory (NREL), six companies will begin 18-month projects:

- **1366 Technologies** (Lexington, MA) will receive up to US$3 million to help in its development of a new cell architecture and related processes for low-cost multicrystalline silicon cells. This project is expected to enhance cell performance by light-trapping texturing and grooves for self-aligned metallization fingers. By improving the light trapping and charge carrier movement within the cell, this project will significantly increase the efficiency of multicrystalline cells. By the end of the project, 1366 Technologies plans to deliver a 19% efficient, 15.6 x 15.6cm², multicrystalline silicon cell with a technology that is applicable across the crystalline silicon cell industry.

- **Innovalight** (Sunnyvale, CA) will receive up to US$3 million to develop very high-efficiency, low-cost solar cells and modules, which use ink-jet printing of the company's proprietary "silicon ink" onto thin-crystalline silicon wafers. The company's contactless printing process has been shown to significantly reduce both the manufacturing costs and the complexity required to make today's highly efficient cells and modules.
- **Skyline Solar** (Mountain View, CA) will receive up to US$3 million for its efforts to further develop an integrated lightweight, single-axis tracked system that has been demonstrated to reflect and concentrate sunlight more than 10X onto silicon cells. The use of mirrors to concentrate light will reduce the use of the greatest cost driver for traditional silicon modules, the solar cell, by over 90%. Additionally, the design leverages the mainstream PV industrial base and amplifies its capacity through significant concentration to enable rapid scaling. It seeks to dramatically lower the cost to manufacture modules and install complete systems to achieve a levelized cost of energy below grid parity. By the end of this project, Skyline plans to deliver modules that exceed 12m² area and 15% aperture-area efficiency.
- **Solasta** (Newton, MA) will receive up to US$2.6 million for development of a novel cell design based on an amorphous-silicon "nanocoax" structure, which increases current and lowers materials cost by shortening the path charge carriers must travel to the cell's conducting wires. This approach effectively decouples the optical and electronic pathways. If successful, the company will deliver 15% efficient, 100cm² preproduction cells at the end of the project.
- **Solexel** (Milpitas, CA) will receive up to US$3 million to move forward on its plans to commercialize a disruptive, 3-D, high-efficiency monocrystalline silicon cell technology, while dramatically reducing manufacturing cost-per-watt. Through a series of novel yet low-cost processing steps, this project will manufacture a solar-cell architecture which efficiently traps light using minimal material. At the end of this project, Solexel plans to deliver a 17-19% efficient, 156 × 156mm² single-crystal cell that consumes substantially lower silicon per watt than conventionally sliced wafers. Solexel aspires to be a gigawatt-scale PV producer within five years.
- **Spire Semiconductor** (Hudson, NH) will receive up to US$2.97 million to work on its plans to open up the design space for three-junction tandem solar cells by growing differentiated bifacial cells on a gallium arsenide substrate. This approach will allow the company to better optimize the optical properties of their device layers to better match the solar spectrum. Spire Semiconductor is targeting cell efficiencies >42% using a low-cost manufacturing method.

Open Energy receives financing of US$4.7 million from The Quercus Trust

The Quercus Trust, a leading cleantech venture fund, has committed to investing US$4.7 million in Open Energy, a renewable energy company focused on development and commercialization of building-integrated photovoltaic products and technologies. The agreement will see the investment of US$4.2 million in cash, while the remaining US$500,000 represents a prior loan Quercus made to the company.

In exchange for the investment, Open Energy will issue 235,000,000 shares of common stock to Quercus, at a price of US$0.02 per warrant, with an exercise price of US$0.067 per share. Open Energy received US$1.5 million in gross proceeds pursuant to the financing agreement on September 18th, and issued 75,000,000 warrants to Quercus.

Amtech generates US$100 million in bookings for FY2008

Amtech Systems has said that it has achieved record booking in its FY2008, topping US$100 million, compared to 2007's recorded bookings of US$56 million. Approximately 70 percent of total bookings in FY2008 came from the photovoltaics market, according to the company.

Polysilicon pricing to begin precipitous plunge' in 2009

iSuppli forecasts that the price of polysilicon will begin a "precipitous plunge in 2009 after peaking this year," as the supply of the raw material exceeds demand. At fault, according to the research firm, are "fundamental imbalances in the solar supply chain."

The 27-page report, 'Immature Photovoltaic Supply Chain to Result in Major Polysilicon Price Volatility,' says that the global poly supply will likely double in 2009, while demand will increase by only 34%. Although poly demand will continue to exceed supply in aggregate next year, the sharp increase in supply will cause poly pricing to fall.

As new companies enter the poly market, supply will outstrip even aggregate demand starting in the beginning of 2010, causing prices to fall further, with spot market pricing decreasing to as low as US$100 per kilogram.

Wafer-based solar cell operational production capacity will increase from 6.2GW in 2007 to 17.8GW in 2010 and 27.5GW in 2012, iSuppli predicts. However, polysilicon production will rise even more rapidly, with production equivalent to 5.7GW in 2008, to 19.4GW in 2010 and to 37.6GW in 2012.

All of these factors could lead to a shakeup in the solar wafer market.

Solar Academy introduced by Sharp in U.S.

Sharp recently announced the U.S. launch of the Sharp Solar Academy. Working with education experts, Sharp created a curriculum and presentations that address the topics of environmental awareness, climate change/global warming, recycling and renewable energy, including solar power. Sharp has operated a similar Solar Academy program in Japan for the past three years. The Solar Academy will begin pilot programs in the U.S. on the East and West coasts with fourth and fifth grade classes.

The Sharp Solar Academy at Solar Power International 2008.

The Solar Power International (SPI) conference and exhibition is the largest solar industry event in the U.S. The 2008 event was held in San Diego, California, with a surprise appearance by California Governor Arnold Schwarzenegger on the opening night. This special feature highlights some of the key news from the three-day event.

SunEdison and the state of California signed a power purchase agreement to install PV systems on 15 of the state university campuses – from Humboldt in the north to San Marcos in the south – as well as the chancellor's office. SunEdison will finance, build, and operate the systems for 20 years, delivering 8MW, or 5% of the entire university systems' annual energy load.

The Masdar Initiative of the Abu Dhabi government plans to "channel its oil wealth into the renewables space", with "five pieces to the puzzle", as explained by Steven Geiger, Director of the Masdar Initative's PV Industries unit. The Initiative plans a new nonprofit institute of science and technology, a "utility asset management unit," which will be involved in cleantech funds, a carbon management group and the Masdar Green City project, a new 640-hectare zero-carbon/zero-waste burg located near Abu Dhabi's international airport; the first all-renewable-powered city home to a 40MW PV power plant. Abu Dhabi wants to reduce dependency on outside technologies and become a primary developer and exporter of solar PV, especially to the neighbouring countries in its own region.

Day 1: Solar Power

Kyocera Solar introduced a 220W back-contact solar module at SPI. The company's most powerful module to date, it uses high-efficiency, multicrystalline solar cells. The company also showed off the all-black back-sheet 187W module.

XsunX said it was reviewing the use of a new solar module encapsulation material for use in the assembly of its TFPV solar module design, which could potentially reduce assembly times and material costs. The company is to offer a frameless glass-on-glass assembly design for its thin-film modules in combination with a new encapsulation process that is expected to reduce module costs further.

Day 2: Solar Power

Spire Corporation entered the thin-film turnkey production world by securing a contract to supply various systems of a module line for XsunX's first 25MW production line being assembled in Portland, Oregon. Spire is providing parts of its Spi-Line 25TF production line, as well as providing training and knowledge transfer. According to the company, the Spi-Line 25TF is capable of producing modules from any of the most popular thin-film technologies.

Xantrex Technology launched its GT500 Grid Tie Solar Power Inverter, a 500kW system designed for large-scale applications with an estimated weighted California Energy Commission (CEC) efficiency rating of 96.5%. Aimed at utility-scale markets, the GT500 is important to the company after the ITC bill allowed utilities to build, own and operate solar farms.

Ascent Solar gave an update on its first volume production plant for flexible thin-film photovoltaic modules. The plant in Thornton, Colorado is in the final stages of completion and should be ready to accommodate installation of the equipment in early 2009. The company noted that it had placed orders for critical CIGS deposition equipment as well as laser scribing, encapsulation and testing equipment for the initial 30MW line.

Evergreen Solar introduced its 'American-Made' String Ribbon solar panels in a new line of 200, 205 and 210W panels. The company recently received both CEC recognition and ETL Listing to the American and Canadian UL Standard 1703. The new ES-A Series panels also have a CEC approved 90.4% PTC/STC rating compared to that of sub-90% for most other multi-crystalline silicon panels. The new ES-A series panels are the first in production using the company's new Quad furnace technology.

GE Energy Financial Services said that it had joined a group of other investors in providing nearly US$21 million in venture capital to CPV start-up Soliant Energy. GE's investment was put at US$2.5 million. Soliant Energy is focused on the commercial market with the aim of providing the highest solar return on investment and the cheapest solar electricity at the plug.

Sharp Corporation promised to bring its next-generation multi-junction thin-film solar modules to the U.S market as soon as it starts production at its new manufacturing plant in Katsuragi City, Nara Prefecture, in November 2008. Sharp will target its thin-film modules at large-scale projects.

Sanyo Electric will boost PV module production at its plant in Mexico to 50MW by April 2009, up from its 20MW current nameplate capacity. This is in addition to its recent announcement to build a module plant in Oregon.

Day 3: Solar Power

Global Solar Energy showed its Copper Indium Gallium diSelenide (CIGS) thin-film modules after recently obtaining IEC (International Electrochemical Commission) certification. Its CIGS solar modules have been subjected to the IEC battery of tests and passed the first time, the company said. Certification was delivered by the Arizona State University Photovoltaic Testing Laboratory (ASU-PTL).

REC launched its SCM Series solar module in the U.S., highlighting that the product features a 10-year limited warranty of 90% power output and 25-year limited warranty of 80% power output. The module is also backed up by a 63-month limited warranty on materials and workmanship.

Owens Design completed its ninth collaborative design and build project in time for SPI. Owens' expertise is in solar manufacturing tool development that spans both crystalline -silicon and thin-film-based manufacturing approaches. The company developed photovoltaic cell solutions for handling, inspection, magazine and carrier handling and factory automation. Its thin-film-based solar manufacturing solutions have targeted custom automation for glass, flexible substrate, vacuum and atmospheric systems; material handling and factory integration.

Konarka's low cost organic flexible thin film technology offers a cost-effective renewable power solution. The company announced the opening of the world's largest roll-to-roll flexible thin film solar manufacturing facility in New Bedford, Massachusetts, preparing for the mass production of its Power Plastic products.

CH2M HILL has been selected by the U.S. Department of Energy (DOE) to help 25 American cities accelerate the adoption of solar energy. This is a strategic component of The Solar America Initiative, a DOE effort to make solar electricity from photovoltaics cost competitive with conventional forms of electricity from the utility grid by 2015. The contract is worth US$5.5 million to CH2M HILL.

Realistic optimism reigns on the U.S. photovoltaic market

Patrick Rossol-Allison, EuPD Research, Bonn, Germany

ABSTRACT

Three buzzwords dominate the discussion about the future of the photovoltaic market in the U.S. right now: ITC (investment tax credit), credit crunch, and Obama. All three have the potential to shape how the solar industry will look in the next decades. Primary data results from EuPD Research show that after a year that featured much wailing and gnashing of teeth, market participants are now "realistically optimistic" on the prospects for the industry, despite the influence of the international credit crisis.

The Obama factor

Barack Obama's election as U.S. president on November 4, 2008 stirred the PV industry's hopes for a more supportive national energy policy. On numerous occasions, his campaign has promised to spend US$150 billion over the next 10 years to advance clean energy and to create a total of up to five million green-collar jobs. In addition, Obama supports a national renewable portfolio standard (RPS) that would require 10 percent of total energy generation to come from renewable energies by 2012 and 25 percent by 2025. This year, the proposed introduction of a national RPS failed by a mere two votes in the Senate. However, the general election did not only bring Barack Obama into the White House but also a solid democratic majority into the Senate. This makes the passage of this national RPS very likely in the New Year.

The question is whether there will be benefits to the PV industry if the Obama administration pushes the renewable portfolio standard through the legislative process. Barack Obama has not yet discussed a specific solar energy policy and it is questionable whether a national RPS without a solar set-aside would change anything for the photovoltaic sector. Only a solar set-aside would guarantee strong growth of both photovoltaics and concentrating solar power (CSP).

"If the new clean energy commitment lacks such a solar-set-aside, photovoltaics will have to compete with other less expensive sources of renewable energy throughout the country", warns Markus A. W. Hoehner, Chief Executive Officer of EuPD Research. "Of course there might be regions and circumstances that allow photovoltaics to be a feasible option, considering its advantages in deployment and scalability," Hoehner adds. In those cases, the utilities sector in particular could become a principal customer, purchasing large quantities of photovoltaic modules. On the other hand, that would make the module manufacturers one of the winners of the new legislation.

Another Obama promise is the introduction of a mandatory cap for CO_2 emissions, explicitly including the auctioning of pollution permits. This plan would require heavier polluters to buy credits from cleaner companies. The future administration's goal here is to reduce carbon emissions to 80 percent of the current output by 2050. But the "billion dollar question" is whether Congress will agree to pass the auctioning bill right in the middle of an upcoming recession.

Market growth: the ITC effect

Any legislation passed by the Obama administration will complement the positive developments in federal energy policy that came into place when Congress passed an eight-year extension of the investment tax credit (ITC) earmarked to the bailout legislation package in early October. The two cherries on top of this legislative deal were the removal of the US$2,000 cap on residential solar investments and making the 30 percent tax credit available to utilities.

> "Only a solar set-aside would guarantee strong growth of both photovoltaics and concentrating solar power"

When asked for an evaluation of the future market potential of photovoltaics in the U.S. based on the new ITC legislation, respondents of the EuPD Research survey on the future potential of the U.S. market expressed cautious optimism. Market participants cited the looming financial crisis as a reason for their hesitancy to embrace a stronger market growth prognosis. The companies' market forecast up to 2012 reflects those statements. From 2007 to 2012, the Compound Annual Growth Rate of newly installed capacity of PV systems is estimated to be 55.86 percent.

Sarah Endres, Research Manager in charge of a study on the U.S. photovoltaic market, sums up the new market situation. "The indicators for change – especially concerning energy policy – have never been more promising in the US. The recently-passed ITC will most likely help the US PV market to witness its long-desired upturn and will let it prosper to become a more profit-yielding and stable branch of the economy. At the same time, some factors such as the high solar power generation costs or the financial crisis which might make the capital procurement difficult in some cases put a question mark on the short-term development within the next five years".

Will the U.S. market become the global Number One?

According to a press release from the Solar Energy Industries Association (SEIA), Rhone Resch, President of SEIA, states that the "eight-year extension of the ITC will allow the U.S. to reclaim leadership as the number-one market for photovoltaics." Currently, the U.S. PV market only ranks as one of the global top markets, with an estimated 964MW (cumulative) installed at the end of 2008. As the above analysis of the most recent developments shows, political and economic framework conditions for photovoltaics have, for the most part, improved significantly from over a year ago.

While the extended ITC is the most important energy policy instrument, a wide range of state, county, municipality, and even utility promotions are available depending on the geographical location. While the lion's share of renewable energy promotion has been pushed by states like California and New Jersey, every town potentially has its own incentive structure. Gainesville Regional Utilities, a small municipality-owned utility for instance, is

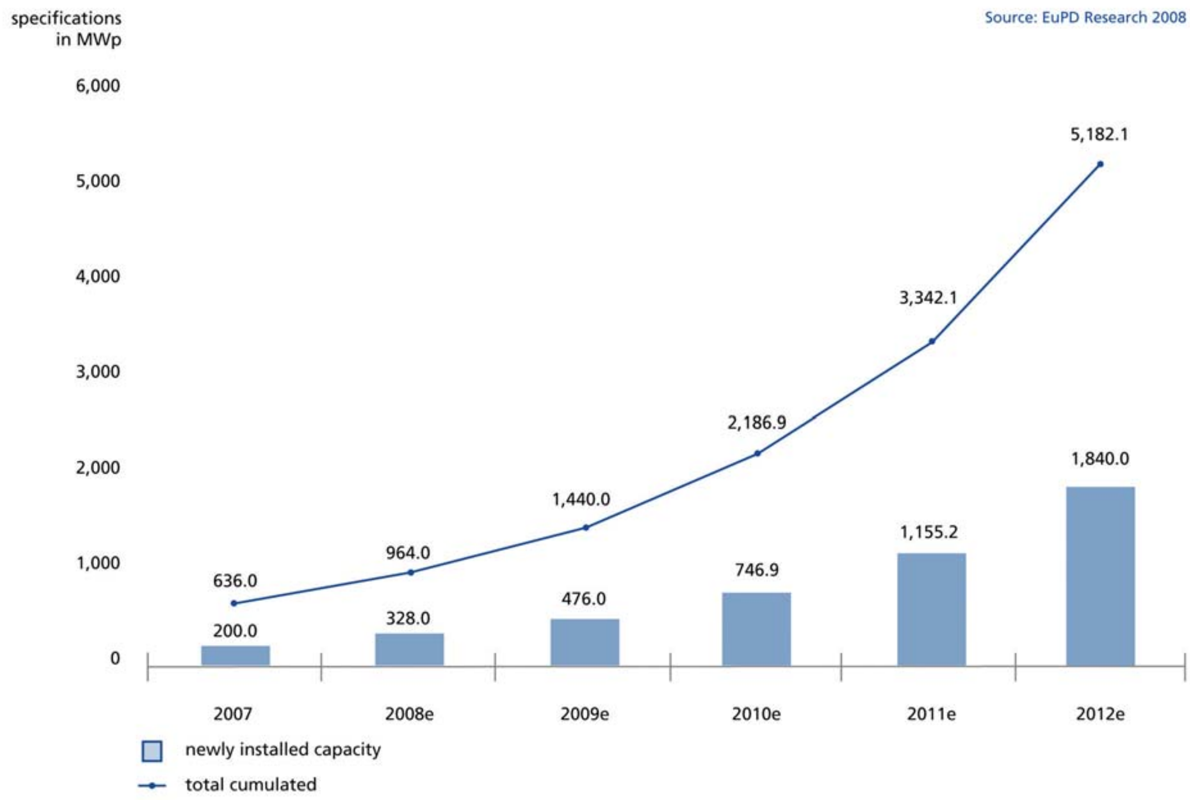


Figure 1. Market forecast after the introduction of the new ITC based on estimations by market participants.

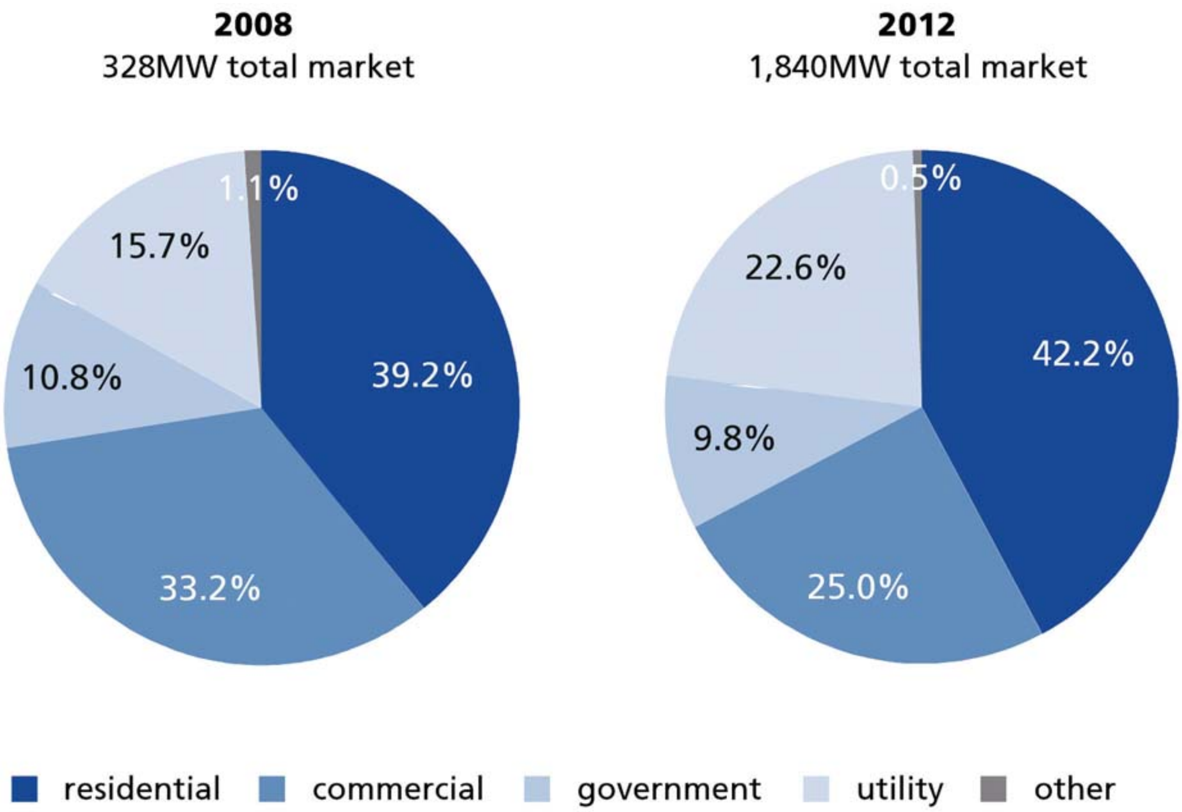


Figure 2. Estimated share of end customer groups in the U.S. market for the years 2008 and 2012.

on the brink of adopting its own promotion scheme, modeled after the German feed-in tariff, starting early next year. This fragmented nature of promotion structures is truly exceptional in international comparison and the non-transparent subsidies for PV have caused confusion and a sense of unpredictability in the industry.

According to the respondents of the EuPD Research survey, market participants do not think this situation will change. "When asked about which changes regarding the legal situation of PV they expected within the next five years, only 4.2 percent of the survey's respondents expected the implementation of a FIT," Sarah Endres delivers an insight. Indeed, market participants emphasized that they would prefer some significant module price reductions as opposed to new subsidies.

Which market sectors might boom

"Nevertheless: with the inclusion of utilities in the ITC tax credit scheme as well as the removal of the US$2,000 cap in the residential segment, market participants expect stronger growth in those two segments as opposed to the commercial segment", Research Manager Endres explains. Right now, residential PV installations represent a market share of 39.2 percent, according to respondents of the EuPD Research survey, and commercial installations follow closely with 33.2 percent, propelled by the popularity of power purchase agreements (PPAs). The utility share is currently at 15.7 percent. But according to the respondents of the survey the residential share might grow to 42.2 percent, the utilities' share to 22.6 percent and the commercial segment to 25 percent by 2012.

Mike Taylor, Director of Research at the Solar Electric Power Association (SEPA) is a bit more cautious about the utility involvement in the next year. "There are still a lot of unknowns out there. Utilities are waiting to see what regulators decide on big projects. At the same time, ten to 20 utilities are keeping their toes in the water with smaller-sized projects". Ken Parks, Team Leader in Customer Generation at Sempra Utilities, is equally careful when it comes to an evaluation of future utility activities in the PV market. He cites specific reasons why utilities, in this case in California, are still hesitant to invest. "Many of the announced large-scale PV projects are still contingent on a final decision from the California Public Utilities Commission. Also, module manufacturers are not willing to give discounts based on economies of scale right now, because of the ongoing shortage for PV modules. I'm expecting that the real breakthrough will take place in three to five years".

Outlook – where the market is heading

Regardless of all the optimism, these conservative prognoses are not based on thin air. According to EuPD Research, even other market participants were cautious concerning the future development of the market. "The main reason seems to be that PV is not yet profitable in the U.S. Consequently, an investment market like the one in European countries simply does not exist yet. Nevertheless, the market is on its way to gaining more importance in the worldwide comparison. However, sustainable market growth will only be possible when political support, financial incentives and public awareness reach the same level. Grid-parity will be the final key to unlocking profitability", Markus A. W. Hoehner sums up.

About the Author

Patrick Rossol-Allison, M.A., studied political science at the University of Bonn and Duke University in Durham, NC. He has been working for the International Institute for Economic Policy, University of Bonn, and the Consulate General in Los Angeles, CA, and also spent a year and a half abroad in Costa Rica. He is now Vice President of the U.S. office of EuPD Research in Mission, KS.

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Taiwan thin-film manufacturers set for rapid growth

Mark Osborne, Photovoltaics International

ABSTRACT

The continued tight supply and high cost of polysilicon, coinciding with the growth in demand for solar energy, has been a key catalyst for the rapid adoption of thin-film technologies in the last two years. Although the technology has been in development for over 15 years, it is only now that thin film has emerged as a viable low cost-per-watt alternative to conventional crystalline silicon cells. Taiwan, a powerhouse in the electronics and microelectronics industries, is also turning its attention to photovoltaics. Playing catch-up is something at which the Taiwanese have proven to be very effective, with a growing emphasis on thin film as a means to become another major centre and net exporter.

First Solar setting the benchmark

After a long (15-year) gestation period, North America-headquartered First Solar has single-handedly thrust thin-film technologies into the spotlight with an impressive manufacturing ramp and full order book that is now worth US$6.3 billion through 2013 [1]. First Solar announced its third quarter financial results that ended on 27th September 2008, highlighting that production had reached 137MW in the quarter, which was up 20% quarter-on-quarter and an impressive 97% year-on-year [2]. This would mean that First Solar has reached an annualized capacity of 49.3MW per thin-film production line.

Significantly, the cost-per-watt, excluding non-production based expenses now stands at US$1.01 per watt [3], a 9% reduction quarter-on-quarter and the lowest in the industry, acting as a benchmark for all others. Indeed, an important point for thin film start-ups is the fact that First Solar turned profitable in 2006 at an annual production rate of 75MW. With cadmium telluride (CdTe) conversion efficiencies of 10% and a roadmap goal of US$0.70 per watt by 2012, competitors need to take note.

The very public success of First Solar has seen thin-film technologies gain huge interest from potential new entrants as well as from established crystalline solar cell producers such as Q-Cells, Suntech, Sharp and E-Ton to pursue thin-film manufacturing.

Thin films have also proven attractive to late entrants eager to utilise turnkey processes and equipment solutions that significantly reduce the entry risks, while potentially allowing faster megawatt-scale production ramps and a quicker return on investment (ROI).

As Figure 1 shows, Taiwan has attracted a small but growing group of thin-film converts that have established, or are in the process of establishing, initial volume production manufacturing plants.

Our research relies partially on projections produced earlier in 2008 by ITRI, as well as checks and updates we have undertaken subsequently. In 2006, nominal capacity stood at only 13MW, which consisted primarily of pilot line operations. As some of those projects have since matured, capacity is estimated to have risen to 27.5MW in 2007.

These capacity figures are small; however, when compared to ITRI/*Photovoltaics International*'s estimates of crystalline silicon cell capacity having reached 990MW in 2007 (see Figure 2), it seems thin film has a long way to go to challenge silicon solar cells.

As Figure 3 highlights, there is the possibility that thin-film MW capacity will account for over half the capacity in Taiwan in 2010, a possible testament to the faster ramp capability of thin-film technology over conventional Si-cell approaches.

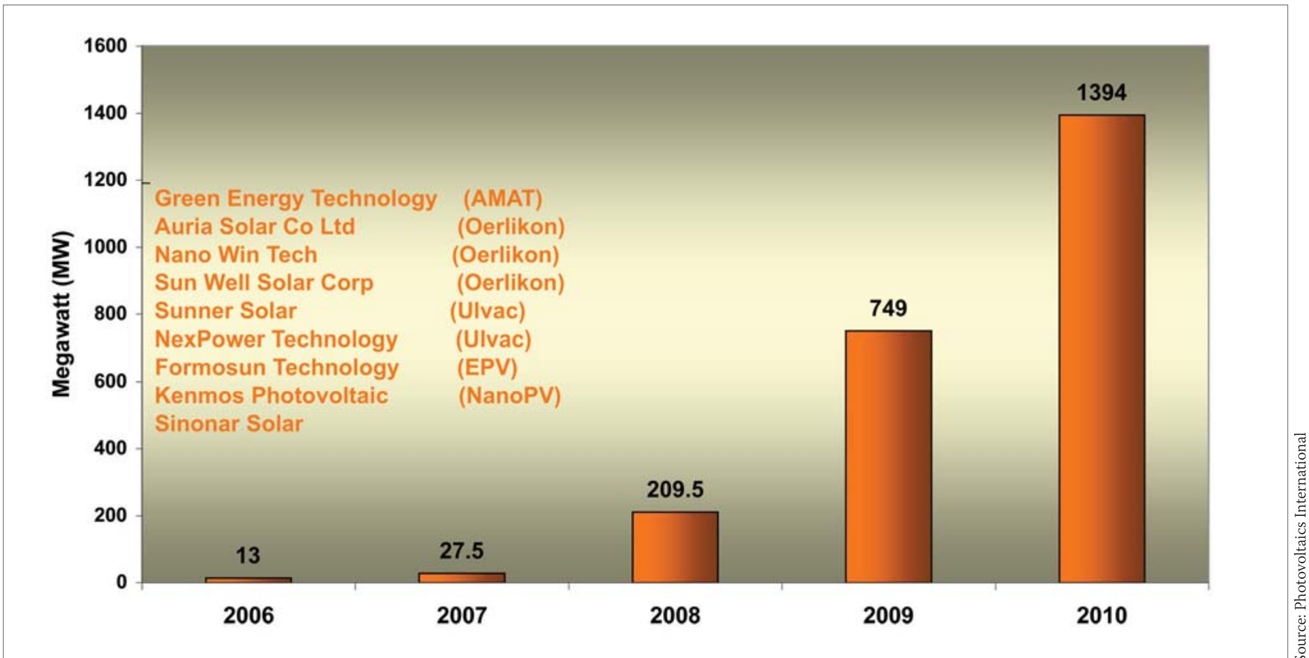
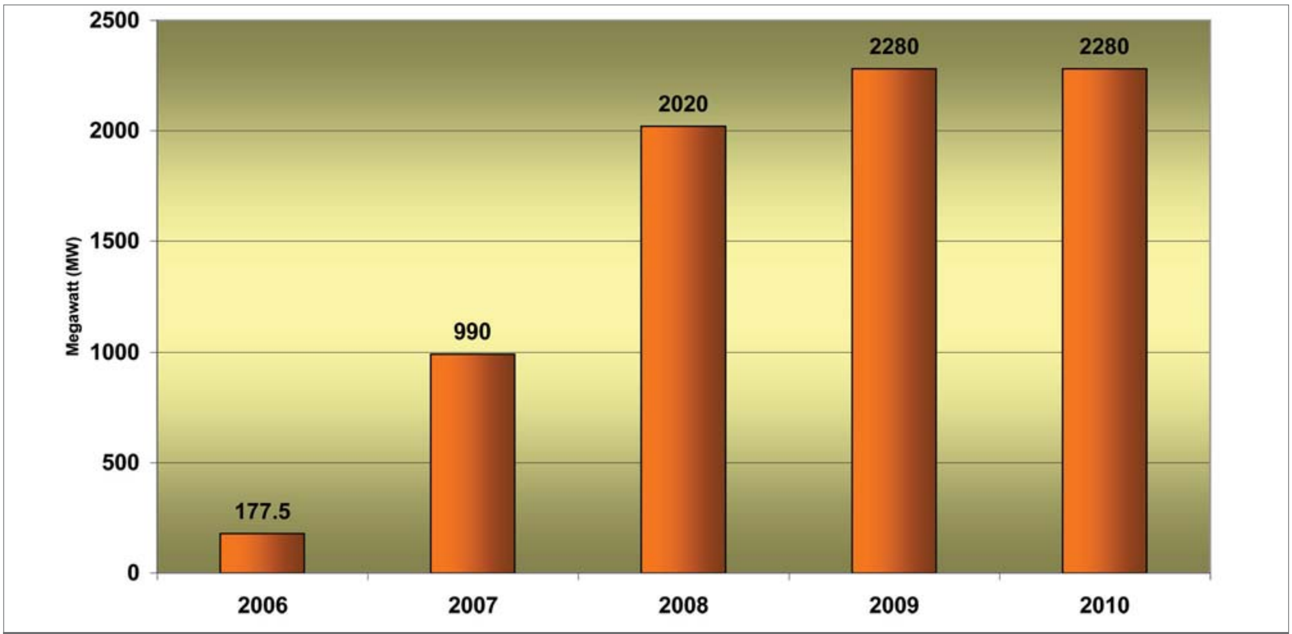


Figure 1. Taiwan thin-film manufacturers' capacity expansion plans.



Source: Photovoltaics International

Figure 2. Taiwan c-Si cell producers capacity ramp forecast.

Amorphous thin-film

Interestingly, all of the current thin-film entrants have selected amorphous thin-film technologies from all of the key current suppliers (Applied Materials, Oerlikon Solar and Ulvac). Although development is taking place on cadmium telluride (CdTe) and copper indium gallium (di)selenide- (CIGS) based thin-film solar cells, current production ramps are all a-Si based. The reason for this preference is the less demanding learning curve with a-Si compared to the technical hurdles with which these alternative technologies are associated.

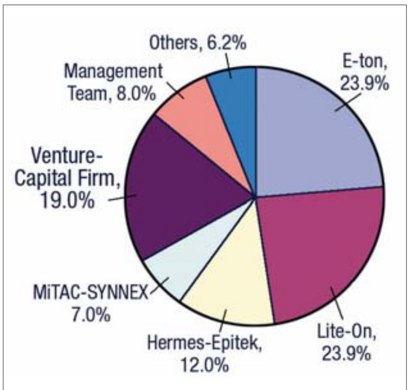
Work is also ongoing to boost conversion efficiencies to the 10% range with twin junction configurations to make them more competitive with CdTe and CIGS technologies. Currently, first generation a-Si module efficiencies are in the region of 6.5% and Oerlikon Solar's second generation technology a-Si/μc-Si tandem structure has 8.7% module efficiency

Company focus

Auria Solar

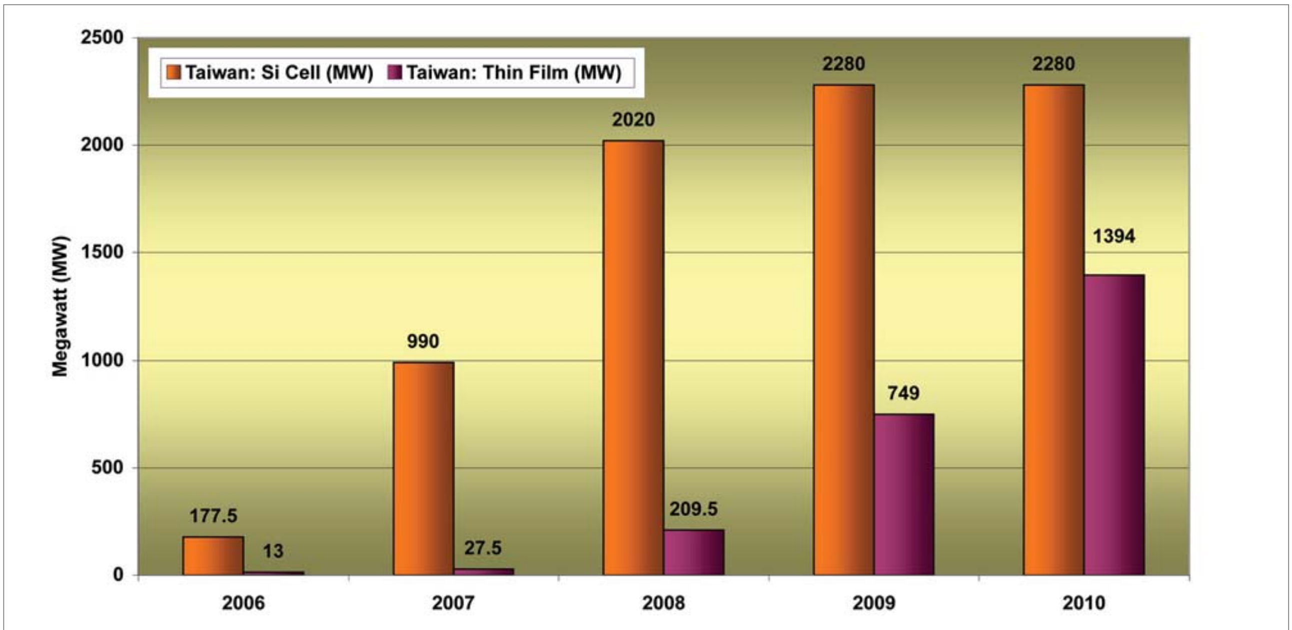
Founded in October 2007, Auria Solar, a joint venture operation with TON Solar Tech, Lite-On Technology Corp., Hermes-Epitek Corp. and MiTAC-SYNNEX Group (see Figure 3 for financial breakdown) has already announced that its first 30MW thin-film line will include Oerlikon Solar's micromorph tandem technology that utilises amorph and microcrystalline materials to boost conversion efficiency by 50%. Pilot production is expected before the end of 2008.

Auria Solar has had an initial capital injection of approximately US$43 million and is expected to expand production by 60MW per year, with an ambitious goal of achieving 500MW capacity in 2012.



Source: Photovoltaics International

Figure 3. Auria Solar JV – financial breakdown.



Source: Photovoltaics International

Figure 4. Taiwan PV manufacturers' Si-cell and thin-film capacity expansion plans.

Sun Well

Sun Well Solar Corp. was established in mid-2007 as a subsidiary of CMC Magnetics Corp. The thin-film start-up is using Oerlikon Solar's turnkey technology for an initial single production line with a 40MW capacity. Recently (1st September 2008), Oerlikon Solar stated that Sun Well's first line became operational within nine months. The company was said to have produced 10,000 solar panels in its first month.

Sun Well is planning further line additions with a plan for over 220MW production capacity in 2010. Two additional Oerlikon Solar end-to-end fab lines have been purchased by Sun Well. One 60MW line is for Sun Well's existing site in Taiwan and one 120MW line is for a second facility currently under construction, which will utilize Oerlikon Solar's micromorph tandem technology. Sun Well has future plans to increase capacity to 1GW in 2012, by far the company with the most aggressive capacity plans for the near future.

Sunner Solar

Sunner Solar was founded in June 2007 and is located in the Central Taiwan Science Park. The start-up has employed ULVAC's thin-film technology and has said that it too will incorporate ULVAC's tandem structure that uses a microcrystal (μc-Si) layer followed by an a-Si process to boost efficiencies. Initial production is a 25MW line (1.1x1.4m modules), which is expected to be operational in 2Q09; however, plans are for Sunner Solar to rapidly migrate its second-phase expansion to microcrystalline tandem technology developed by ULVAC in the second half of 2009. Production capacity is planned to reach 100MW in 2010, while its third-phase capacity increase is planned to hit 200MW before 2012.

Figure 5. NexPower's first thin-film modules.

NexPower Technology

Another customer of ULVAC's thin-film technology and turnkey production lines is NexPower Technology. NexPower Corporation was founded by one of the worldwide leading semiconductor foundry manufacturers, UMC Group, in 2005.

Initial production in 2008 is on a 12.5MW/year line using ULVAC's 1.1x1.4m modules, but plans are in place to ramp lines and capacity to 100MW/year. Like Sunner Solar, NexPower will migrate to microcrystalline tandem technology developed by ULVAC.

ULVAC is providing turnkey production lines that include systems for PECVD, laser scribing, sputtering and sealing as well as technical training and start-up assistance.

Another potential major thin-film producer in Taiwan is Green Energy Technology (GET). GET is a c-Si wafer producer with 200MW annual capacity and uses Applied Materials' SunFab turnkey production technology. GET is expected to have its first 40MW line operational by the end of 2008.

Conclusion

These projections do not account for the likely possibility of the emergence of new thin-film entrants as well as greater capacity ramps from existing start-ups, should initial volume ramps prove highly successful. However, the challenging global economic environment that resulted from a worsening credit crunch could yet impact newcomers' ability to raise funds and for current start-ups to access further capital to expand operations. The prospect for Taiwanese companies to compete with other PV manufacturing regions of the world remains a realistic one (see Figure 6). Efforts for improving conversion efficiencies are underway and experience in low-cost and high-yield electronics manufacturing is a given.

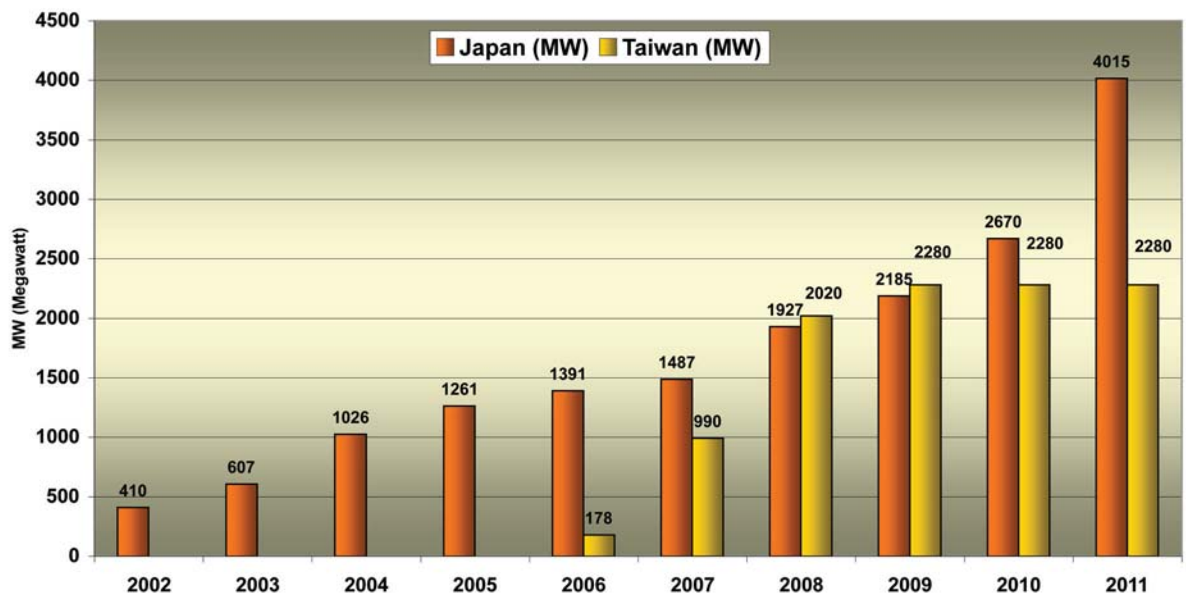
Therefore, 2008 looks like being a year of transition for the photovoltaics industry in Taiwan with both Si-cell and thin-film technologies ramping capacity considerably. Two Oerlikon Solar customers, Sun Well Solar Corp. and Auria Solar Co. Ltd., have stated that installed capacity using a-Si thin-film technology will reach 100MW combined by year-end. With further ramps still expected through 2010, Taiwan is positioning itself as a key hub for PV manufacturing, something it has been successful in doing from semiconductor to PC manufacturing.

References

[1] Gartner Dataquest Newsletter, Issue 43, 3rd November 2008.

[2] First Solar, Inc. 3Q08 Financial Statements.

[3] First Solar, Inc. 3Q08 Financial Statements [note: deducts new facility ramp costs and executive stock-based compensation].



Source: Photovoltaics International

Figure 6. Thin-film capacity ramp comparison (Japan vs. Taiwan).

Structuring standards for the photovoltaic manufacturing industry

Win Baylies, **Marty Burkhart**, **Don Cook**, **Dick Hockett**, **Matthias Meier** & **Bettina Weiss**, SEMI/PV Group Photovoltaic Standards Committee

ABSTRACT

Standards have traditionally been used in other industries, especially semiconductor, to increase efficiencies and reduce costs. This article will illustrate these efforts, as well as acting as a call for participation to become involved in SEMI's standardization developments for PV. Four active task forces have been initiated to tackle these much-needed standards for the PV industry, namely, the Analytical Test Methods Task Force; the PV Equipment Interface Specification Task Force; the PV Gases and Chemical Purity Task Force; and the PV Facilities Task Force. As a follow-up to an article featured in the first edition of *Photovoltaics International* [1], SEMI has prepared this summary regarding the collective efforts of the PV Group's standards developments.

Introduction

Unlike other pre-established industries, where standard activities are mainly initiated by mature companies with clear requirements to standards, the PV industry, with its huge number of newly founded companies, is currently focused on ramping up their production lines and stabilizing their production processes. By structuring and utilizing standards requirements, it is possible to focus recourses to the most valuable standards in this critical phase of the fast-growing PV industry. SEMI intends to achieve these goals by proving recommendations for new standards activities, linking experts together to accomplish the deliverables, and speed up the process of standards deployment.

The SEMI Standards and Safety Guidelines directly contribute to bringing the various segments of the manufacturing supply chain together to optimize options, agree on basic parameters, investigate and address safety concerns and introduce new ways of end-of-life treatment for both equipment and materials.

While standardization efforts are being initiated in several regions of the world, this article provides a closer look at particular activities in Europe and North America, and outlines the steps being taken to develop standards for the PV industry.

History

In March of 2007, at the PV Fab Managers' Forum in Leipzig, Germany, industry leaders focused on issues and concerns affecting overall manufacturing costs. Due to the results of their discussions, in July 2007, the European Photovoltaic Committee was approved, and, in January 2008, SEMI announced the details of their Global Photovoltaic (PV) initiatives, including the formation of the SEMI PV Group. In the spring of 2008, a joint SEMI/EPIA PV Needs Assessment Survey was completed and work began on PV standards assessment and development of new PV-specific documents.

SEMI's PV Group Task Forces

Currently, there are four active task forces working on these items: Analytical Test Methods Task Force, PV Equipment Interface Specification Task Force, PV Gases and Chemical Purity Task Force, and PV Facilities Task Force. The recent and planned efforts of each of these task forces are summarized.

Analytical Test Methods Task Force

The International PV Analytical Test Methods Task Force has a charter to develop standards for analytical test methods for the International photovoltaic industry. The scope of the Task Force includes GDMS and ICP-MS as applied to impurities in silicon feedstock for multi-crystalline Si PV. Additional analytical techniques for solid materials will be considered as appropriate for application to both thin-film PV and bulk PV, Si and non-Si, such as SIMS, XPS, AES, TOF-SIMS, SPM, TEM, SEM, EDS, RBS, HFS, PIXIE, TXRF, XRD, XRR, LEXES, FTIR, Lifetime and Raman.

The Task Force has successfully developed a trace element test method [2], follow-up work to which includes a round robin test and a line item ballot to replace the term "photovoltaic-grade" to avoid some confusion on the meaning of this term. Work is planned for a second test method on the use of ICP-MS for measuring trace elements in silicon feedstock. Analysts with experience in the use of ICP-MS, specifically for this material, are encouraged to join the Task Force.

PV Equipment Interface Specification (PV-EIS) Task Force

Looking at other industries, such as semiconductor manufacturing, suitable IT (Information Technology) interfaces for production equipment have proven to be essential to run factories efficiently and effectively. Data sent and received through these interfaces is not only the prerequisite for line monitoring and control, but also for the implementation of sophisticated quality assurance, traceability and advanced process control strategies. Starting from the first discussions in early 2006 regarding the need for standardized IT interfaces for these purposes in PV, the awareness of the necessity has continuously grown. In September 2007 the European Equipment Interface Specification Task Force (PV-EIS TF) was formed to develop a corresponding framework of standards.

Initially, the taskforce installed two working groups to assess the requirements of the PV industry on the one hand and to review existing IT equipment integration standards and best practices from other industries and the PV industry on the other. The evaluation process based on the results of both working groups led to the decision to build upon the IT integration standard framework developed within the semiconductor industry (SECS/GEM). To facilitate the utilization of these standards within the PV industry, the PV-EIS task force developed the *Guide for PV equipment communication interfaces* (PVECI) that describes how to integrate process, automation and metrology equipment in the PV manufacturing environment. It contains a number of restrictions and clarifications that should simplify the application of SECS/GEM compared to the original version used in semiconductor manufacturing. The document has been submitted for balloting and is expected to be available as an approved SEMI standard in spring 2009. As the next step, the task force plans to initiate a new activity to extend the capabilities of the PVECI guide in terms of material tracking.

PV Gases and Chemical Purity Task Force

The Gases and Chemical Purity Taskforce is comprised of people from leading industries that produce/manufacture solar cells, gases, liquid chemicals, purification, components and ancillary equipment used in photovoltaic (PV) production. These industry experts come together in a neutral forum to develop common standards and guidelines helpful to the PV industry.

The taskforce is not intent on defining what purity of gases or liquid chemicals are needed to produce solar cells. Rather, like its counterpart started many years ago for the advancement of semiconductor production, we intend to provide to the industry (end-users and suppliers alike) a set of written documents for gases and chemicals that can be used to obtain consistent, specified process materials.

The expected outcome will:

- Remove the ambiguity in what is being produced and provided - the customer gets what is truly needed and the supplier knows what to produce
- Provide a level playing field by preventing low bid possibilities where suppliers might meet the nomenclatural intent of the material but not the actual customer's need
- Avoid customer/supplier discussions about rejected material not performing as expected
- Give the end-user the ability to improve the process by ratcheting up a notch in purity if deemed advantageous.

Our global taskforce constantly seeks producers/process engineers, tool manufacturers, gas and chemical suppliers as well as component manufacturers of gas and liquid distribution systems to provide us with a well-rounded approach within this important forum.

PV Facilities Task Force

The PV Facilities (PV-FAC) Task Force held its initial meeting in October 2008 with participants representing PV industry manufacturing leaders, as well as designers, architects, engineers, tool manufacturers, materials providers and components suppliers. To leverage as much as possible of the existing SEMI Standards portfolio, the Task Force is now assessing about 130 of the 750+ existing SEMI standards as to their applicability to PV manufacturing, regardless of whether the facilities are common to known manufacturing technologies or unique to specific methodologies. The PV-FAC Task Force will be documenting utility lists, process flows, facilities features, and other characteristics during the assessment.

The PV Facilities Task Force will develop a Prioritization Matrix, including numerical ranking (1-2-3, high-medium-low), of the SEMI Standards assessed in order to determine:

- Applicability of SEMI Standard to PV
- Ease of transition from SEMI to PV
- Urgency to PV industry
- Cost-effective potential
- Environmental, Health Safety (EHS) and/or IP Implications (Intellectual Property).

These priorities will be compared to and matched with the results from the SEMI-EPIA PV Standards Needs Assessment Survey (February 2008), and will support the Photovoltaic PV International Standards Roadmap (ISR-PV) currently in progress. The Task Force anticipates that draft versions of the priority assessment be sent out in December 2008, and that draft PV Facilities Standards will be published for consideration in Q109.

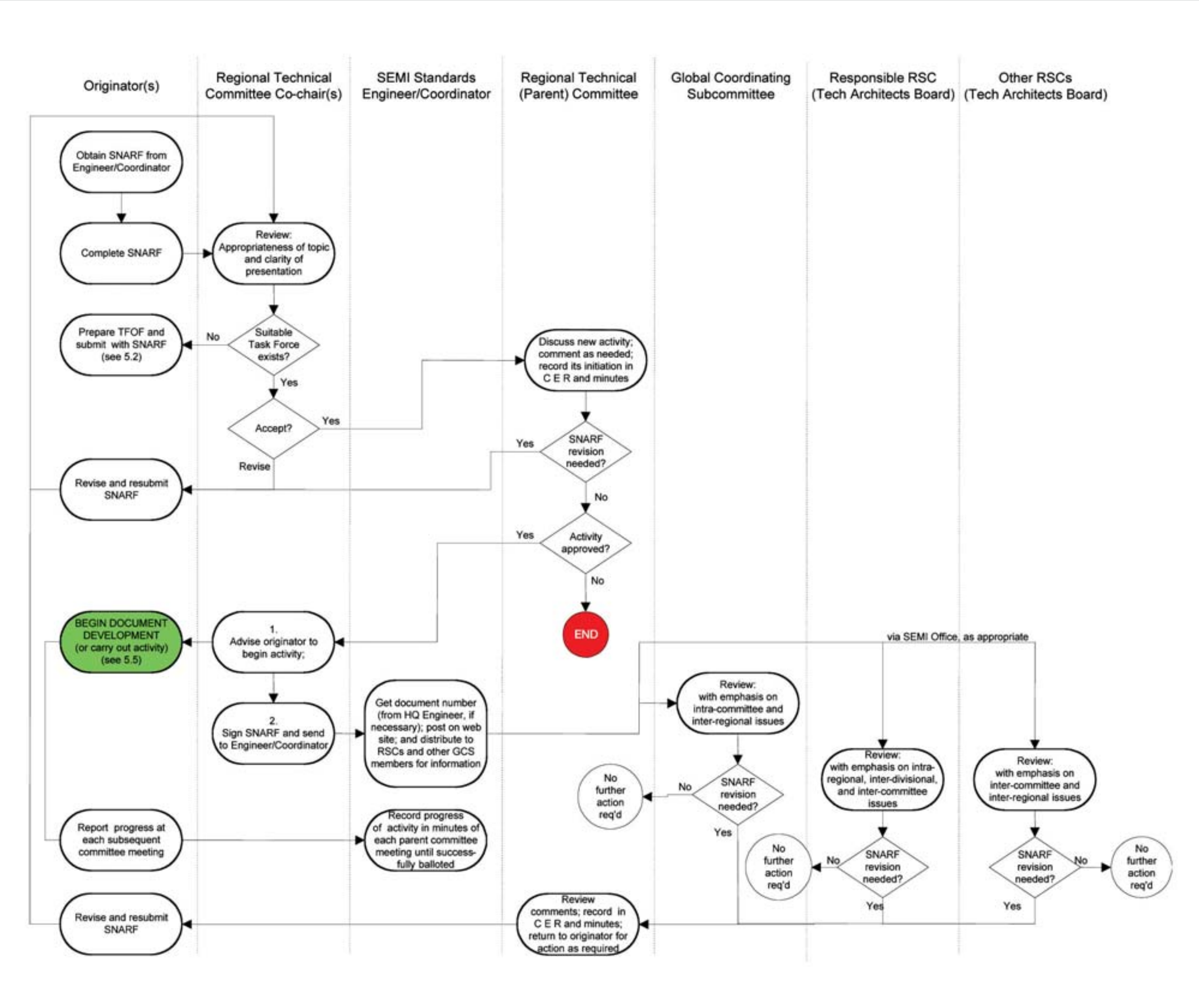


Figure 1. SEMI TFOF and SNARF development process flow.

Market Watch

How SEMI Standards are developed

Successful standards development requires just two ingredients: 1) a consensus of the PV Standards Committee that a standard is needed, and 2) a team that includes experts in that field and in standards development procedures. The SEMI International Standards Program infrastructure supports and guides the team's efforts. Key elements include:

- **Standards Regulations (the "Regs")**: these ensure a level playing field, are "evergreen" to reflect emerging needs, and provide the bedrock for all successful international standards activities. They are the unique responsibility of the International Standards Committee. Regional committee and task force leaders are usually very familiar with these regulations.
- **Procedural Guide:** this practical "how to develop standards" is written for the general standards membership. Its necessary rules and suggestions, including meeting conduct, balloting (development, execution and review of standards), and new activities for documents, provide a means for the group(s) to communicate and interact while maintaining protocol.
- **Document Guide:** through the efforts of the Task Forces, documents are prioritized, developed, and classified based on their application and to the type of standard needed. The practice of using standard specifications numbering, terminology, revision control, and outline is closely adhered to, and meets the intent of most international standardization organizations.

Figure 1 illustrates a SEMI process of how documents are developed through a Standards New Activity Report Form (SNARF) after task forces are created with an approved Task Force Organization Form (TFOF). Please note that larger or electronic versions are available through SEMI, as well as clarification of any terms or abbreviations unique to this particular chart.

Coordination with PV industry and standards organizations

Photovoltaic documentation needs have a host of standards organizations involved where SEMI's PV-related activity will be included. Examples include the following:

- **Product hierarchy:** determining standards for system installations, components of systems (e.g., structural components, inverter, module), components of modules (e.g., cell, substrate, support films, shell), and other PV aspects (e.g., software, operations, maintenance) can be defined by industry leaders as well as end users.

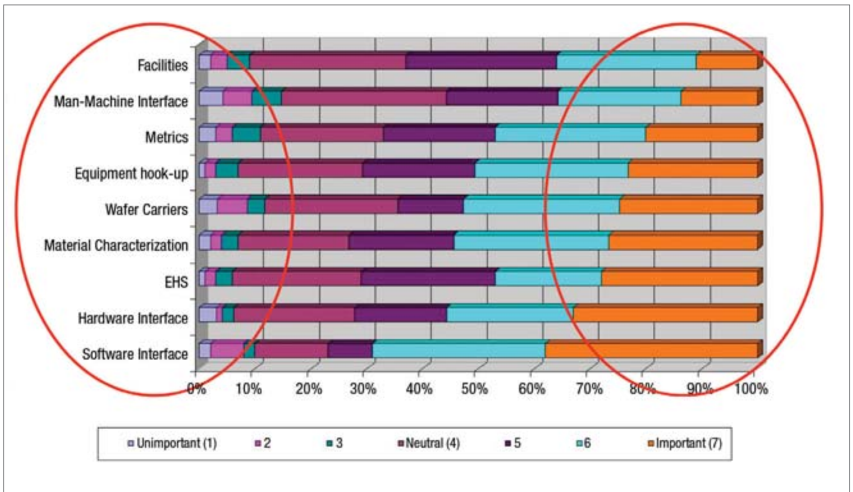


Figure 2. Assessment survey showing the areas where standards can have the most positive impact on the industry.

- **Standards hierarchy:** priority standards need to address performance certification, organizational capability, design approval (e.g., test methods), and product approval (e.g., processing, materials, equipment, and services).
- **Organizational hierarchy:** SEMI has excellent working relationships and continuously coordinates efforts with several organizations pertaining to the following groups: international (e.g., ISO, IEC), national (e.g., ANSI, DIN), services (e.g., UL, TUV, GSQ), SDOs (e.g., ASTM, SEMI, IEEE), and industry associations (e.g., EPIA, JPEA, SEIA).

SEMI's first PV Standard

The first PV standard to be submitted by the SEMI PV Group will be entitled *PV1: [Test Method for Measuring Trace Elements in Photovoltaic-Grade Silicon by High-Mass Resolution Glow Discharge Mass Spectrometry]*. The efforts to create this very important standard began in November 2007. It then went through two ballot cycles throughout 2008, and will be published in February 2009 – a 15-month cycle. Other topics in similar committees have been shorter when consensus and theme were relatively easy or longer when the topic required much discussion, investigation and task force agreement.

A specific topic's affect on the industry, its technical difficulty, and its urgency will directly impact how long it takes from idea and task force creation to it becoming a published document. These criteria are evaluated by the sponsoring Technical Committee prior to granting document development approval. International balloting often improves technical relevance and can sometimes add time.

Determining priorities

The SEMI PV Group activities described above were initiated by groups within the PV industry that saw the need for standardization in a specific area. Coincidentally, most of these activities had a high priority assigned in the various SEMI surveys. For example, the following figure indicates the initial priorities first reviewed at the SEMI - EPIA PV Needs Assessment Survey Priority Ranking at the SEMI North America PV Committee Meeting in May 2008:

> "The benefits that occur through global standardization efforts cannot be felt and measured until a document is approved, published and used in the industry."

However, additional coordination that generates priorities and promotes re-use is expected to boost the standards development process. For this reason, a core team in the SEMI PV Group has been set up to assess priorities and facilitate the transfer of relevant standards from SEMI to PV. In addition to the survey results, Q-Cells provided the SEMI PV Group with a set of objectives regarding SEMI standards, priorities, timelines, and related documents. Based on these inputs, the core team is in the process of determining an International Standards Roadmap (ISRM) and is developing an initial assessment matrix for determining SEMI-based PV-related standards. In addition to the appropriate priority settings, the most critical success factor for standards development for a given industry is the availability of a sufficient number of qualified volunteers who are willing and able to transition the industry requirements into documented standards and to reach consensus over these solutions. Figure 3 further illustrates

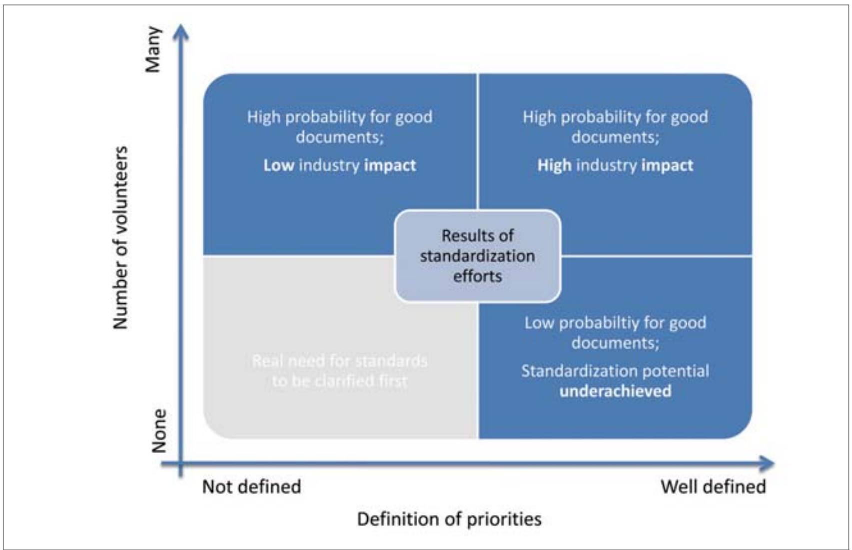


Figure 3. Standards assessment decision matrix.

the expected correlation between a structured approach and the willingness of an industry to actively participate in the development of standards.

Benefits of standards

As described in the SEMI website, companies accrue two kinds of benefits by participating in the development of standards: immediate and deferred. The immediate benefits are brought about by access to technical resources, communication and networking with peers in the industry, the ability to influence the development of the standard and recognition for participation. The deferred benefits come about when the standard is released and accepted by its user community.

Although it is true that all users of the standard experience these benefits (whether they participated in the development or not), participation ensures that the standard is in fact developed, accelerates the development so benefits begin sooner, and of course, participants get a jump on the implementation of the standard.

Currently, over 2000 volunteers worldwide participate in the SEMI International Standards Program. There are over 200 task forces working in 17 global technical committees. Meetings take place in Europe, Japan and North America. Efforts are just underway in PV, and are expected to grow exponentially in the coming quarters.

Summary and conclusion

Standards development is an up-front investment – of people, skills, time and money. The benefits that occur through global standardization efforts cannot be felt and measured until a document is approved, published and used in the industry.

The semiconductor industry is a shining example of how investments can flourish through application of suitable standards. Millions of dollars have been saved by collaboratively developing specifications and test methods for critical areas such as wafer diameter, safety, carriers, software interfaces and purity of chemicals, among many others. The semiconductor industry would be absolutely crippled if these standards did not exist or were not used globally by all stakeholders.

The PV industry can benefit greatly by leveraging the work that has already been done. By using existing standards to fill similar needs and allowing sufficient time and energy to investigate those areas truly unique to PV, solutions and approaches can be developed that will help propel the industry forward towards a more efficient, cost-conscious manufacturing process by the industry and for the industry.

References

[1] Weiss, B. 2008, 'International Standards: a critical step towards reducing PV manufacturing cost,' *Photovoltaics International*, First Edition, pp. 24-26.

[2] SEMI: 'SEMI PV1-0309 – Test method for measuring trace elements in photovoltaic-grade silicon by high-mass resolution glow discharge mass spectrometry.'

About the Authors

Win Baylies is a specialist in international photovoltaics, flat panel display and semiconductor metrology and measurement technologies. He has authored numerous technical articles, test methods, international round robin tests and related research reports. Mr. Baylies is assisting SEMI in developing photovoltaic standards as co-chair of the N.A. PV Standards Committee, and is aiding in the creation of SEMI's PV International Standards Roadmap (ISRM) as a member of the Core Group. He is a member of SEMI, SID, SPIE and ASTM. Enquiries:winba@comcast.net

Marty Burkhart is the owner of Hi Pure Tech, which provides high quality technical writing and document review services as well as consulting in clean production practices and contamination control for companies and individuals in the areas of industry and academia. Between 1992 and 1996, he was employed by Georg Fischer as a technical marketing manager for high-purity products in Switzerland. He also has 13 years' experience with Texas Instruments in Dallas, Texas and has co-chaired several SEMI taskforces.

Don Cook, PE, is President of Cook Engineering, Inc., and is currently the Chairman of the SEMI PV Group Facilities Standards Task Force. Mr. Cook has over 20 years' experience in design, construction, operations, and technological developments for microelectronics and advanced technologies projects. Prior to starting Cook Engineering, Mr. Cook was a Lead Corporate Technologies Engineer for Intel Corporation, as well as Director of Engineering at Kinetis. Mr. Cook holds a B.S.M.E. from the University of the Pacific, and is a registered mechanical engineer in the State of California. Mr. Cook is an active member of SEMI, ASES, SEIA, and the City of San Carlos.

Dick Hockett is Chief Scientist at Evans Analytical Group in Sunnyvale, California. He is Chairman of the SEMI PV Analytical Test Methods Task Force, both for NA and EU. He was previously Chairman of the Surface Analysis Task Force under SEMI's Silicon Wafer Committee in the 1990s, and Chairman of Section C (Surface Analysis) for ASTM F-1.06 (Si Semiconductors), also in the 1990s.

Matthias Meier is Project Manager and researcher at the Ultraclean Technology and Micromanufacturing department of the Fraunhofer Institute for Manufacturing Engineering and Automation (Fraunhofer IPA) in Stuttgart, Germany. His main area of research targets issues in the manufacturing IT environment. Furthermore, he is actively contributing to the emerging PV-related standardization activities within SEMI as a coach of the PV-EIS task force. Mr .Meier holds an M.Sc. in information technologies from the University of Stuttgart, Germany.

Bettina Weiss is Sr. Director, Photovoltaics Segment (North America) for SEMI/PV Group. She has been working with SEMI for 12 years. From November 2003 to March 2008, she served as Director, International Standards as chief staff of the SEMI International Standards Program. Since April 1, 2008, she has held responsibility for all initiatives and activities in SEMI's photovoltaic segment in North America, with continued global responsibility for PV standardization efforts as well as successful execution of the PV Standards Roadmap project. Ms. Weiss is assisted by Kevin Nguyen, Manager of NA Standards Committee for SEMI.

Enquiries

Website: www.semi.org

Field Engineer
GCL-Silicon
U.S., China

GCL Silicon aspires to be one of the world's leading solar companies, and we invest heavily in our people and our technologies because we understand they are both fundamental components of our mission of bringing green power to life. We recognize the need to build a sustainable future and our employees can take pride in their individual contribution to that process.

The position will be based in the U.S. with frequent travel to China.

· You will be responsible for implementing our R&D outcomes or streamlining our polysilicon production or other technical projects as our business requires.
· You should have an Associate or Bachelor's degree in a related discipline with over seven years of operations experience in production in the solar or semiconductor industry, particularly in polysilicon and/or wafer production.
· You should be a team player with strong communication skills.
· Fluency in English is essential.

Equipment Project Manager- Solar
First Solar, Inc.
Perrysburg, Ohio. U.S.

In this position you will oversee the process of equipment acquisition, fabrication, installation, start-up and transition into production. Responsibilities include: schedule, budget and vendor management of specific equipment to be replicated under the First Solar Copy Smart Philosophy. Specific knowledge required in project management principles and practice along with a working knowledge of mechanical, electrical and control systems for highly automated production equipment.

Essential Functions & Responsibilities:
· Responsible for overseeing the entire process of replicating equipment into factory expansions.
· Manage critical timelines and schedules while constantly working to improve lead times.
· Manage capital equipment budgets.
· Responsible for interfacing with other company, customer and supplier representatives.
· Maintain effective communications levels and foster team building.
· Adhere to all safety procedures and good housekeeping standards.

Manufacturing Engineer
First Solar, Inc.
Kulim, Malaysia

The successful applicant will conceive, develop and evaluate plans and criteria for the completion of process improvement projects and programs in a cost-efficient manner.

Essential Functions & Responsibilities include :
· Develop, continually improve and document robust solar module manufacturing processes to achieve the highest product performance in a cost-efficient manner.
· Interface with other Company, customer and supplier representatives.
· Evaluate new proposed equipment according to process standards.

Qualification Requirements:
· Bachelor's Degree in Engineering Discipline or Physical Science Field or equivalent.
· Three to eight year's process engineering experience in a manufacturing environment; will usually have specific experience in vacuum deposition.
· Fluent with Microsoft Office Suite.
· Knowledge of ISO 9000 standards, statistical methods and SPC tools.
· Glass, photovoltaic and/or thin-film deposition experience preferred

Vice President of Engineering
Veeco Instruments
New Jersey, U.S.

ESSENTIAL SKILLS:
· Provide strategic leadership for engineering, hardware and process technology.
· Expert level of mastery of engineering and scientific aspects of compound semiconductor epitaxial growth MOCVD including process development and material characterization.
· Recognized as an expert in the field and technical community.
· Knowledge of compound semiconductor device physics, processing application and design of complex scientific process equipment.
· Excellent oral and written communication skills and ability to speak before large groups.

EDUCATIONAL/EXPERIENCE REQUIREMENTS:
· Master's degree in Engineering, Material Science and/or Physics. Ph.D. preferred.
· Ten year's experience in a semiconductor equipment, capital equipment environment or semiconductor priced technology.
· Specific experience in product development in semiconductor capital equipment.
· Three or more years of epitaxial growth with previous experience in design or testing complex scientific or semiconductor process equipment.
· Experience in leading technology teams.

Director, Yield Engineering, Solar SunFab,
Applied Materials
Santa Clara, CA, U.S.

The Director of Yield Engineering will develop a technology yield improvement plan with SunFab Technology development team and Process Sustaining to incrementally improve each generation of process technology (Thin films, cSi)

General responsibilities involve the development of key methodologies for overall monitoring and improving the rate for which yield improvement occurs. The Director will lead all task force activities around yield excursion or slow yield learning within a factory and design methodologies that will enable factory yield learning though applying sophisticated analytical statistical techniques and tools. The Director will become familiar with and help define leading-edge measurement equipment to enable early inline feedback of processing results of the various solar technologies. Specifically, the Director will be responsible for:
· Increasing fab yield by utilizing yield Enhancement Methodologies.
· Proliferating Best Known Methods (BKMs) across SunFabs .
· Improving tool, mechanical, electrical and overall process yields .
· Developing methodologies to improve yield across production lines.
· Optimizing existing process flows for manufacturability and improved product performance.
· Routinely reviewing and improving device performance and yield.

Applied Materials is an Equal Opportunity Employer committed to diversity in its workforce.

Factory Start-Up Director/Manager
(Solar Factory Operations)
Applied Materials
Various worldwide locations

Supplying complete production lines, including process and systems to a wide range of existing players and new entrants in the Solar/Photovoltaic manufacturing industry, the company will be starting up multiple production lines per year in a wide range of locations around the world.

· The factory (start-up) managers will be key factors in successful, on-time, high yield/quality start-up and ramp. Customer payment schedules to future sales and service business will depend on high performance of customer satisfaction services.
· You will report to the VP of Factory Projects, Solar Business Unit but will be expected to take direction and work closely with a wide range of executives in Sales and the Solar Business Unit. This will be a high-level position with very broad responsibility and exposure.
· You will have full responsibility for all aspects of the local start-up, including hiring and developing the local team (with the permanent manager), working with the customer on site readiness and supervising the Solar Business Unit/AGS start-up team on-site. Will coordinate start-up activities between the site and the solar business group and other support groups as needed.
· You will be assigned to a specific customer and site several months before production starts and will continue until final factory-sign off and healthy local operations are in place. You will hand-off responsibilities to a local Site Operations Manager.
· You will also be assigned various projects to help develop solar factory start-up and operations as core competencies within the company.

Applied Materials is an Equal Opportunity Employer committed to diversity in its workforce.

Going Places

MEMC

Nabeel Gareeb leaves MEMC

Nabeel Gareeb, President and Chief Executive Officer of MEMC, resigned his executive position and seat on the Board of the major polysilicon supplier to the semiconductor and photovoltaics industries. Gareeb (pictured) will assist in a transition through the end of 2008, while Board member Marshall Turner will serve as interim CEO, effective November 12, 2008. The search for a permanent replacement for Gareeb will be conducted during this period.

SunPower

CFO succession at SunPower announced

With the retirement of SunPower's current CFO, Manny Hernandez, the company has announced utilities veteran Dennis V. Arriola (pictured) will become its Senior Vice President and CFO in November. Arriola will work closely with Mr. Hernandez through January 2009, the company said.

Arriola was most recently Senior Vice President and CFO at San Diego Gas & Electric and Southern California Gas Co., Sempra Energy's California regulated utilities. He earned a Master's degree in business administration from Harvard University and a Bachelor's degree in economics from Stanford University.

Tigo Energy

Tigo Energy opens new facility in Israel; Modi Avrutsky appointed as Manager

Tigo Energy has announced the opening of its first international office in Kfar Saba, outside Tel Aviv, which will focus on engineering activities. The company has also appointed Mordechay Modi Avrutsky (pictured) to serve as Vice President of Engineering and General Manger of the site.

Avrutsky was formerly with Enercon as the General Manager of engineering. He started the company as a development engineer and later worked in the design, production and certification of power systems for military and industrial applications. Mr. Avrutsky received his Bachelor's degree in electronic engineering from Ben Gurion University in Israel.

Sunways AG

Sunways reassigns executive positions

Sunways AG has announced that Roland Burkhardt CEO and founder of the company, will pass his position of CEO and Sunways strategic and operational management to CFO Michael Wilhelm, effective 1 January 2009. In addition, the Supervisory Board has named Jürgen Frei as Management Board Member holding the responsibility of the new distribution and marketing division. Sunways attributes the various changes in its management positions to its preparation for its expected growth in 2009 and beyond.

Oerlikon Solar

MW Zander's Robert Gattereder new Senior VP, New Business at Oerlikon Solar

Oerlikon Solar has chosen Robert Gattereder for the newly created position of Senior VP, New Business where he will be expanding the business opportunities for the company. His functional experience of over 15 years in management positions includes eight years with MW Zander.

CNPV

B. Veerraju Chaudary named new Chief Technology and Operating Officer of China Solar Photovoltaic SA

CNPV announced today its selection of B. Veerraju Chaudary as CTO & COO, effective immediately. Chaudary brings over 17 years of experience in the photovoltaic industry to CNPV with previous positions at Siemens Solar Industries, Pentafour Solec Technology, TATA BP Solar, and Trina Solar. He also has extensive background in technology, product development, quality assurance, and SCM and operations. Chaudary received his B.S. in electronics from Andhra University and has trained in solar photovoltaic system design and engineering from the Indian Institute of Technology, Mumbai.

Evergreen Solar, Inc.

William Ovitt selected as Director of Sales, Asia Pacific by Evergreen Solar

Evergreen Solar, Inc. has selected William Ovitt for the newly created role of Director of Sales, Asia Pacific in which he will oversee the sales and marketing in the Asia Pacific region. Ovitt boasts more than a decade worth of international sales experience in the energy market, much of which focused on renewable energy in the Asia Pacific region.

Ascent Solar

Ascent Solar recruits LG.Philips LCD executive as new Chief Marketing Officer

Former Chief Marketing Officer of LG.Philips LCD, Bruce Berkoff (pictured) has been appointed the new Chief Marketing Officer at Ascent Solar Technologies, Inc. The appointment was viewed as strategic with Berkoff's 25 years of executive experience, especially in the highly competitive and low margin LCD business.

Mr. Berkoff currently serves on the boards of directors of LG Display and Unipixel as well as serving as Chairman of the LCD TV Association. Mr. Berkoff was CEO of Enuclia Semiconductor, CMO and EVP at LPL, Vice President and General Manager at Philips Components FDS, and has held various other executive positions. He holds undergraduate and graduate degrees from Princeton and UC Berkeley, respectively.

Daystar Technologies, Inc.

DayStar names new Vice President of Corporate Development

DayStar Technologies, Inc. has appointed Patrick J. Forkin III (pictured) as Vice President of corporate development. Reporting to company CEO Stephan DeLuca, Mr. Forkin brings over 25 years of experience in equity research, M&A, strategic planning and corporate finance to the role.

Conergy Solar Module GmbH

Conergy's Sylvère Leu accepts The 3S Group's COO role

Sylvère Leu, former Managing Director of Conergy Solar Module GmbH in Frankfurt (Oder), has departed the company to take up a role as COO for The 3S Group. The newly created role will come into effect from October 1st, 2008, and will see Mr. Leu apply his more than 20 years of industry management experience to the operation of the solar module production technology company.

Mr. Leu's past career has seen him work with companies such as Fabrisolar AG, Küsnacht, Suntechnics GmbH and Hamburg (DE), as well as his most recent role with Conergy, where he was instrumental in building up its Frankfurt (Oder) solar factory. He studied engineering at the University of St. Gallen, Switzerland and the Swiss Federal Institute of Technology in Zürich.

Going Places

Sputnik Engineering AG

Sputnik Engineering AG names new General Manager for Spanish office

Solar inverter company Sputnik Engineering has announced a management change in the replacement of Alejandro Lupion with Fernando Sánchez García as General Manager of the Sputnik Engineering Ibérica S.r.l. in Madrid. The change came into effect on September 15th, 2008.

HelioVolt

Thin-film solar PV producer HelioVolt names Patel to run global sales and marketing

Thin-film solar PV producer HelioVolt has named Haresh Patel as its Vice President of sales and marketing. Patel joins the copper-indium-gallium-(di)selenide (CIGS) TFPV company with more than 20 years of experience at firms such as WJ Communications, Agilent Technology, PMC Sierra, Fujitsu, and Texas Instruments. In this newly created position, the company says that Patel will direct its planning and execution of global sales and marketing efforts along with related technology development for advanced solar products.

Spire Corp.

Spire adds five new members to leadership team

Spire Corp. has announced the addition of five new recruits to its management team. The senior staff members, all Vice Presidents of their respective departments, bring years of experience in the semiconductor, technology and marketing industries to their roles. The new additions are: Dr. Avishai Kepten, Jae-Bok Young, Martin Stein, Louis Insalaco, Jr., and Michael Hurton.

Dr. Avishai Kepten will take up the role of Vice President of Solar Cell Lines. Joining Spire as Vice President of Business Development – Far East is Jae-Bok Young Martin Stein joins the company as Vice President of Engineering and New Product Development. Louis Insalaco, Jr. assumes the role of Vice President of Manufacturing and Michael Hurton joins Spire as Vice President of Strategic Resource Management.

Solaicx

GE's Steven Concklin moves to Solaicx as Supply Chain Manager

Solaicx, the monocrystalline silicon ingot and wafer manufacturer, has added the experience of Steven Concklin to its team. A 25-year veteran of the industry, Mr. Concklin joins the company as Supply Chain Manager from his former role in GE Energy's Solar Technologies Division. His new role will involve management of the company's supply chain operations and liaise with key global vendor partners.

Tigo Energy

Intel insider Jeff Krisa moves to Tigo Energy

Tigo Energy has brought aboard veteran sales and marketing executive, Jeff Krisa. Krisa brings over 20 years of noteworthy experience in semiconductor technology, systems development, international marketing, and general management as well as a long history of involvement in alternative energy. Tigo's new Sales and Marketing V.P. began his career at the U.S. Department of Energy alternative energy project at Princeton Plasma Physics Laboratory. Krisa also has developed a reputation within the semiconductor industry for his track record spanning 17 years at Intel.

eSolar

Sandia National Laboratories veteran Craig Tyner joins eSolar as Senior VP of Engineering

eSolar has announced its appointment of Dr. Craig Tyner, a 31-year employee of Sandia National Laboratories, as Senior Vice President of Engineering. At Sandia, he was manager of the company's solar and geothermal research and development programs and in his new role with eSolar will lead the company's technology development.

During Dr. Tyner's 31 years at Sandia, he was program manager for all Sandia activities on the Solar Two Project, including a role as the Department of Energy's primary advisor. Dr. Tyner has a Ph.D. in chemical engineering from the University of Illinois and a B.Sc. from the California Institute of Technology.

Surfect Technologies

Industry veteran David Pham joins Surfect Technologies as Solar Product Manager

David Pham has joined the Surfect Technologies team in the role of Solar Product Manager. This role will see him oversee all process, software, and product development and global sales strategies. He joins the company from his former role as Chief Consultant at the NextLevelGroup.

Prior to joining the NextLevelGroup, he worked as Global Applications Engineering Manager for Solvision Incorporated, and has also held roles with Hitachi Semiconductor, Advanced Micro Devices, and Motorola. A much-published author of books and technical papers and presentations, he has a B.Sc. in electrical and computer engineering from the University of California.

Advent Solar

Advent Solar adds Trueblood, Wilimitis to executive team

Advent Solar has added financial veteran Dick Trueblood and manufacturing expert Bernard Wilimitis to its executive management team. Trueblood joins the company as its CFO, responsible for financial management, taxation, and global business structuring in support of international growth. Wilimitis was promoted to VP of manufacturing and operations, where he oversees all manufacturing and operations.

Before joining Advent, Trueblood was a partner at Tatum LLC, conducting international due diligence for potential acquisitions. Wilimitis takes over as Advent's VP of manufacturing and operations, after serving as the company's director of manufacturing for two years. Wilimitis has a B.S. in industrial technology from Purdue University and is bronze-level trained in lean manufacturing methods.

Open Energy

BIPV company Open Energy announces executive changes

Open Energy has announced the appointment of three new board members following the company's receipt of financing from The Quercus Trust, and the appointment of a new Chairman and CEO, effective October 31st, 2008. The Board of Directors will consist of five members, three of whom will be appointed by Quercus. The two other board members will be represented by Kenneth Potashner as independent director and by a member of Open Energy's management.

The company's President and COO David Field (pictured) assumed the roles of Chairman of the Board and CEO from October 31, 2008, replacing David Saltman in both roles. The three Quercus-appointed board members are: David Anthony (Managing Partner of 21Ventures), Joe Bartlett (The Quercus Trust), and Dr. Gary Cheek (independent solar expert.

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The Technology Resource for PV Professionals

The time is now! The economic, technological and political forces are converging to make photovoltaic manufacturing one of the fastest growing and dynamic industries in the world. As fuels for traditional energy supplies dwindle and end consumers become increasingly conscious of their impact on climate change and the environment, the time is now for PV to gain a strong share of the renewable energies marketplace.

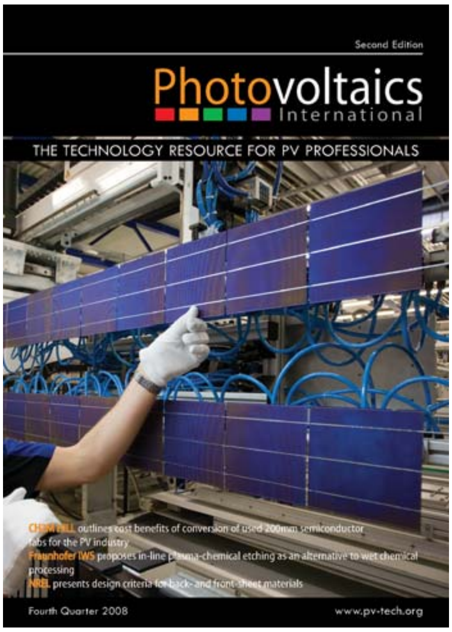
Focussing on technology, Photovoltaics International is the only journal specifically designed for the PV supply chain, including materials, components equipment, manufacturing and large-scale utility installation. It is a business-to-business publication that will influence the purchasing decisions of professional PV manufacturers and integrators through independent editorial and high-quality technical articles.

Articles presented in Photovoltaics International are independent and depict actual data and findings for the education of facilities managers, executives and engineers. We will provide coverage of the best and latest developments in the PV manufacturing industry, and present these in a clear, easily navigable format.

Photovoltaics International is free to manufacturers of wafers, cells and modules as well as professionals responsible for creating and installing large-scale solar power plants. Fill in the form overleaf and we will process your request.

Editorial Contributions

Prospective writers are welcome to provide content for technical papers covering the most pertinent issues in the PV industry. All submissions will be reviewed by our experienced editorial team.



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Martin Zimmer, Fraunhofer ISE.

"E.U. Government Incentives: a new landscape for 2009"

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