Sixth Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS

Fraunhofer IST compares different ceramic target materials from Al to Zn

Q-Cells unveils its production technology roadmap for boosting cell efficiencies

SolarWorld presents yield management results direct from the fab

Wright Williams & Kelly assesses equipment cost of ownership

BIPV comes of age in our new focus

Fourth Quarter, November 2009

www.pv-tech.org

Photovoltaics International

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

Publisher: David Owen
Managing Editor: Síle Mc Mahon
Senior Contributing Editor (U.S.): Tom Cheyney
News Editor: Mark J. Osborne
Production Manager: Tina Davidian
News & Features Editor: Emma Hughes
Design: Andy Crisp
Commissioning Editor: Adam Morrison
Account Managers: Adam Morrison
Graham Davie
Daniel Ryder
Gary Kakoullis

Front cover shows the Automatic Bussing Equipment (ABE) of the BIPV fully-automated production line of SYSTEM Photonics – The Energy Design Company.
Picture courtesy of SYSTEM Photonics.

Printed by Ghyll Print Ltd.
Photovoltaics International
Sixth Edition
Fourth Quarter 2009
Photovoltaics International is a quarterly journal published in February, May, August and November.

ISSN: 1757-1197

USPS Information
Periodicals Postage Paid at Rahway, NJ.
Postmaster: Send changes to:
Photovoltaics International
c/o Mercury International Ltd.
365 Blair Road
Avenel, NJ 07001

Publisher's foreword

Is it a bounce or a rebound?

Starting in September at EU PVSEC, the solar industry has been showing strong signs of recovery in Germany, California and Italy. Perhaps the strongest indicator is the level of new tool orders and tool deliveries for PV manufacturers. Just ask VLSI's John West (p.176), whose tracking of tool data in the PV supply chain has shown that equipment, component and materials companies are capitalising on a sudden surge in tooling demands.

Utilization rates are up, inventories are leaner and some capacity expansion projects are no longer on hold. Most importantly, average selling prices are stabilising, driven by better-than-expected sell-through rates in end markets, particularly in Germany and California. Germany is being driven by fears that the new coalition government may reduce tariffs as early as next July, while the U.S. market is buoyed by utility-scale projects coming back online due to financing from DOE grants schemes and improving access to debt globally.

New leadership in Japan appears very supportive of solar at this early stage. France and Italy are working hard to encourage a new wave of building-integrated installations with much higher tariffs, and Eastern Europe, North Africa and South America are poised to enter the solar installation fray. The future looks bright indeed for the solar industry at both ends of the supply chain.

Such a shift will see the technology leaders re-emerge to implement new research and development strategies that have been fostered during the demand downturn in 2009. In this issue we take a look at the approaches of some of the industry leaders to this burgeoning market change. **SolarWorld** (p.130) addresses yield management at the process level to help maintain quality; **PV Crystalox** (p.36) presents the advantages of using slurry during the wafering process; **Q-Cells** (p.64) reveals the company's cell technology roadmap for the next three years; **Tata BP Solar** (p.83) looks at the advantages of using ARCs to enhance cell efficiency; while **Nanosolar** (p.98) is placed under the microscope by our resident thin-film expert Tom Cheyney.

Expanded tariffs in France and Italy for aesthetically integrated solar systems are sparking a great deal of interest for 2010. *Photovoltaics International* will be covering all the developments in **BIPV** in greater detail to service the needs of our architecture- and construction-based subscribers. Check out our special **BIPV** focus in this issue (p.160).

The growth of the industry has been reflected in the growth of our own team. We now have six editors around the world and in November we opened a satellite office in Düsseldorf, Germany. This will allow us to better serve our German audience going forward.

Don't forget that entries are now open for the Cell Award 2010, the only independently adjudicated awards in the solar industry. Be sure to nominate your favourite solar technology at www.cellaward.com.

Sincerely,

David Owen
Photovoltaics International

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 SE

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

Takashi Tomita, Senior Executive Fellow, Sharp Solar

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

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

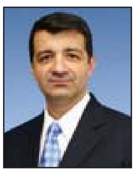
Dr. Kuo En Chang joined Motech in 1999 as Chief Technology Officer and became President of the Solar Division in 2008, with responsibility for all technology and manufacturing. Motech is the sixth largest solar cell producer in the world. Before Dr. Chang joined Motech Solar, he worked on secondary battery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

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

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

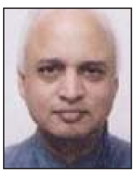
Dr. Zhengrong Shi, Chief Executive Officer, Suntech

Dr. Zhengrong Shi is founder, CEO and Chairman of the board of directors of Suntech. 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.



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

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

Contents

Photovoltaics International

Fab and Facilities

News

Suniva to invest US$250 million in Michigan manufacturing facility

Michigan Governor Jennifer M. Granholm has announced that Georgia-based Suniva will invest US$250 million in a new solar manufacturing facility in Saginaw County's Thomas Township. With this development, Suniva will create 500 new jobs over the next five years subject to receiving a Department of Energy (DOE) loan guarantee, for which the company recently applied.

The Michigan Economic Growth Authority (MEGA), on Michigan Economic Development Corporation recommendation (MEDC), has approved a PV Michigan Business Tax (MBT) credit valued at US$15 million over the five years. Michigan's PV MBT credit provides a refundable tax credit for the construction and operation of a facility that develops and manufactures solar PV technology, PV systems or PV energy.

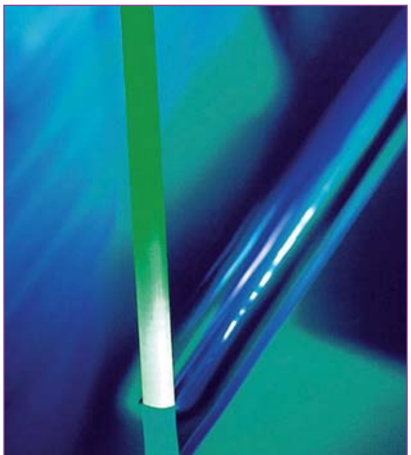
Michigan Governor Jennifer M. Granholm.

Capacity News Focus

Centrosolar Glas increases PV glass production, readies new antireflective nanocoating process

Centrosolar's Glas unit has increased its annual solar glass manufacturing capacity to six million square metres at its factory in Fürth, Germany, and has a new antireflective nanocoating process set to go into volume production before the end of the year. The company says that it has invested €10 million over the past two years to double its production output because of the addition of new customers in Europe, North America, and Asia, and that the newly installed capacity is being fully utilized, with further expansion plans already in the pipeline.

The company says that its best-selling product is antireflective-coated solar glass that can boost the annual power output of a solar module by 4-7%. The new patented nanocoating feature set to go into volume production soon can now also be applied just on one side, and across the entire surface, making the processing of this solar glass even more efficient. Two major American solar companies and a Chinese solar module manufacturer were recently added to the company's portfolio of customers.



Centrosolar Glas PV glass.

Source: Sanyo

Salem Energy and Technology Park.

Sanyo opens Salem Energy and Technology Park: 600MW capacity in sight

Sanyo North America, subsidiary of the North American regional headquarters of Sanyo Electric, based in San Diego, has officially opened its latest manufacturing plant for solar PV products: the Salem Energy and Technology Park.

The plant, based in Salem, Oregon, is now fully opened for business, with production already in progress. The plant is designed to produce silicon ingots and wafers for Sanyo's HIT (heterjunction with intrinsic thin-layer) solar cells and modules. Although the new facility is now up and running, it is not expected to reach full production capacity (70MW annually) until at least April 2010, by which time the company has an overall goal of 600MW capacity.

Sanyo Energy has also opened its plant in Nuevo Leon, Mexico. As a subsidiary of Sanyo Electric, Sanyo Energy will use this Monterrey site to produce HIT solar modules for installation in North America. The new plant will contribute another 50MW per annum, towards the company's goal of an annual 600MW. At present, the company has module assembly plants in Japan, Mexico and Hungary.

"Our Monterrey plant was our first overseas module assembly facility in our solar business," said Mr. Mitsuru Homma, Executive Vice President and Member of the Board of Sanyo Electric. "The Monterrey plant is important and vital in North America for the assembly of our world's highest efficiency HIT modules and the work done here has largely contributed to the growth in sales in North America, and will remain a factor as this region continues to grow."

SolarWorld at full production load: further capacity expansions planned

Despite many PV manufacturers holding back on further capacity expansions in the first-half of 2009, major producer, SolarWorld has retained its capacity investments, which were pegged to approximately 20% of sales throughout the year. However, due to increased sales, shipments have increased 22% in the first nine months of 2009. This has sparked further capacity expansion plans at its facilities in the U.S. and South Korea.

SolarWorld reported revenue of €232.5 million in the third quarter, down from €238.3 million in the same period a year ago. This was due to lower module prices but increased shipments. In the first nine months SolarWorld generated revenue of €634.1 compared to €665.4 million in the same period of 2008.

The new wafer and cell production facility in Hillsboro was successfully ramped in the first half of 2009, while its Camarillo facility completed the conversion to a new module production line. The Hillsboro facility would increase the production of crystalline solar power modules to an expected capacity of 350MW by 2011. However, SolarWorld is now planning module production in the U.S. with expected expansion of up to 500MW, though no timing details were given.

At its plant in South Korea, SolarWorld had said mid-year that the nominal capacity was 110MW per annum and was fabricating modules for rural, off-grid applications in module classes of capacity ranging from 25Wp to 120Wp. SolarWorld said that it will expand capacity to 300MW, again without giving schedules.

SolarWorld to triple module production in Freiberg to meet demand

In further news for the company, SolarWorld is citing strong demand for German-made solar modules and operating at capacity limits to expand production at its plant in Freiberg, Saxony to 450MW by the end of 2010. The company said that more than 500 new jobs would be created with a tripling of production. SolarWorld is already expanding wafer production to 1GW at a new facility also in Freiberg.

The new wafer plant has an investment of approximately €350 million and will be fully operational by the end of 2010. SolarWorld did not say what the investment would be for the expansion on module production.

Bridgestone to install new solar EVA production lines at Seki plant, increase overall capacity

Bridgestone will increase its production capacity of ethylene vinyl acetate (EVA) film, which is used as an adhesive for solar modules. The company said it will install new production lines at its Seki Plant in Seki City, Gifu Prefecture, adding to its existing EVA film manufacturing site in Iwata City, Shizuoka Prefecture.

The production capacity at the Seki plant will be 1200 tons per month by the second half of 2011, at a total investment of about ¥4.4 billion (US$48.67 million), according to the company. In September 2008, Bridgestone said it had earmarked approximately ¥5.4 billion (US$59.76 million) for investment in the Iwata plant, with plans to begin increasing production in early 2011. Combined with the previously announced capacity expansion plans in April 2008 which will take effect in late 2010, the leading tyre and rubber company stated at the time that it expected total monthly production of EVA film to reach approximately 3000 tons, once the lines ramped to volume.

Bridgestone's EVA film-coated modules.

Bridgestone says it will continue to consider further production increases in line with projected growth in demand for solar modules, especially in Europe and China.

Green Energy Technology to expand ingot and wafering capacity

Green Energy Technology (GET) has been running its ingot and wafer production facilities in both Taiwan and China at full capacity throughout the third quarter of 2009, prompting the company to announce plans to expand capacity further by the end of the year.

At its Taiwan facilities, GET said that ingot production would be expanded from 300MW to 360MW and its wafer slicing capacity increased to 300MW, up from 235MW currently. The expansions are all planned to take place by the end of

2009. In China, GET said that its wafer slicing capacity would be increased to 50MW during 2010. GET is currently bringing online 30MW of wafer slicing capacity at its facility in Shandong, China, which will start operations in the fourth quarter of 2009.

Dow Corning to build PV monosilane gas manufacturing plant in Michigan

Dow Corning has started construction of a high-purity monosilane gas manufacturing plant in Thomas Township, MI. The factory, located adjacent to Hemlock Semiconductor's polysilicon production facility, is expected to be completed in 2011.

Monosilane is a key specialty material used in the production of certain thin-film photovoltaic devices as well as liquid crystal displays. The company says the new facility represents an investment of hundreds of millions of dollars and will initially employ about 30 workers. Dow Corning also unveiled an installation of 136 PV panels at the Solar Discovery Center at its corporate headquarters in Midland, MI.

In addition to providing 30kWh of clean energy to the electrical grid, the installation serves as a testing ground for the company's silicone encapsulation solution. Half of the solar panels in the installation are encapsulated with its advanced silicone encapsulation solution to compare and test in real-life conditions, with the other half encapsulated using standard technology.

Evergreen Solar to close U.S. module plant: US$70 million write down on Sovello JV

As part of its plans to conserve cash and reduce module assembly costs to remain competitive as module prices have declined over 30% since last year, Evergreen Solar is planning to shift its Devens module assembly production to China, starting in mid-2010. When the company announced its manufacturing partnership in China with Jiawei Solar back in May, 2009 executives had said that the Deven's module plant would continue to make modules for the expected expansion of the U.S. market. Now the company will shut-down production next year and only reopen the facility should demand dictate.

In reporting third quarter financial results, Evergreen Solar also noted it undertook an impairment charge of approximately US$70 million on its investment in Sovello. The company noted in the revaluation of this asset that if Sovello was not able to 'restructure the terms of its loan agreements or its operations continue to deteriorate, the carrying value of this investment could be further impaired in the future.'

With respect to quarter results, Evergreen Solar posted sales of US$77.7 million, including US$2.2 million of fees from the Sovello JV. Second quarter sales were US$63.8 million, including $1.1 million of fees.

The company shipped 31.3MW from its Devens facility, an increase of 35% over second quarter shipments of 23.2MW, shipping all its production in the quarter.

Total manufacturing costs were reduced to US$2.24 per watt, down 17% from US$2.70 per watt for the second quarter. Wafer manufacturing cost was approximately US$0.75 per watt, down from US$0.85 per watt in the second quarter.

Production of its String Ribbon cells will continue at the Deven's facility, Evergreen Solar said. As a single 'open' facility the module line is in affect mothballed, subject to market demand conditions before it could be restarted.

Solar Cell News Focus

Arise, Scheuten sign agreement for PV cell Technology Centre

Arise Technologies has entered into multi-faceted agreements with Scheuten Solar for Arise to create a photovoltaic cell Technology Centre in Gelsenkirchen, Germany, establishing a relationship with

Scheuten as a potential PV cell customer and modules supplier. Arise intends to use the building as a Technology Centre with a pilot production line to commercialize the company's high-efficiency PV cell technology.

Both companies have signed non-binding letters of intent whereby Scheuten intends to purchase PV cells from Arise, while Arise will purchase OEM modules from Scheuten. On its side of the agreement, Arise has purchased the assets – including inventory – of the Scheuten PV cell manufacturing plant. It is the intention that the payment for the assets will be satisfied through pricing reductions on PV cells sold to Scheuten.

Arise will also employ all of the 55 people currently working at the Gelsenkirchen plant, where staff have agreed to work under the same terms as their existing employment agreement.

Photo: Roth & Rau

Roth & Rau silicon wafer coats.

Roth & Rau starts Swiss unit, opens solar-cell technology development center at IMT

Roth & Rau has opened a technology center for the development of future-generation solar cells at the Swiss Institute for Microtechnology (EPFL/IMT), as part of a three-year agreement that the two organizations signed in May 2008. A Swiss subsidiary of Roth & Rau has been established in conjunction with the installation of the research line and siting of a team of scientists and engineers at IMT's Neuchâtel campus.

The facility will be used to develop equipment, technologies, and processes for the production of highly efficient crystalline silicon solar cells based on heterojunction technology, according to the partners.

"We are doing intensive research at Neuchâtel into the next-but-one generation of solar cells, which will achieve efficiency ratios of 20% and more," said Roth & Rau's CEO, Dietmar Roth. "We have already obtained the first promising results and are confident that the new manufacturing technologies including the required plant technology and processes will be ready for mass production in 2011."

Up to this point, heterojunction solar-cell technology has been used on an industrial scale by a single company--Sanyo. Heterojunction cells are based on a relatively simple low-temperature manufacturing concept; they are characterized by excellent passivation, which leads to very high efficiencies and excellent temperature behavior, the company said.

"We aim to consolidate our technology leadership with innovative products and hence to grow our company in the long term," explained Bernd Rau, managing director of Roth & Rau Switzerland and group R&D officer. "Comprehensive investments in research and development like here in Neuchâtel are the basis for this growth."

The IMT operation is not the only external technology center where Roth & Rau has become heavily involved over the past year. The company announced in July its intention to renew and expand its partnership with SVTC Technologies, including the establishment of a 30MW development and manufacturing line at SVTC's new Silicon Valley Photovoltaic Development Center in San Jose.

Canadian Solar module integration (China).

Canadian Solar integrates cell and module operations with Camstar's SolarSuite software package

Manufacturing software house, Camstar Systems has been selected by Canadian Solar to implement manufacturing execution and quality control measures that will better integrate cell and module manufacturing operations. The vertically integrated PV manufacturer will use Camstar's SolarSuite software on Camstar's Enterprise Platform. Canadian Solar will deploy the solution in its cell manufacturing site in Suzhou and its module-manufacturing site in Changshu, both in Jiangsu Province, China. The aim of the project is to create a more effective manufacturing process that enables better quality control tracking and improved process control.

Thin-Film Production Focus

M+W Zander completes thin-film factory: hands keys to Q-Cells subsidiary, Solibro

The international engineering company M+W Zander has handed over a new solar module factory to Q-Cells subsidiary, Solibro. The final acceptance took place at the Thalheim factory in Saxony-Anhalt, Germany. Even though a harsh

winter prevented work for three weeks, M+W Zander delivered on budget and on schedule. The new factory has an annual nominal capacity of 90MW and a production floor area of around 15,000m². The facility will manufacture thin-film solar modules based on CIGS technology.

Air Liquide plans large thin-film production unit in Germany

Air Liquide is to build a large thin-film production unit to serve customers in the world's largest Solar Valley in Thalheim near Leipzig, Germany. The unit will be built to accommodate the increasing demand for thin-film technology in the area. The company will produce more than 38,000 tons of nitrogen per year, representing an investment of around €10 million. Air Liquide will also ensure the nitrogen supply for Sunfilm and Calyxo, a subsidiary of Q-Cells. The new production unit is due to start up in 2010.

Other News Focus

SolarEdge opens new European office based in Germany

SolarEdge, the solar power-harvesting provider, has opened a new European office located in Dresden, Germany. The company's new office will provide sales and technical support for solar power harvesting and monitoring systems.

Several partnerships are being formed as strategic alliances for SolarEdge with Germany's Schott and Gehrlicher as well as the recently announced HaWi Energietechnik. SolarEdge's distributed power harvesting and monitoring system tackles common solar performance problems, such as lost electricity production from partial shading and other glitches in the electronic equipment that transports power between the panels.

HaWi Energietechnik and SolarEdge announced at the same time as the new office opening, a strategic partnership in which HaWi will offer the SolarEdge innovative power harvesting solution to its customers. HaWi is headquartered in Germany, and has additional offices in Italy, Spain, France, Greece and one opening soon in Israel. The announcement follows over six months of cooperation during which the SolarEdge solution was tested by HaWi in comparison to traditional inverters, under a variety of real-life conditions.

SEMI PV Group forms Photovoltaics Standards Committees in Japan and Taiwan

The PV Group, a special interest group of SEMI, has announced the formation of Photovoltaic Standards Committees in Japan and Taiwan. The initial focus of work in the Japan Committee will be to standardize the dimensions of thin-film substrates; in Taiwan, the Committee will build on the recently introduced development standards for crystalline-silicon cell appearance as well as a vibration test method.

The aim of these Committees is to lower costs, improve quality and accelerate innovation in the PV industry. The PV Group promotes standards development for all aspects of PV manufacturing including thin films, machine interface, process control and others through the SEMI International Standards process and in collaboration with partner associations around the globe.

The PV Standards Committee's charter is to explore, evaluate, discuss, and create consensus-based standard measurement methods, specifications, guidelines, and practices. Through voluntary compliance, these consensus-based standards promote mutual understanding and improved communication between users and suppliers of photovoltaic manufacturing equipment, materials and services. The SEMI PV Group has also recently released a Standards Guidance Document that identified 64 SEMI Standards topics as "Applicable" to the PV industry. The new standards development groups join SEMI Standards committees in Europe and North America, which have been active since 2006.

Solel to build solar thermal components factory in Spain with US$2.6million grant

The Ministry of Innovation, Science and Enterprise of the Andalusian Region of Spain has awarded large-scale solar thermal supplier, Solel a grant of US$2.6million as part of plans to build and operate a components factory that will construct parabolic reflectors, metal supports for solar collectors and other components. The construction of the plant in La Carolina is expected to be completed in 2012, though part of the manufacturing lines will be operational this year.

Solel has already been involved in 15 solar thermal power plants in Spain, with a total of approximately 750MW of power produced for these projects. Solel has also created a joint venture with Sacyr Vallehermoso, a Spanish construction company to build three power plants with a total capacity of 150MW. The first of these plants, the 50MW Lebrija 1 facility, will begin operations in 2010.

Komax USA wins Process Excellence award at 2009 Chief Service Officers' Summit

A recent awards ceremony organised by the Aberdeen Group, a market research company that focuses on the global technology industry, saw Komax USA receive a prestigious award for its process technology. The Service Management Achievement Awards bestowed the title of winner of the 2009 Process Excellence Award on the automation company for its "process ingenuity, agility, flexibility and scalability to address evolving business requirements."

Komax's technology uses Single Source Systems' software solution to enable its service operations to run smoothly. The company relies on SM-Plus, the software solution, to maintain critical assets, track and monitor KPIs, for scheduling and dispatching of field service technicians, tracking critical customer/machine-related incidents and warranty information.

Astronergy Solar invests €1 million for European branch in Germany

Astronergy Solar has invested €1 million to establish a German branch of the company, Astronergy Solar Deutschland. The European branch will be located in Munich and will be responsible for market development, technical support, customer service and logistics.

PV experts at Astronergy Solar Deutschland will provide clients with technological references as well as business consultation. Dr. Liyou Yang, the chief executive officer of Astronergy Solar, said that Europe is one of the most important markets in the world for the photovoltaic industry and is a part of Astronergy's international marketing strategy to establish a European branch.

ReneSola boosts OEM strategy with acquisition of Dynamic Green Energy

ReneSola is increasing its capacity to offer PV OEM services and further its efforts to become a fully-integrated PV manufacturer with the acquisition of China-based Dynamic Green Energy. The mainly share-based transaction has been approved by both companies' boards of directors. Jiawei Solarchina was a subsidiary of Dynamic Green Energy, which is currently partnering with Evergreen Solar on a 100MW plant in China. GE Capital Asia Pacific was also a major investor in Dynamic Green Energy.

Photo: ReneSola

ReneSola integrated solutions.

Dynamic Green owns and operates ingot and wafer manufacturing facilities in Sanhe, Hebei province, as well as an upgraded metallurgical grade silicon manufacturing facility in Guiyang, Guizhou province. Its module and cell manufacturing facilities are in Wuhan, Hubei province and OEM facilities in Shenzhen, Guangdong province.

Product Briefings

Swagelok Company

Swagelok offers new UHP specification aimed at protecting quality and containing cost

Product Briefing Outline: Swagelok Company has unveiled a new process specification designed to meet the needs of the photovoltaic market, aimed at helping to ensure quality and reduce cost of ownership for the industry. The Swagelok Photovoltaic Process Specification (SC-06) outlines testing, cleaning, and packaging steps for stainless steel components for use in PV applications.

Problem: Common UHP semiconductor standards are often well beyond what is required for solar cell manufacturing. The limited cleaning and purity requirements for general industry products are often inadequate for solar processing applications. The SC-06 specification defines a set of baseline requirements so that products can be processed at a level appropriate for the industry to balance the need for ultrahigh-purity processing with the cost containment that will help them achieve grid parity.

Solution: The baseline requirements include specifying the high-quality surface finish, visual inspection criteria and particle counts the PV industry needs to maintain reliability and process control for improved uptime, while identifying areas (such as work area classification, analytics, and packaging) where costs can be contained. Swagelok products are designed to provide reliable, leak-tight performance in critical PV manufacturing processes, such as PECVD and diffusion.

Applications: The products currently available with SC-06 processing include DP and DPH springless diaphragm valves, HB and BN series bellows valves, CW series check valves, VCR metal gasket face seal fittings, and Micro-Fit miniature tube butt weld fittings.

Platform: The SC-06 is one of Swagelok's high-purity products, and can be used in place of the company's other specifications: SC-01 (Ultrahigh-purity Process), SC-10 (Standard Cleaning and Packaging), and SC-11 (Special Cleaning and Packaging).

Availability: Currently available.

Morgan Technical Ceramics

Morgan Technical Ceramics' fused silica rollers retain hot glass flatness during processing

Product Briefing Outline: Morgan Technical Ceramics is offering its fused silica rollers for use in solar energy applications from its manufacturing site in Fairfield, New Jersey, USA. Traditionally used for handling sheet glass for automobiles, appliances and architectural applications, fused silica rollers are now being used in the manufacture of solar cells. Their mechanical properties and special surface quality make them ideal for use in both diffusion and thin-film processing of solar panels.

Problem: Retaining glass panel flatness during deposition processes limits yield impact and throughput. Downtime and replacement costs can also ensue if the rollers are subject to erosion from cleaning acids.

Solution: The thermal stability of silica is very high; it has a coefficient of thermal expansion (CTE) of <1 x 10-6/°C – lower than any other ceramic material, according to the company. This low CTE combined with its chemical compatibility with glass ensures the glass panels remain flat during the manufacturing process. The rollers are also used to move silicon wafers through the acid doping process where corrosive acid and high temperatures are required. The thin silicon wafers maintain their shape due to the low coefficient of thermal expansion and chemical resistance of the fused silica rollers.

Applications: The fused silica rollers move hot glass panels through the deposition process.

Platform: The rollers are available in a wide variety of standard dimensions, with outer diameters ranging from 15 to 110mm, and in lengths ranging from 305 to 4100mm. Custom designs and dimensions are also offered.

Availability: Currently available.

Shuttleworth, Inc.

Shuttleworth's Rotary Turntable enables speedy product conveyance

Product Briefing Outline: Shuttleworth, Inc. has introduced a new line of products for thin-film and crystalline solar panel handling. Their new 'Rotary Turntable' can be located anywhere in the manufacturing process where the product must be rotated to maintain the proper orientation.

Problem: In order to maximize the use of valuable floor space, process equipment may be arranged perpendicular to other equipment. This may require that the solar panel be rotated prior to entering the next process.

Solution: Using Shuttleworth's Rotary Turntable, the product is gently conveyed on Shuttleworth's chain-driven, Slip-Torque conveyor embedded within the unit. The conveyor and product is rotated 90, 180, or 270 degrees. Once rotated, the product is conveyed off the unit and the turntable returns to accept the next product. Up to two products may be safely rotated per minute.

Applications: Flat glass sheet handling found in most solar panel production facilities.

Platform: The turntable is powered by an AC motor-driven, rotary indexer.

Availability: Currently available.

Edwards

New Spectra ZW from Edwards provides total solution abatement for high-flow particulate and acid gas capture

Product Briefing Outline: Edwards has introduced the new Spectra ZW abatement system for solar cell and flat panel manufacturing. The Spectra ZW is a single compact system for abating the deposition and clean gases used in the very high gas flow chemical vapor deposition (CVD) process steps in solar and flat panel manufacture. A wet scrubbing system is integrated within the Spectra ZW for a total abatement/waste processing solution.

Problem: In high-volume production environments, the matching of process gas flows with adequate abatement capacity is required. However, volume production facilities require low minimum downtime and short maintenance times.

Solution: The Spectra ZW is a very efficient total solution with maximum standard process gas flows exceeding 16 standard litres per minute of silane, 200 standard litres per minute of hydrogen, and 40 standard litres per minute of nitrogen trifluoride, all of which are commonly used materials during the CVD processing step in solar cell manufacturing. In addition, most other dopant materials such as phosphine, diborane or trimethyl borate, as well as etch materials, can be abated and processed effectively by these units. When combined with the optional wet electrostatic precipitation (WESP) unit, the Spectra ZW provides a comprehensive gas abatement and powder handling solution that captures greater than 99.5% of silica powder produced during the abatement process. The systems are designed to enable production maintenance; for example, multiple units are linked together with valve manifolds that allow back-up of systems in the rare event of failures

Applications: Efficient abatement of CVD deposition and chamber cleaning gases.

Platform: The Spectra ZW can be a standalone gas abatement system with wet scrubbing or it can be integrated with the WESP to provide enhanced powder handling capability. The Spectra ZW can also be combined with the Zenith for an integrated vacuum pump/abatement custom-built solution.

Availability: Currently available.

Location Briefing

Toledo, Ohio, USA

Location: Toledo is located in northwest Ohio, in the upper Midwest region of the United States. Located within a day's drive of nearly half the U.S. and Canadian markets, Toledo/Northwest Ohio is ideally situated to reach customers and suppliers. Nearly 100 million people live within a 10-hour drive.

Introduction: With more than 6,000 people employed in photovoltaic/solar cell development, the Toledo and Northwest Ohio region has been dubbed "Solar Valley" by the national media.

The region became an international leader in solar because of its successful history and knowledge base in the glass industry. Continued university research eventually led to the commercialization of solar startups, including what would become First Solar, the world's No. 1 thin-film manufacturer of photovoltaic modules whose only U.S. manufacturing plant is located in the Toledo area. Today, Toledo and Northwest Ohio are uniquely positioned for success in solar due to manufacturing and glass-making heritage, world-class research and educational facilities, thin-film and next-generation photovoltaic expertise and supply-chain resources and logistics.

Infrastructure:

- A critical mass of industry presence and activity.
- Pioneering research and development – the University of Toledo Center for Photovoltaics Innovation and Commercialization.
- A national and international reputation for technology leadership and product manufacturing.
- A highly trained and educated workforce.
- An excellent location for distributing finished products throughout much of North America and overseas by rail, truck or ship.
- University of Toledo Scott Park campus of Energy and Innovation – a clean energy demonstration site.
- One of the nation's only solar installer training programs.
- Facilities/site availability.

Key features/incentives:

- Pre-seed capital
- Angel investment
- Statewide network of capital
- Ample funding for R&D

Contact **Dean Monske** at the Regional Growth Partnership (rgp.org) for more information at (419) 252-2700 x311

Key tenants

First Solar, Calyxo USA (subsidiary of Q-Cells), University of Toledo Center for Photovoltaics Innovation and Commercialization, Xunlight.

What they say: "Toledo has become a center for photovoltaic solar energy. The glass technology here in Toledo makes this an ideal location for the solar industry." **Norm Johnston** (pictured), President & CEO of Solar Fields, Vice Chairman of Calyxo GmbH.

The semiconductor and photovoltaics industries have a lot of similarities throughout the manufacturing processes. Acting under guidance from the advisory board, *Photovoltaics International* will feature articles from semiconductor companies presenting best-practice knowledge garnered from the semiconductor industry. This particular paper marks the beginning in a series of papers looking at cost of ownership issues.

Cost of ownership and overall equipment efficiency: a photovoltaics perspective

David W. Jimenez, Wright Williams & Kelly, Inc., Pleasanton, California, USA

ABSTRACT

It is not surprising that the photovoltaics industry has adopted many of the same metrics developed for the semiconductor industry. With suppliers serving both markets, Semiconductor Equipment and Materials International (SEMI) organized the PV Group to, among other things, look at the portability of standards between these two industries. This paper will examine the application of two such standards, the Guide to Calculate Cost of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment (SEMI E35) [1] and the Standard for Definition and Measurement of Equipment Productivity (SEMI E79) [2]. This latter standard is also known as overall equipment efficiency (OEE). Recent work at the National Renewable Energy Laboratory (NREL) regarding cost reduction also references SEMI E35. The application of these standards is examined using a case study comparing an in-line doping furnace and a phosphorus ($POCl_3$) batch furnace.

History

In the mid-1980s, companies became more concerned with understanding the COO concept. COO is the analysis of all costs associated with the acquisition, use and maintenance of a good or service. This analysis takes more than price into consideration, also considering product quality, failure costs, administrative costs, and maintenance, among other factors.

It has now been discovered that low price does not always mean the lowest total cost or satisfactory performance. COO is a tool that allows a company to determine the most cost-effective product or service. Activity-based costing and activity-based cost management also support the concept that cost allocation should be linked to the activity that causes the cost to be incurred.

Recent trends have increased the interest in COO:

- Quality emphasis: the tighter the specification, the higher the quality, and the higher the supplier price. How tight a specification should be to see lower reject rates, improved quality, and higher customer satisfaction is a question answered by COO analysis.
- Supply base rationalization: reduce the number of suppliers but use suppliers that have high quality standards, low cost, and responsive service. COO analyses help to determine which suppliers to keep.
- Increased global competition: Japanese businesses have a thorough understanding of how to manage total costs on a purchasing and total product basis. This is a part of their accounting practice. Companies competing on a global basis must have access to cost data to determine their competitive position in the market.

COO models in the semiconductor industry began at Intel, where, in the mid-1980s, a concentrated analysis began of the total cost of acquiring, maintaining, and operating purchased equipment. Intel's objective was explicit: develop a purchasing methodology that establishes a sound, quantitative, business-like basis for equipment acquisition. The COO concept first came to Sematech when one of Intel's employees was assigned to the consortium's strategic/competitive analysis area.

The original Sematech COO models developed were not very user-friendly. However, they improved over time and received wide acceptance. During the early 1990s, Sematech decided not to introduce any changes to their model so users could become familiar and comfortable with the software. They determined that this would not occur if the software was always in a state of flux [3].

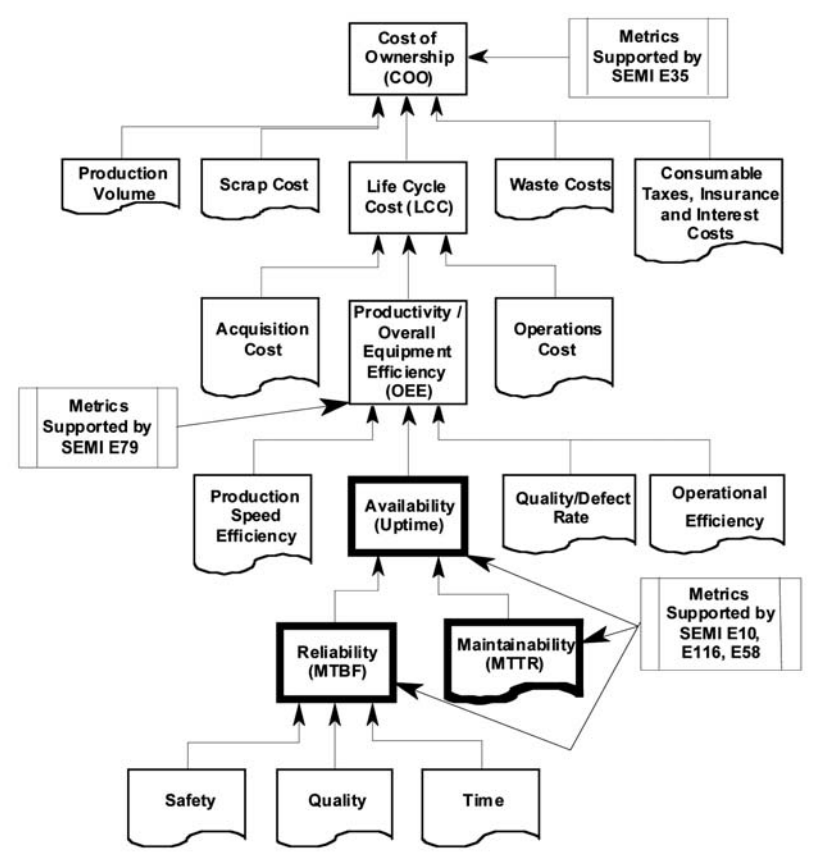


Figure 1. Hierarchy of equipment performance metrics [5].

Once COO was an accepted part of the semiconductor industry, Sematech decided to move forward in providing enhanced versions of COO software. To that end, Sematech contracted Wright Williams & Kelly in 1994 to provide ongoing worldwide support and training for COO as well as enhanced software products. These enhanced software models have been commercially available on a worldwide basis since 1995 and were updated to include other manufacturing areas, including photovoltaics, in 2000.

OEE [4] was created in Japan during the late 1960s by Nippondenso, a major manufacturer of automobile parts, as part of the development of total productive maintenance (TPM). TPM focuses on eliminating 16 major losses that affect production efficiency.

- Seven major losses affecting equipment effectiveness.
- Planned equipment idle time for preventive maintenance, overhaul, and operator meetings.
- Five major losses affecting manpower efficiency.
- Three major losses of material and energy utilization.

Originally OEE was a metric used to determine how much loss was related to the equipment and where these losses occurred. OEE measured the seven major losses of equipment and categorized them into four areas: availability, utilization, throughput rate, and yield.

Semiconductor companies in the United States became very interested in OEE during the mid-1990s, so a task force was formed and SEMI E79 was created to establish a common metric and define OEE as a true equipment efficiency measurement that included all aspects of equipment performance. There were two areas of the original OEE metric that the semiconductor industry felt needed to be addressed to make OEE more useful.

- Include planned equipment idle time in the OEE calculation. This identified opportunities to increase equipment utilization by streamlining activities and reducing ineffective scheduled downtime.
- Base all measurements on time. This area affected the yield measurement that had previously been calculated as good parts produced/total parts produced. As a review of SEMI E79 will show, using time to calculate yield provides an opportunity to identify a greater loss of efficiency.

Many variations of OEE are used around the world across all types of industries. We have found that the SEMI E79 standard is all-inclusive and adaptable for use in many applications including those in the photovoltaics industry.

Basic COO algorithm

Estimating a tool's COO is neither complex nor difficult. With attention to a few significant details, users can determine the life-cycle cost of owning a photovoltaic process tool. The basic COO algorithm is described by:

$$C_U = \frac{C_F + C_V + C_Y}{L \times TPT \times Y_C \times U}$$

Where:

C_U = Cost per good unit (wafer, cell, module, etc.)
C_F = Fixed cost
C_V = Variable cost
C_Y = Cost due to yield loss
L = Process life
TPT = Throughput
Y_C = Composite yield
U = Utilization

Fixed costs include purchase, installation and facility costs that are normally amortized over the life of the equipment. Variable costs such as material, labour, repair, utility and overhead expenses are costs incurred during equipment operation. While correctly a subset of variable costs, yield loss cost is a measure of the value of units lost through breakage and misprocessing and is broken out separately to demonstrate the importance of yield to both the numerator and denominator. Process life is the length of time the process is in operation. Throughput is based on the time needed to meet a process requirement such as depositing a nominal film thickness. Composite yield is the operational yield of the process and includes breakage and misprocessing. Utilization is the ratio of production time compared to total available time.

Definition: E79

Productivity is defined as good unit production rate in relation to the available capacity of the equipment. One of the most popular productivity metrics is OEE, which is based on reliability (mean time between failures, or MTBF), maintainability (mean time to repair, or MTTR), throughput, utilization and yield. All these factors are grouped into the following four submetrics of OEE: availability (joint measure of reliability and maintainability), operational efficiency, throughput rate efficiency, and yield/quality rate.

OEE is defined by SEMI E79 as "the fraction of total time that equipment is producing effective units at theoretical efficiency rates." From a high-level perspective, OEE can be reduced to the following equation:

OEE = Theoretical Production Time for Effective Units /Total Time

or

OEE = Availability Efficiency x Performance Efficiency x Quality Efficiency

Availability efficiency

Availability efficiency, defined as "the fraction of equipment uptime that the equipment is in a condition to perform its intended function," is represented in the following equation:

Availability efficiency = equipment uptime/total time.

Performance efficiency

Performance efficiency, defined as "the fraction of equipment uptime that the

Parameter	In-line Diffusion System	$POCl_3$
Throughput	1,500 wafers/hour	800 wafers/hour
Wafer size	156mm	156mm
Wafer cost	$3	$3
Mean time between failure (MTBF)	4,500 hours	336 hours
Mean time to repair (MTTR)	3 hours	5 hours
Equipment cost	$1,200,000	$1,300,000
Equipment yield	99.96%	99.96%
Utilities	$142,820/year/system	$211,086/year/system
Dopant mixture	$66,340/year/system	$100,622/year/system
Quartzware, cleans, breakage	$0	$130,200/year/system
Maintenance	Owner provided	Owner provided

Table 1. Major COO inputs.

	In-line	$POCl_3$
Cost per system	$1,200,000	$1,300,000
Number of systems required	1	1
Total depreciable costs	$1,220,000	$1,390,000
Equipment utilization capability	97.97%	96.02%
Production utilization capability	97.67%	95.72%
Composite yield	99.96%	99.96%
Good wafer equivalents out per week	246,026	128,598
Good wafer equivalent cost		
With scrap	$0.04	$0.16
Without scrap	$0.04	$0.16
Average monthly cost		
With scrap	$47,304.38	$89,782.17
Without scrap	$46,021.02	$89,111.35
Process scrap allocation		
Equipment yield	100%	100%
Defect limited yield	–	–
Parametric limited yield	–	–
Equipment costs (over life of equipment)	$1,353,646	$1,570,127
Per good wafer equivalent	$0.02	$0.03
Per good cm^2 out	$0.00	$0.00
Recurring costs (over life of equipment)	$2,619,922.17	$5,971,574.65
Per good wafer equivalent	$0.03	$0.13
Per good cm^2 out	$0.0002	$0.0007
Total costs (over life of equipment)	$3,973,568	$7,541,702
Per good wafer equivalent (COO)	$0.04	$0.16
Per good wafer equivalent supported	$0.04	$0.16
Per good cm^2 out	$0.0002	$0.0008
Per productive minute	$1.11	$2.14

Table 2. COO comparative results.

Cost drivers per good wafer equivalent for in-line	
Material/consumables	$0.0189
Depreciation	$0.0136
Labor	$0.0059
Maintenance	$0.0019
Floor space costs	$0.0014
Scrap	$0.0012
Support personnel	$0.0012
System qualification costs	$0.0001
Other materials	$0.0001
Training	$0.0000
ESH preparation and permits	$–
Moves and rearrangements	$–
Other support services	$–
Cost drivers per good wafer equivalent for $POCl_3$	
Material/consumables	$0.0745
Labor	$0.0442
Depreciation	$0.0296
Maintenance	$0.0046
Floor space costs	$0.0035
Support personnel	$0.0022
Scrap	$0.0012
Other materials	$0.0004
Training	$0.0002
System qualification costs	$0.0002
ESH preparation and permits	$–
Moves and rearrangements	$–
Other support services	$–

Table 3. Pareto of cost drivers.

equipment is processing actual units at theoretically efficient rates," is represented in the following equation:

Performance efficiency = operational efficiency x rate efficiency
or
Performance efficiency = (production time/equipment uptime) x (theoretical production time for actual units/production time).

Quality efficiency

Quality efficiency, defined as "the theoretical production time for effective units divided by the theoretical production time for actual units," is represented in the following equation:

Performance efficiency = theoretical production time for effective units/theoretical production time for actual units.

As we see above, many parameters are required to calculate OEE. If the accuracy requirement is not a critical factor, use the following formula to calculate an approximate OEE value:

OEE = number of good units output in a specified period of time/ (theoretical throughput rate x time period)

Relationship between metrics

There are many equipment performance metrics at different levels, which may cause the system to appear disjointed. However, this is not true as these metrics all fit nicely into a hierarchal tree.

Fig. 1 depicts the hierarchy tree of the equipment performance metrics. As the schematic shows, when a time dimension is added to quality and safety, it becomes reliability. Reliability and maintainability jointly make up availability. When production speed efficiency and production defect rate are combined with availability, this becomes productivity (OEE). Acquisition and operational costs make up life-cycle cost (LCC). When scrap, waste, consumables, tax, and insurance cost are added to LCC and the total is normalized by the production volume, it becomes COO.

Case study: in-line doping furnace vs. batch $POCl_3$ furnace

Starting silicon wafers are usually p-type, that is, boron-doped. It is then customary to form the p-n junction by introducing phosphorus, an n-type impurity, from the front surface. At sufficiently high temperatures, phosphorus atoms can diffuse into the solid silicon wafer. For a typical diffusion time of 15-30 minutes the penetration depth is very small (approximately 0.5µm) as required for optimal solar cell operation. The conventional way of performing phosphorus diffusion is to use a quartz diffusion furnace. A common dopant source is a liquid chemical containing phosphorus ($POCl_3$), which is conveniently carried into the furnace by bubbling nitrogen through it. In addition, oxygen is injected into the furnace so that it reacts with the $POCl_3$ and forms phosphorus oxide (P_2O_5). At the surface of the wafers the P_2O_5 turns into silicon dioxide (SiO_2) and atomic phosphorus, which can diffuse into the wafer. The oxide that is left on the wafers is usually removed chemically after the diffusion [6].

An alternative to the batch $POCl_3$ furnace is BTU International's Meridian in-line diffusion system, which combines a direct-spray phosphorus coater integrated with a conveyor belt diffusion furnace. The coater includes backside, topside, and drying capability. This analysis will examine which of these is the most desirable on the merits of COO and OEE.

Cost of ownership inputs

The following are the results of the COO analysis run on the in-line and $POCl_3$ furnaces. Table 1 highlights the major input parameters. It should be noted that the major application in COO and OEE analyses is for relative comparisons, that is, before vs. after an upgrade or change, or between competing solutions. By using these metrics as a relative measure, the modeller is not required to build the 'perfect' model or obtain 100% of all possible data to 100% accuracy.

In addition to the parameters presented in Table 1, where required, the author used example values from SEMI E35 for administrative rates and overhead. These values were provided by SEMI North American members and may not be applicable to other geographic regions. However, it is the author's experience that these example values do not impact the COO results on a relative basis.

Cost drivers

Examination of the detailed TWO COOL cost of ownership models in Table 2 highlights the main cost and productivity differences between the two approaches. (TWO COOL is a commercial software package from Wright Williams & Kelly.) The throughput differences between the furnaces drive a relatively small fixed cost per cell delta ($0.02 vs. $0.03). The majority of the cost advantages of the in-line system come in the area of operational or variable costs ($0.03 vs. $0.13).

Table 3 takes a closer look at the cost breakdown according to the 13 categories specified in SEMI E35. The top 5 Pareto costs for both systems are materials/consumables, which includes utilities, supplies, consumables, and waste disposal; depreciation, which is impacted by equipment costs, throughput rate, and utilization; labour; maintenance, including repair parts and technician labour; and floor space. The only difference in ranking is that labour is a higher cost in the $POCl_3$ furnace as would be expected when comparing batch and in-line systems.

The top three cost drivers account for over 90% of the total cost of ownership in both analyses. For this reason, we will focus our attention on those areas as we examine the cost sensitivities to input parameters that drive material/consumable, depreciation, and labour costs.

Cost driver sensitivities

Since the $POCl_3$ furnace shows the higher COO, the following sensitivity analyses will be run from the perspective of what needs to be done to the $POCl_3$ furnace to drive down its cost structure. The first analysis looks at dopant cost in two ways: the amount used per wafer and the cost per gram (see Figs. 2 and 3).

As can be seen from these figures, $POCl_3$ price and consumption changes cannot close the COO gap. Looking at quartzware, another material/consumable cost, it is clear that horizontal furnaces have costs associated with quartz liners and boats. Not only are there acquisition costs, but further concerns are cleaning costs and the risks associated with breakage during the cleaning process. Likewise, there is a finite life for quartzware (see Fig. 4).

The remaining major cost driver in materials/consumables is electricity. It should be noted that any change in the cost per kilowatt-hour will impact both furnace types by an equal percentage. Fig. 5 shows the sensitivity of the $POCl_3$ furnace COO to annual electricity costs.

As can be seen from the sensitivity analysis graphs, it would be difficult for the $POCl_3$ furnace to close the cost gap with any reasonable improvement in the area of material/consumables. Therefore, we will turn our attention to the factors impacting depreciation: purchase price and throughput (see Fig. 6 and 7).

Purchase price has minimal impact on COO in high throughput tools, especially those with higher variable costs. However, as can be seen in Fig. 7,

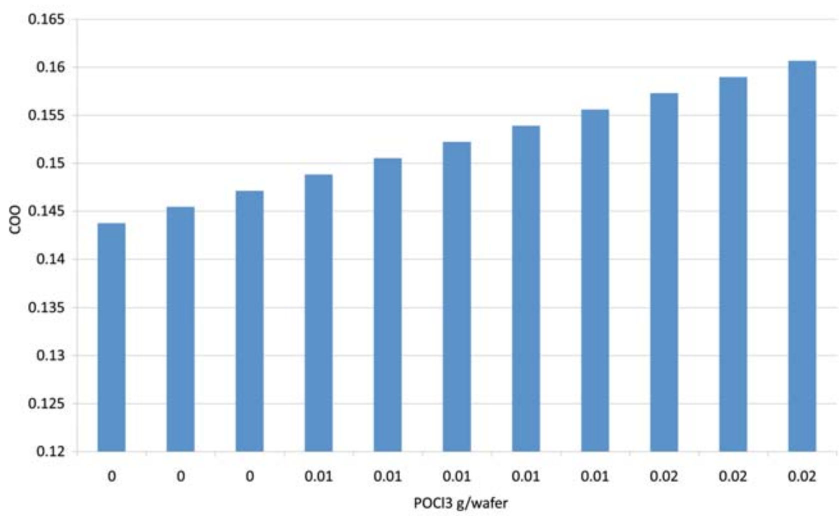


Figure 2. Sensitivity analysis of $POCl_3$ (4g/tube, 200 wafers, $750/Kg) usage per wafer vs. COO.

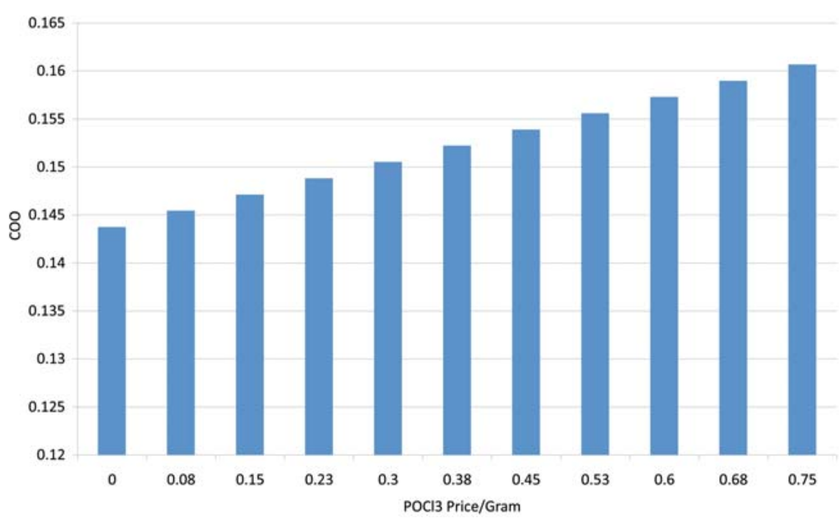


Figure 3. Sensitivity analysis of $POCl_3$ (4g/tube, 200 wafers, $750/Kg) price per gram vs. COO.

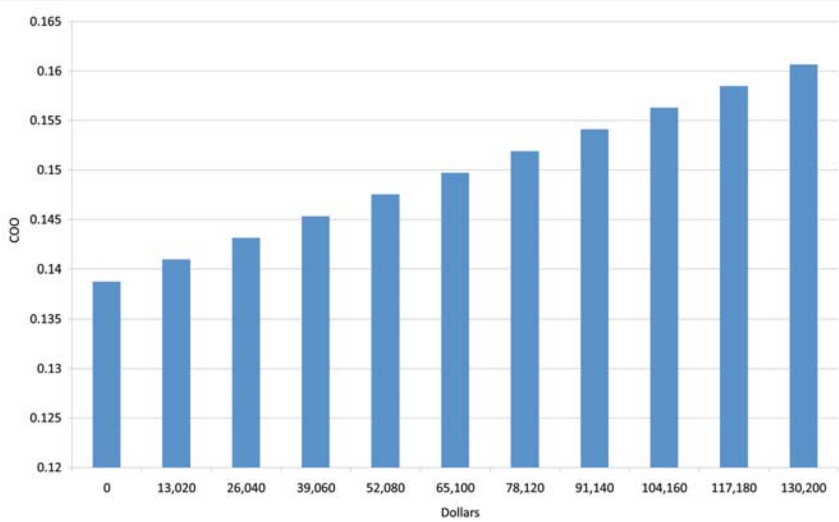


Figure 4. Sensitivity analysis of quartzware furnace (4 tube) annual cost vs. COO.

improvements in throughput have a significant impact on COO. The sensitivity analysis depicted in Fig. 7 does not, however, include any increased material consumption that might be needed to achieve the increased throughput (e.g., longer furnace tube with more wafers using more $POCl_3$ or higher cost quartzware).

So, if the $POCl_3$ furnace is to match or exceed the COO of the in-line system, it will need to focus resources on improvements in throughput as well as incremental reductions in material/consumable costs. However, $POCl_3$ furnaces have been in operation longer than in-line systems and have, therefore, undergone more cycles of learning. It might be reasonable to assume that yield would be higher in such a system. The preceding analyses were based on an identical yield of 99.96%. Fig. 8 examines what level of yield degradation would be needed in the in-line system to raise its COO to that of the batch system.

The above sensitivity analysis shows the significant impact of yield loss (scrap) on COO. A 3% increase in the scrap rate completely eliminates the operational advantages of the in-line system. The above analysis is based on simple pass/fail criteria and does not attempt to assign variable costs to cell efficiency binning.

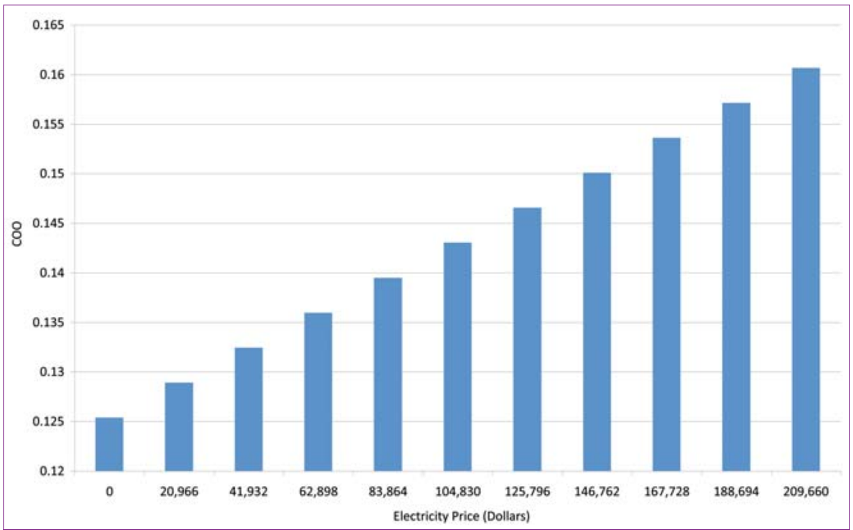


Figure 5. Sensitivity analysis of annual electricity cost vs. COO.

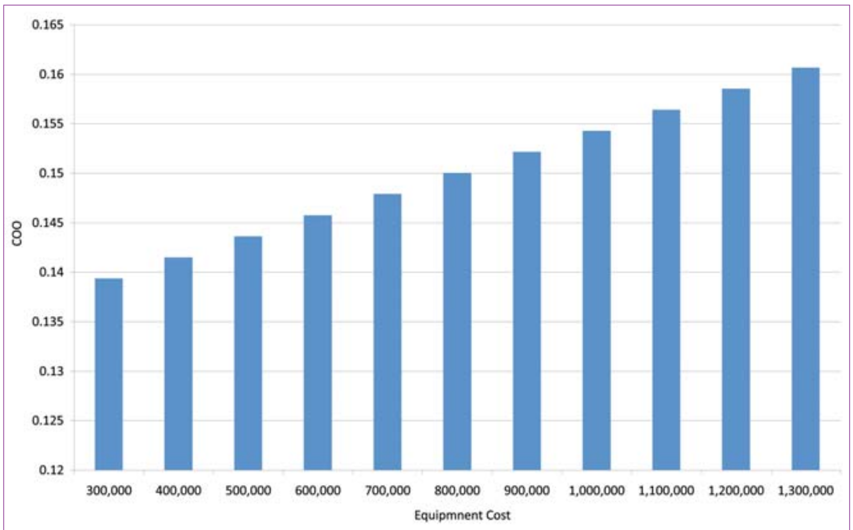


Figure 6. Sensitivity analysis of equipment purchase price vs. COO.

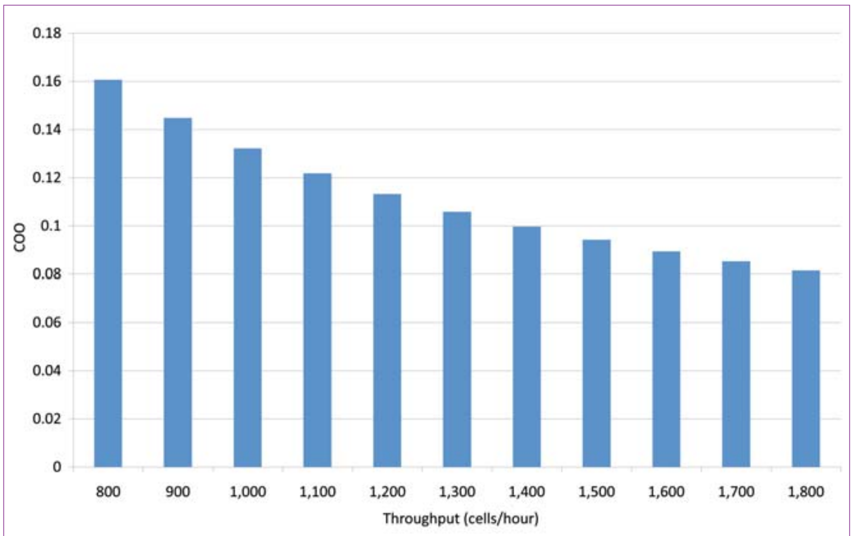


Figure 7. Sensitivity analysis of throughput vs. COO.

Overall equipment efficiency

OEE is frequently used to improve the usage or productivity of an existing equipment set. Better understanding of the OEE of the constraining (or bottleneck) equipment can result in capacity improvements that increase the potential usage of every other equipment set in the factory. For example, a production schedule that improves doping OEE by reducing time lost due to scheduled downtime can increase the capacity of the entire factory. Thus, an improvement of the constraint equipment improves the OEE of all the manufacturing equipment. In the case of linked operations – as seen in PV factories using all in-line systems – the line can be balanced to such a degree that any tool in the line can itself become the constraint. This makes factory planning very difficult and leads to the use of in-line buffers to keep tools loaded regardless of tool interruptions.

In general, not all of the equipment used in manufacturing should have high OEE. Diagnostic equipment can best impact production when it is readily available for use if a manufacturing problem should occur. If several operators are waiting for an available inspection system, then the higher OEE of the inspection system comes as a result of lower OEE for the manufacturing system.

Finally, OEE analysis without cost analysis may result in high OEE at the expense of COO increases. Since OEE is a subset of COO and lacks any activity-based cost-related input or output, it is highly recommended that COO be considered when applying OEE to non-bottleneck or non-near-bottleneck equipment. Since COO is limited by definition to looking at the cost impacts of individual process steps, OEE improvements in bottleneck tools are best measured in terms of cost or revenue impacts by factory-level modelling tools such as WWK's Factory Commander or Factory Explorer software.

Table 4 shows the OEE differences between the in-line and batch furnaces.

The in-line system has an approximately 2% higher OEE. This is driven by differences in availability efficiency driven by differences in mean time-to-failure or interrupt (MTBF or MTBI). Since the doping furnace can be a constraint tool, this 2% OEE improvement could relate to a 2% improvement in factory performance.

Conclusion

Because COO and OEE were driven by the needs of the IC industry in the late 1980s, it may well be the case that these metrics are more important to the photovoltaics industry. While ICs have some level of differentiation in form and function, the holy grail in PV is cost per watt. With technologists looking to improve cell and module efficiency, the need to ensure that those improvements are not increasing the cost per watt is critical.

This discussion and the examples provided herein have shown how easily COO and OEE can be applied to comparative analyses both in terms of procurement decisions but also in equipment improvement decisions. The broad adoption of these metrics as is being fostered by the SEMI PV Group, NREL and others will go a long way to ensuring that the industry as a whole stays ahead of its cost projections.

References

[1] SEMI Standard E35: "Guide to Calculate Cost of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment", [available online at www.semi.org].

[2] SEMI Standard E79: "Standard for Definition and Measurement of Equipment Productivity", [available online at www.semi.org].

[3] LaFrance, R.L. & Westrate, S.B. 1993, "Cost of Ownership: The Supplier's View", *Solid State Technology*, p. 33-37.

[4] OEE source information based on information provided by V.A. Ames, Equipment Manager, SVTC Technologies, Austin, TX.

[5] Dhudshia, V. 2008, *Hi-Tech Equipment Reliability: A Practical Guide for Engineers and Managers*, iUniverse.

[6] *Solar Electricity*, 2nd Edition, Ed. Tomas Markvart, University of Southampton, UK.

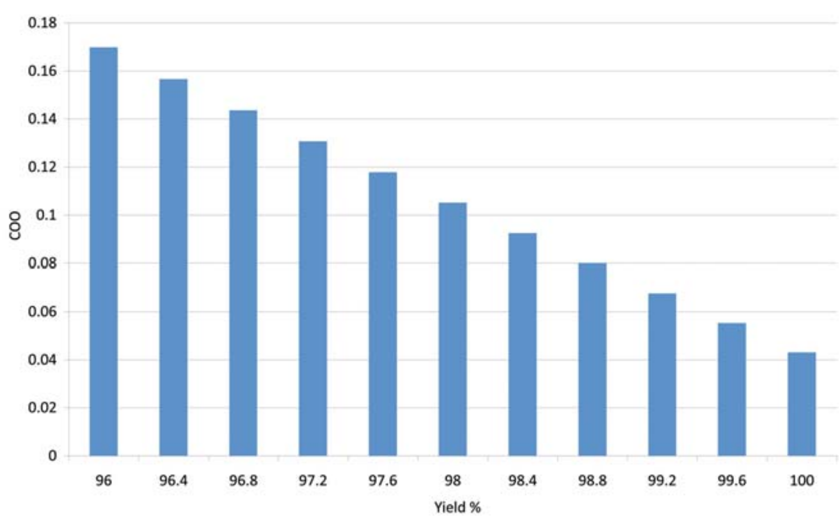


Figure 8. Sensitivity analysis of equipment yield vs. COO.

	In-line	$POCl_3$
Overall equipment efficiency	97.63%	95.68%
Availability efficiency	97.67%	95.72%
Engineering usage (hours/week)	–	–
Standby (hours/week)	–	–
Hours available/system (productive time) (hours/week)	164.08	160.81
Down time (hours/week)	3.92	7.19
Scheduled maintenance (hours/week)	3.00	4.00
Unscheduled maintenance (hours/week)	0.13	2.69
Test (hours/week)	0.50	0.50
Assist (hours/week)	0.28	–
Non-scheduled time (hours/week)	–	–
Equipment uptime (hours/week)	164.08	160.81
Total time (hours/week)	168.00	168.00
Performance efficiency	100%	100%
Throughput at capacity/system (wafers/hour)	1,500	800
Theoretical throughput (wafers/hour)	1,500	800
Operational efficiency	100%	100%
Rate efficiency	100%	100%
Quality efficiency	99.96%	99.96%
Equipment yield	99.96%	99.96%
Defect limited yield	100%	100%
Parametric limited yield	100%	100%
Alpha error factor	100%	100%
Beta error factor	100%	100%
Redo rate	–	–

Table 4. OEE comparative results.

About the Author

David Jimenez is president and cofounder of Wright Williams & Kelly, Inc., the largest privately-held operational cost management software and consulting services company. He has approximately 30 years of industry experience including management positions with NV Philips and Ultratech Stepper. He holds a B.S. in chemical engineering from the University of California, Berkeley and an M.B.A. in finance. Responsible for the design of the semiconductor industry's de facto standard in cost of ownership, TWO COOL, he holds a patent for his work on PRO COOL for Wafer Sort & Final Test. He is a recipient of the Texas Instruments Supplier Excellence Award for his contributions to their cost reduction efforts. For over 18 years, he has been a facilitator in the SEMI sponsored workshop, "Understanding and Using Cost of Ownership." He is also the author of numerous articles in the fields of productivity and cost management.

Enquiries

Wright Williams & Kelly, Inc.
6200 Stoneridge Mall Road
3rd Floor
Pleasanton
CA 94588
USA

Tel: +1 925 399 6246
Email: david.jimenez@wwk.com

The semiconductor and photovoltaics industries have a lot of similarities throughout the manufacturing processes. Acting under guidance from the advisory board, *Photovoltaics International* will feature articles from semiconductor companies presenting best-practice knowledge garnered from the semiconductor industry.

A realistic approach to achieving zero equipment failures

Mark Boone, Texas Instruments, Inc., Dallas, Texas, USA

ABSTRACT

In most complex manufacturing environments, equipment failures dominate. These failures are commonly referred to as 'fires' because of the chaos and damage they inflict on factory operations. This paper recommends taking specific non-disruptive steps to establish 'fire prevention' and induce a culture change to set the organization on a path to achieve zero production disruptions.

Fire-fighting culture

Consider this common scenario. A key piece of equipment fails, creating a blockage in the production line. One or more personnel are quickly dispatched to fix the problem. The situation is dire, threatening to slow daily product starts and slip output goals. Those working the problem know this failure is being discussed at the highest levels and they feel the heat. They know if they can just get the machine working well enough, everyone will be satisfied and the stress will be lifted. Their logic leads them to suspect a specific component. They replace it, hold their breath, test the machine, then celebrate when they realize the problem is gone. The machine is now processing and those involved in 'getting it running again' receive praise from management before being quickly directed to the next fire. So was the problem resolved? Those that were directly involved might answer in the affirmative because of a common tendency to associate 'problem' with a source of pressure or stress. Once the pressure is lifted, so too is the perceived problem. But in truth, the problem was clearly *not* resolved. This failure will occur again, at any time and with an unpredictable severity because the *reason* for the failure was not determined. Did the part simply reach its expected lifetime, or did it fail for some other reason? Perhaps the part had a manufacturing defect, or something else in the machine is causing it to fail prematurely; without this knowledge, the abundance of work applied to this problem will produce only temporary relief, not sustained improvement. This is the fire-fighting culture, which only values efforts that quickly 'get it running again'. Inevitably, these fires return, because the real cause was either not found, or not properly addressed to prevent reoccurrence.

Factories with a pure fire-fighting culture ultimately cannot survive. If sources of failure are not identified and eliminated, they will accumulate with equipment age, eventually becoming too costly for the company to sustain (see Fig.1).

So why are robust equipment-focused continuous improvement programs absent in many organizations, especially since equipment performance clearly impacts nearly all factory performance metrics? Sustained improvement in equipment performance, availability and stability will increase factory capacity, improve cycle time, improve predictability of product out (planning), improve safety, prevent customer disruptions, improve morale and transform cost into company profit. Emergency repair work can cost an organization three times more than the same repair when pre-planned, which can amount to an annual cost of multiple millions of dollars for a semiconductor fab [1].

Zero Unscheduled Maintenance (ZUM) is an equipment-focused continuous improvement program developed at Texas Instruments that mandates fire prevention and provides the tools needed to achieve continuous and cumulative equipment downtime reduction. ZUM contains aspects of Total Productive Maintenance (TPM) that enable comprehensive analyses, closed-loop problem solving, and effective equipment knowledge management. It also embraces the fundamental TPM principle that zero equipment failures can be achieved. *Unlike* TPM, ZUM can bring about an equipment-centric culture change with minimal disruption to existing operations.

The right mindset for culture change

Maintenance is not glamorous. It lacks intuitive appeal. For many, the thought of 'maintenance' conjures up images of mechanics in auto shops replacing oil. Maintenance is neither considered at the heart of what most hi-tech companies do, nor considered essential to what factories do, i.e. developing new processes that enable more advanced products or more profit. Maintenance is often just tolerated. Here are three reasons why this mindset must change.

1) *Managing equipment performance in complex manufacturing environments is incredibly complicated*. Typical semiconductor fabs have 500 to 1000 individual processing machines, each built with combinations of the most advanced technologies available today, using a wide range of exotic energies, chemicals, gases and materials, all managed with a very lean workforce. In some factories, each of these machines might fail as often as once every week.

2) *The skills required to master equipment performance are significant.* Maintenance is the pursuit of perfection; perfect understanding of and control over equipment behaviour. To accomplish this, one must seek an understanding of how thousands of components within a single machine interconnect and interact; of how degradation of one aspect of a single component can affect other components causing chain reactions and complex problems. A skilled person attempting a repair on such a machine may seem distant and disengaged, because their mind is completely occupied sorting through the associations and hierarchies of this vast complexity. They may develop a 'feel' for the system is basically the recognition of patterns in this vast complexity that indicate a potential for certain outcomes. These are practical, curious and tenacious perfectionists who often make the equipment achieve more than the OEM designers would have thought possible.

3) *Equipment performance has an overwhelming impact on profit, quality and nearly every aspect of product creation.* For this reason alone, it must be given a top priority.

Although the challenge is significant, there is no magic required. Even the most complex machine functions entirely in accordance with the laws of science and reason, and therefore every problem has a root cause that can be found and addressed. Before an organization can take on this challenge, it must believe they can prevent *all* failures from reoccurring, and be committed to the continuous development and fine-tuning of advanced, comprehensive and concise maintenance.

There is a mountain of work required to achieve zero failures, so the ascent requires patience, and choosing the correct path is crucial. ZUM provides the tools to identify this path. Without these tools, a fab manager may expend energy following many different available trails, only to find years later that they are right back where they started.

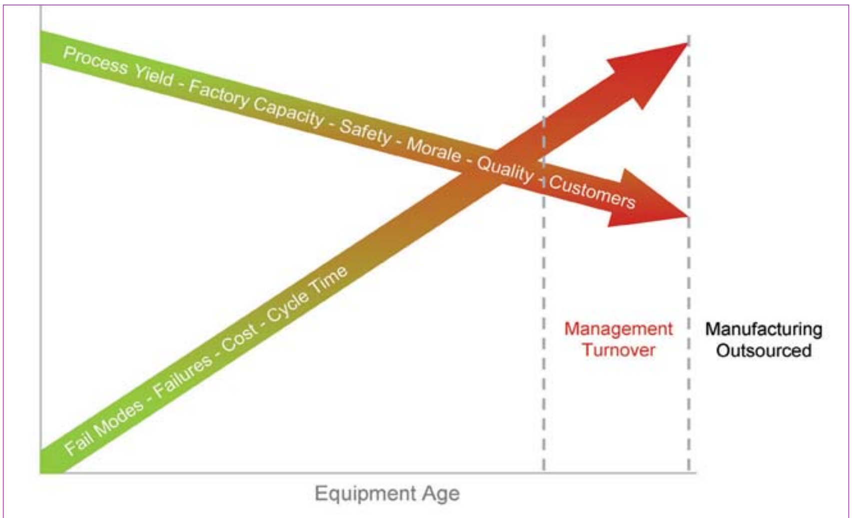


Figure 1. Without fire prevention, failure modes and therefore fails will accumulate with equipment age.

Developing a program that fits into 'what we already do'

It is important that the program resonate within the organization to enable the culture change. There are three well-known key elements for creating change: 1) make it available; 2) make it simple; and 3) make it mandatory. Expanding on the 'simple' element, the program should be practical, feasible and (ideally) non-disruptive meaning the required work must fit into 'what we already do.' Those that have been directly involved with full-blown TPM implementations or Reliability Centered Maintenance (RCM) programs know they require a significant redirection and realignment of resources and overtime, resulting in frustration, resentment, resistance and likely failure. Sources cite success rates of 5 to 30% for TPM, RCM and large-scale changes [2,3]. The required work is often viewed as being in addition to 'what we already do.'

The limited resources of a lean workforce in the semiconductor industry require us to instead take a reactive 'forward-looking' approach. This means that instead of sporadic, lengthy, resource-intensive sessions that take deep dives into the often murky waters of equipment history, we can instead establish a smooth continuous process of analysis and actions based on a 30-day performance. Rather than create a thousand actions to address all known failure modes for a machine, we will address the most significant equipment losses *as they occur*, and map and resolve each failure *as they occur*. Think of it as choosing to disintegrate a boulder either by occasionally hefting an unbalanced 100lb sledgehammer, or by chipping at it continuously, knowing that each tap will produce a chip that will take you closer to your goal. This approach may rankle some purist academic viewpoints, but it is necessary to minimize disruption and achieve the desired culture change.

Clean data, accurate metrics, and the ability to breakdown losses

An organization must achieve two fundamental objectives concerning data and reporting:


America
The Land of
Solar Opportunity
The U.S. PV Market is Now Poised for Exceptional Growth – Are you ready to compete? Spire Solar, the leading supplier of turnkey factories worldwide, has the programs in place to help you site, setup and run a turnkey manufacturing facility or to expand your present operations with our proven systems integration.
Selected Best
Turnkey Factory Company
solar awards
Winner 2009
EU PVSEC
Hamburg, Germany
Solar production in America
with Spire Solar ensures:
State-of-the-art Turnkey Manufacturing Lines
Comprehensive Siting & Management of your facilities
Efficient PV Systems Integration
High Quality Cells & Wafers
Rapid GSA Listing Assistance
Visit us at Photon USA 2010, February 2-4,
San Francisco, CA - Booth G5
Celebrating Forty Years
spire
of Innovation
www.spiresolar.com

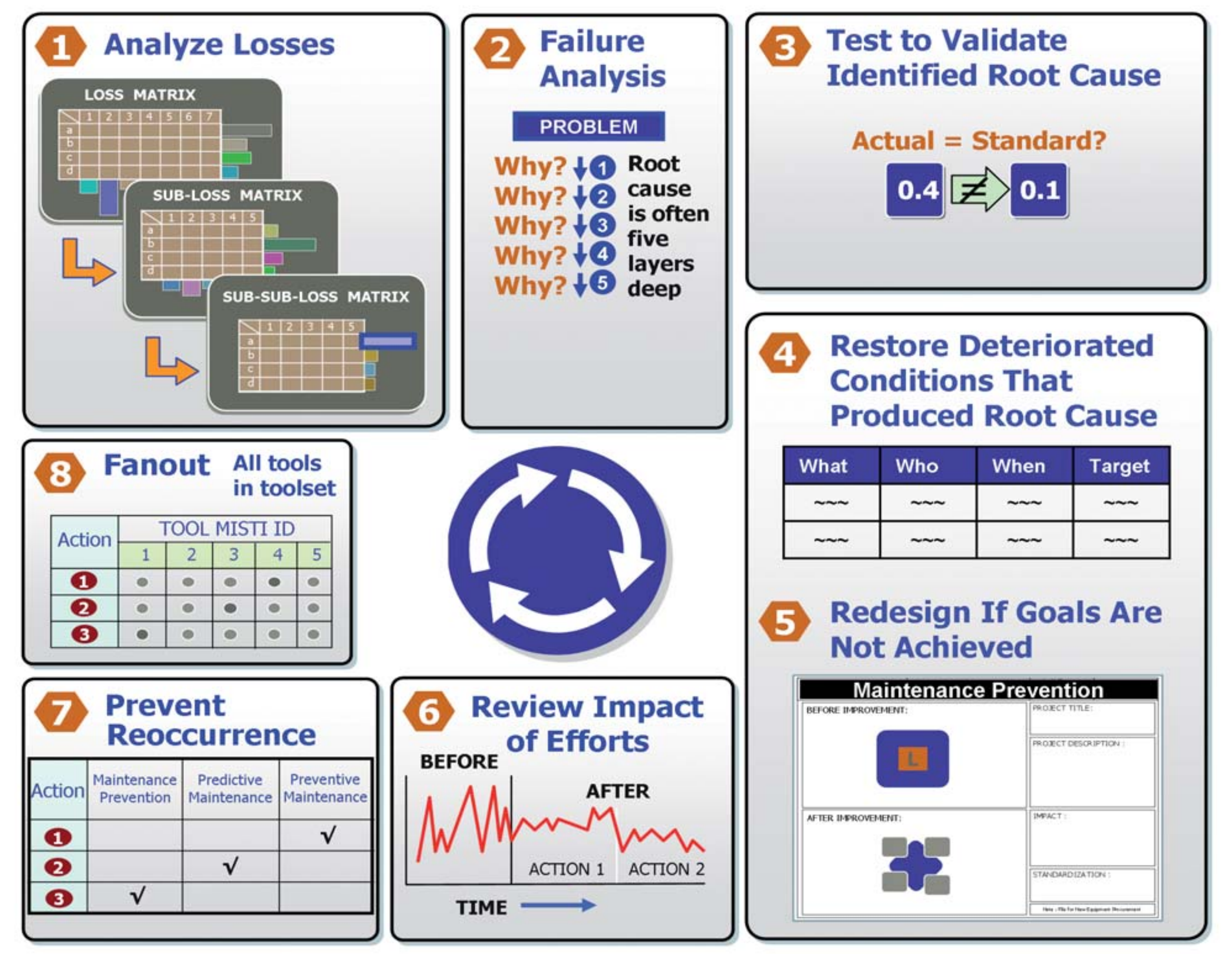


Figure 2. ZUM Methodology: all steps must be completed to ensure elimination of failure modes.

1) *Full transparency of equipment condition and performance.* Human nature dictates that if the capability to manipulate performance metrics exists, some will choose to do it. If the accuracy of your performance metrics is questionable, it will result in perpetual argument and conflict over whether a perceived problem truly exists. The likely result is frustration and mistrust, and what is being concealed will inevitably be revealed in an important customer audit causing embarrassment for the company to the detriment of customer relations. Only full transparency will ensure the organization devotes its time on solutions, and not debate over whether or not a problem exists.

2) *Full access to comprehensive data and tools that will enable anyone in the organization to analyze individual machine losses.* An organization must develop data, systems and clear analytical techniques that enable anyone in the company to confidently quantify equipment performance and quickly break down equipment losses to identify the few issues causing the most disruption to manufacturing. This will ensure that time is preserved for the crucial work of determining root cause and preventive action.

Accomplishing these two objectives will eliminate some potentially gross inefficiencies and sharpen the focus of the organization.

Setting performance goals at the factory and equipment levels

The primary metric used in the ZUM program is equipment availability, or the percentage of time that equipment is available to process production. Goals should be set for the overall factory and each equipment type within the factory. Some will say that working to maintain excellent equipment performance for all equipment types is an ineffective use of resources, because only bottleneck machine performance determines the pace of factory output. However, in fab environments, bottlenecks appear and disappear throughout each day in an unpredictable manner. Therefore applying a proactive maintenance approach to a handful of machines and a reactive fire-fighting approach to the others is not a realistic strategy. In fab environments, all machines are potential bottlenecks, so all require goals that, at a minimum, should represent performance required to meet planned factory output. If a machine or equipment-type does not achieve its goal, it is a potential bottleneck that requires analysis and actions. Working to maintain these goals proactively prevents bottlenecks from occurring.

The overall factory goal is also necessary for measuring overall success and progress for the program, and to ensure performance does not dip too far. As factory equipment performance drops, at some level a 'critical' state emerges. This is a state of particular fragility for the factory, when unpredictability is amplified. At this level, the entire factory is 'sick' and any individual machine failure can cause considerable cycle time delays as alternative routes commonly available are blocked by poorly-performing equipment. A factory that is falling below its known critical performance level should be on high alert due to an exponentially increasing probability of customer disruptions, high costs, safety incidents and cycle time excursions.

The closed-loop equipment problem-solving methodology

Closed-loop problem-solving methodologies are nothing new to complex manufacturing organizations, so it should not seem out of place to apply them to equipment maintenance. Because the challenge of achieving world-class equipment performance is

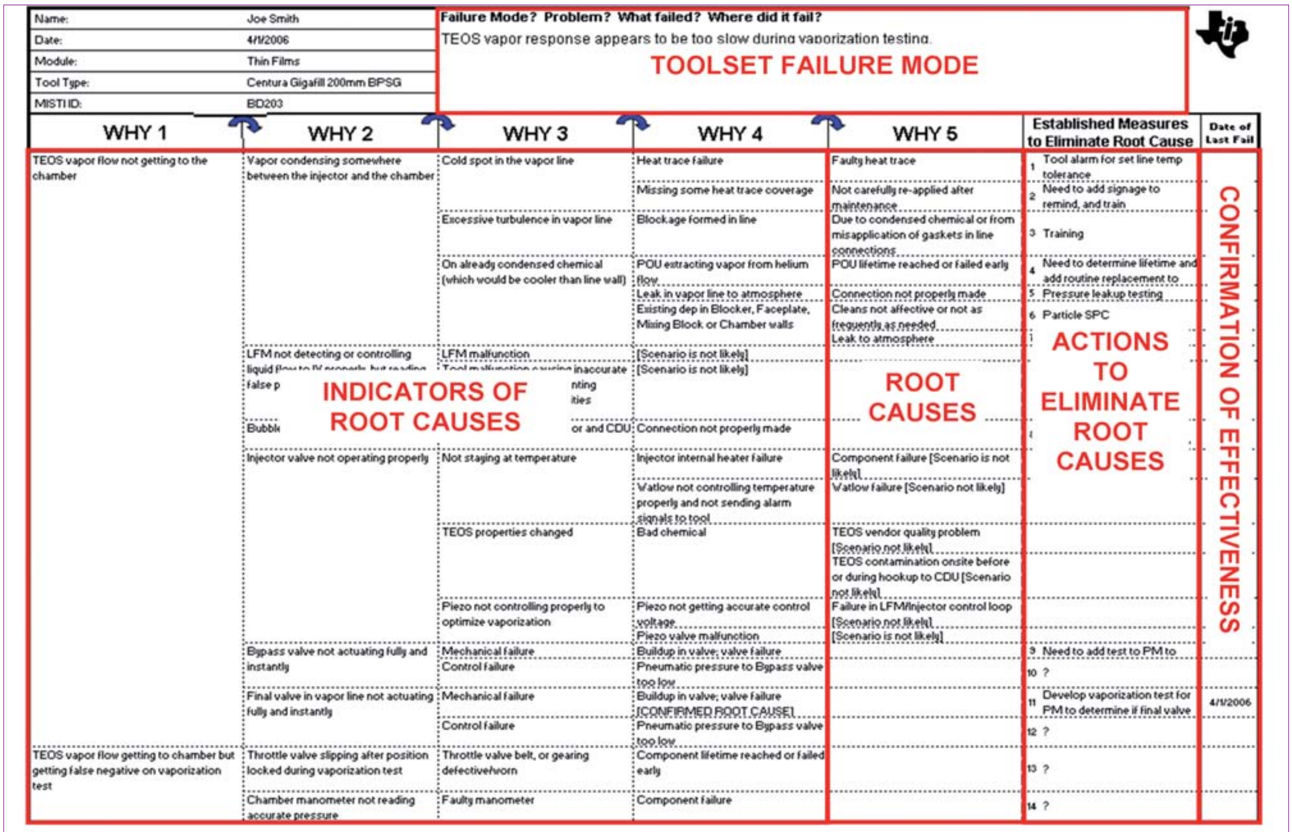


Figure 3. Multi-level 5 Why Failure Analysis is used to capture knowledge, break the cycle of re-learning, quicken troubleshooting and repair, assist root cause analysis and strengthen FMEAs.

so great, the approach to maintenance and problem solving must always be concise and thorough. A closed-loop methodology can communicate these needs and expectations, ensuring everyone's understanding of and commitment to the system. Any skipped step represents wasted efforts and resources, so total compliance is important and should be confirmed.

Pay special attention to Step 7 of the schematic depicted in Fig. 2 which calls for action to prevent reoccurrence. This *Maintenance Decision* represents the difference between simply changing out a failed component and taking action to ensure it does not fail again through redesign, routine replacement, or failure detection. Remember that the overall intent of this program is achieving *Zero Unscheduled Maintenance*, so the Maintenance Decision should be a visible and scrutinized choice.

Defeating chronic problems by mapping failure modes

Chronic problems occur every day in complex manufacturing environments. Due to the complexity of the equipment, it is not uncommon for a failure mode to have 100 or more root causes involving 1000 or more components. The fire fighter assigned to a chronic problem will typically jump in, guess the cause, replace a part, then repeat the process after discovering the guess was incorrect. Such a process could repeat for days, consuming considerable human resource and cost while creating a disruptive bottleneck situation in the factory.

This is not necessarily the fault of the person assigned to the repair. It is simply impossible for someone to retain in their memory all of the hierarchies, interconnections and potential interactions between the thousands of components in these complex machines. Someone in the midst of this type of repair would hear people say things like "I just remembered that the last time this happened we tried..." as the trial and error process stimulates the resurfacing of memories of past repair attempts and findings long forgotten. These machines will fail over and over again for the exact same reason because true component-level root cause was either not sought or not properly documented to break this re-learning cycle.

Resolution of this problem starts with the person attempting the repair seeking component-level root cause. Many are aware of the '5 Whys'; the process that requires the user to ask 'Why?' five times to get to the root cause. Here is a simple example for determining why a room is dark:

Q1: Why is the room dark?
  A: No light

Q2: Why is there no light?
  A: Light bulb won't turn on

Q3: Why won't the light bulb turn on?
  A: Light bulb is defective

Q4: Why is the light bulb defective?
  A: Light bulb filament is broken

Q5: Why is the filament broken?
  A: Expected life of the filament was exceeded

The root cause for why the room is dark is not a defective light bulb; it is the filament component of the light bulb that had exceeded its expected lifetime. Someone attempting a repair must seek this level of root cause. If they do not, they are willingly sustaining the problem for someone else to resolve.

Expanding on the 5 Why concept, allowing multiple answers to each "Why?" results in something very similar to a Fault Tree Diagram with many branches, each ending with a root cause. This is the "Multi-Level 5 Why". Actions to prevent reoccurrence are mapped alongside each root cause so users are aware of those that have been addressed and those they may encounter in the future (see Fig. 3).

Some may say this type of mapping is the same as what is required by RCM and Fail Mode Effects Analysis (FMEA), but it clearly is not. The first difference is that the Multi-Level 5 Why is simple whereas RCM and FMEA entries are relatively complex. Entries for these simple maps can be done quickly and easily, encouraging collaborative development involving everyone that works with the machines, not just equipment owners or engineers. The second difference is that unlike RCM and FMEA, these maps can be built as root causes are revealed day-to-day, so that the process is not disruptive to the organization. An RCM

PHASE 1		PHASE 2		PHASE 3		PHASE 4	
Establish Basic Conditions		**Correct Weaknesses**		**Periodically Restore Deterioration**		**Predict Equipment Life**	
Establish your ***foundation***, correct gross abnormalities and ensure the basics of Preventive Maintenance are in place.		Optimize ***Corrective Maintenance*** (maintenance after failure) with failure analysis, loss analysis, mistake-proofing, maintenance prevention and skills training.		Optimize ***Preventive Maintenance*** by ensuring concise documentation, execution and effectiveness tracking.		Optimize ***Predictive Maintenance*** by implementing it in a prioritized manner; advanced analyses and increased awareness of R&D opportunities.	
Criteria #1	√	Criteria #1		Criteria #1	√	Criteria #1	
Criteria #2	√	Criteria #2	√	Criteria #2		Criteria #2	
Criteria #3	√	Criteria #3		Criteria #3		Criteria #3	
Criteria #4	√	Criteria #4	√	Criteria #4	√	Criteria #4	
Criteria #5		Criteria #5	√	Criteria #5	√	Criteria #5	
Criteria #6	√	Criteria #6		Criteria #6		Criteria #6	
Criteria #7	√	Criteria #7		Criteria #7		Criteria #7	√
Criteria #8		Criteria #8	√	Criteria #8		Criteria #8	

Figure 4. The 4 Phases Gap Assessment is a structured roadmap that guides users through the process of building the optimal maintenance system for their equipment.

or FMEA is not typically utilized on a daily basis by those working to resolve existing equipment problems.

After a couple of years, a Multi-Level 5 Why should contain a majority of the root causes for that chronic failure mode and, if preventive actions have been applied, the failure mode should no longer be chronic. There are many benefits of using these simple maps: capturing knowledge, breaking the cycle of re-learning, speeding up the troubleshooting and repair processes, assisting root cause analysis and strengthening FMEAs.

Building the maintenance system to improve and reinforce performance

Exactly what is required to achieve perfect maintenance? It is easy for an organization to say that they have not achieved it, but what is "it"? Those asked will likely provide different answers and none would have the complete answer. The result is a factory with no shared vision of what they want to achieve and how to do it. The criteria for this shared vision should be comprehensive and created with input from all departments associated with the equipment. In TPM, this list is called "The 4 Phases", which divides the criteria in four distinct families: Autonomous Maintenance, Failure Maintenance, Preventive Maintenance, and Predictive Maintenance (see Fig. 4). Using this framework, the criteria become two things to the user: a gap assessment that enables the user to understand what it is they are pursuing and where their weaknesses are, and a 'structured roadmap' that guides the user through the process of building an ideal maintenance system for their equipment, starting with their gaps in the first phase and working towards achieving the ideal predictive capabilities in the fourth.

This gap assessment is a very simple tool that will enable the organization to first understand how they can achieve perfect maintenance, determine existing gaps, and then drive them to closure, one machine at a time.

The future of Predictive Maintenance

It has unfortunately proven to be expensive for factories to develop predictive maintenance systems independent of OEMs. This will surely change in the future as OEMs build new capabilities into their tools that will take warning/interdiction modelling and SPC to the component level. Imagine the future when parts are able to communicate condition and degradation levels, and machines have the capability to detect degradation and defects at the component level. Future machines will understand how component degradation and failure will impact other components and subsystems and assess failure probabilities throughout. These advances will take us another level closer to zero equipment failures.

Summary of required steps to implement a ZUM program

Here are the steps that should be taken in order to implement a ZUM program:

1. Achieve the right mindset for your culture change
2. Develop the program to fit into 'what we already do'
3. Achieve clean data, accurate metrics, ability to break down losses
4. Set performance goals at the factory and equipment levels
5. Establish a closed-loop equipment problem-solving methodology
6. Utilize Multi-Level 5 Whys to collaboratively defeat chronic failure modes
7. Utilize 4 Phases Gap Assessments to build your maintenance system.

References

[1] Powell, D. & Ames, V.A. 1994, *TPM Training Manual*, Sematech.

[2] Yoke Choy, S. 2003, *TPM Implementation Exercises*, Maintenance Resources, Inc.

[3] Bloom, N. 2005, *RCM – Implementation Made Simple*, McGraw-Hill.

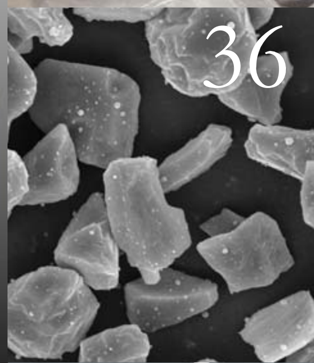
About the Author

Mark Boone is Program Manager for Texas Instruments Semiconductor in Dallas, Texas. He has a B.S. in engineering from the Colorado School of Mines and an M.B.A. from Baylor University. With over 14 years' experience in the semiconductor industry in roles that include Fab Engineer (TI), Production & Facilities Manager (Air Liquide), and his current role as Program Manager (TI), his current areas of research include development of equipment performance improvement, performance tracking, benchmarking and collaboration programs/systems.

Enquiries

Texas Instruments, Inc.
12500 TI Boulevard, Dallas, Texas 75243
USA
Tel: +1 972 995 9011
Email: m-boone1@ti.com
Website: www.ti.com

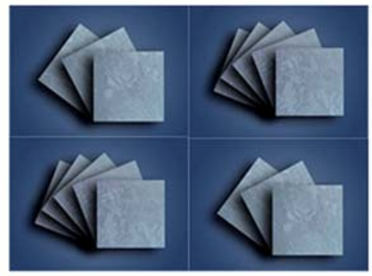
Materials



Q-Cells could claim back US$244.5 million from LDK Solar for missing supply obligations

Major business partners Q-Cells and LDK Solar have fallen out over a significant solar wafer supply deal, which could see Q-Cells claim back US$244.5 million from LDK Solar for missing wafer and polysilicon supply obligations under a contract signed in late 2007. Q-Cells said in a statement that disagreements over the contract supply conditions led to arbitration at the International Chamber of Commerce (ICC) in Paris, yet no amicable settlement has so far been reached.

The 2007 'Take or Pay' supply contract would see LDK Solar deliver more than 6GW of multicrystalline solar wafers to Q-Cells over a 10-year period commencing in 2009 through 2018. Q-Cells said that this equated to 43,000 tonnes of silicon over the contract period and specifically for 2009, approximately 1,000 tonnes of silicon.



Source: LDK Solar

LDK Solar's multicrystalline wafers.

As was typical in 2007 with polysilicon shortages, an advanced payment was made to secure the capacity. Q-Cells noted that it made a US$244.5 million advance to LDK Solar in the beginning of 2008, yet this can be reclaimed in the event of termination of the agreement and is secured by a bank guarantee at a German bank upon first demand. Apparently, an application by LDK Solar for a temporary injunction to be issued against a drawing down of the bank guarantee was refused by the District Court in Berlin. In the statement from Q-Cells, it said it would 'therefore make use of the possibility to draw down the bank guarantee linked to the payment made.'

Polysilicon News Focus

LDK Solar guides higher wafer but lower module shipments

LDK Solar has updated its forecast for the third quarter, noting that revenue will be higher than previously guided on the back of increased wafer shipments but a reduction in expected module shipments. Revenue is now expected to be in the range of US$270 million and US$290 million, up from between US$240 to US$270 million.

Having only started module production in the previous quarter, company shipments are now expected to range between 5MW to 10MW, down from its previous guidance of module shipments of 10MW to 20MW. The company did not cite reasons for the shipment changes.

Wacker withdraws from solar wafer JV: focuses on polysilicon expansion

Wacker Chemie is withdrawing from its joint venture solar wafer manufacturing activities to focus entirely on polysilicon production. The company said that it would transfer its share in Wacker Schott Solar to its partner at a cost of €50 million and an increase in financial debt of approximately €65 million. Both parties have agreed to the change. Wacker noted that the majority of wafers produced under the joint venture were ultimately used by Schott Solar for internal module production.

The company is currently undertaking a massive polysilicon capacity expansion plan in an effort to remain a leading player in the solar market. The current plan is to boost polysilicon capacity from 15,000MT per year in 2009 to 35,500 tonnes by the end of 2011. Scale is rapidly becoming a key competitive advantage as polysilicon production has expanded to an over-capacity situation, resulting in plummeting prices. Only the large-scale, low-cost providers are expected to remain profitable during a period of oversupply.

Since this withdrawal, the company has incurred an investment loss of €51.9 million, nearly €2 million more than its estimate at the end of September 2009 when the exit was announced. This meant that its polysilicon division's profit margins were impacted in its third quarter financial results. Wacker Polysilicon posted sales worth €268.6 million, 12% above the level reached in the same period a year ago, even though prices for short-term orders were lower than a year earlier.

The reported quarterly sales were a new record for the company as it benefited from the ramp-up at its Burghausen polycrystalline silicon facility. The company said that its new plant, currently under construction at Nünchritz, was on track to start production before the end of 2011. The current plan has remained unchanged, whereby Wacker will increase polysilicon capacity from 15,000MT per year in 2009 to 35,500 tonnes by the end of 2011.

Tianwei to take majority stake in Hoku; construction on Pocatello polysilicon plant to resume

Hoku Scientific and Tianwei New Energy Holdings have signed a definitive agreement that will make the vertically integrated Chinese solar company the primary shareholder of Hoku. The deal stipulates that Tianwei take a majority investment in Hoku and that debt financing by Tianwei and China Construction Bank be used to complete Hoku's Pocatello, ID, polysilicon production facility, which has faced numerous delays in its construction schedule because of financing and other issues.

Solar-grade polysilicon.

The companies said that the transaction will involve the conversion of US$50 million of an aggregate of US$79 million in secured prepayments previously paid by Tianwei to Hoku under certain polysilicon supply agreements into shares of Hoku's common stock and related warrants. In addition, there will be a provision of US$50 million in initial debt financing for Hoku, together with a commitment from Tianwei to assist Hoku in obtaining additional financing that may be required by Hoku to construct and operate the Pocatello facility.

Hoku confirmed that the US$50 million in debt, plus prepayments from its existing customers, is expected to be sufficient to complete construction to the point where it could begin shipments to customers, and it intends to delay any additional financing until such time. On the basis of these funding sources, Hoku reported it is preparing to issue orders to resume full-scale plant construction at an accelerated pace on closing of the financing.

REC says trading conditions remain challenging

In an update to its business divisions trading conditions, REC Group announced that its polysilicon production ramp at Silicon III, which had initial ramp problems, will struggle to meet full-year output targets, while its wafer division is having to further revise pricing for 2010 due to the weak market, impacting profit margins. On the solar module front, REC noted that prices are expected to have fallen 35% in 2009 as the glut in finished products continues.

REC said that Sovello, its joint venture operation, continued to not be in compliance with all its financial covenants since the end of 2008 and continues to look for long-term financing for the company. However, REC reiterated that the construction costs of its new facility in Singapore continued to require lower capital requirements due to the lower construction activity in the Island State. Ramp-up is still expected to begin in the first half of 2010.

Chemical and Gases News Focus

Cambrios inks US$14.5 million in series D financing round

Cambrios Technologies has received a total investment in its Series D Financing round of US$14.5 million. All of the company's current institutional preferred shareholders participated in the financing round, which included names such as ARCH Venture Partners, Alloy Ventures and Oxford Bioscience Partners among others. Joining the existing partners, Sumitomo Corporation, Chisso Corporation and Nissha Printing have also invested in the company.

DA NanoMaterials opens new headquarters and ATEC in Taiwan

The joint venture between Air Products and DuPont, DA NanoMaterials, supplier of chemical mechanical planarization (CMP) slurries to the semiconductor fabrication industry, has opened its new Asia headquarters in Jhudong Township, Taiwan. The new headquarters is located just outside the Hsinchu Science Park and features a 300mm-capable Advanced Technology Center (ATEC).

The new ATEC is an Hsinchu-based 300mm-capable laboratory and technical centre dedicated to developing and optimizing advanced CMP processes and consumable sets, whilst providing technical support to customers. The in-house laboratory features a 300mm CMP and defect metrology equipment alongside an advanced chemical formulation laboratory which aims to support product development and optimization. Both the headquarters and ATEC are now open and fully functioning.

SunSi Hong Kong completes audit of Chinese Trichlorosilane production company

SunSi Energies Hong Kong, the wholly owned subsidiary of SunSi Energies, has executed definitive Articles of Association for newly formed joint venture, Zibo SunSi Chemical. The company will own and operate an existing Trichlorosilane (TCS) production facility in Zibo, China.

SunSi will own 90% of joint venture company, which has been specifically molded to own the assets, expertise and technology of

Trina extends long-term supply agreement with GCL-Poly subsidiary

Trina Solar has extended its eight-year long-term supply agreement with Jiangsu Zhongneng Polysilicon Technology Development, a subsidiary of GCL-Poly, for another five years. The initial agreement for the delivery of polysilicon to Trina Solar began in April 2008. The main terms of the agreement will remain unchanged from the combined total of the original and supplemental agreements signed in 2008. However, additional polysilicon and wafer deliveries will be provided starting in 2016 for a five-year period at pre-determined shipment volumes and prices.

GCL-Poly will supply Trina with polysilicon and wafers sufficient to produce approximately 8,500MW of solar modules over the next 13 years. Wafer deliveries are to begin in 2010 and are expected to support production above the company's in-house integrated manufacturing capabilities to address growing customer demand.

Air Products wins bulk nitrogen supply deal with NexPower

Amorphous silicon thin-film start-up, NexPower Technology is to be supplied with bulk nitrogen requirements for its 100MW plant by Air Products San Fu Co., under a long-term contract. Nexpower's plant is based in the Central Taiwan Science Park (CTSP) in Houli, Taichung, Taiwan and will use Air Products' pipeline network in the CTSP. Air Products has won more than 20 new supply contracts in Asia in the past year serving both the crystalline and thin-film PV markets and has since signed gas supply contracts with Best Solar and CHINT Solar in China, Green Energy Technology in Taiwan, and HHV Solar and Jupiter Solar in India.

BOC India signs four new long-term gas supply deals with leading PV manufacturers

BOC India (BOCI), a member of the Linde Group, has signed four new long-term gas supply deals with PV manufacturers Moser Baer, Euro Multivision, Solar Semiconductor and Indo Solar. With India readying itself for the unveiling of its first solar power target, which pledges to boost output from near zero to 20GW by 2020, BOCI's new deals reinforce Linde's standing as a key gas supplier in the PV industry.

"As India plans its solar energy production targets, BOCI is committed to the common goal of bringing the cost of solar electricity to grid parity for mass adoption, by reducing cost per watt of solar cell production," said Srikumar Menon, managing director, BOC India. "Our relationships with this growing list of leading Indian manufacturers are testament to the value of our investment in establishing world class execution capabilitys to serve this rapidly growing and technically demanding industry."

For Moser Baer, BOCI will provide on-site manufacturing of critical gases for the Greater Noida, India facility. They will also focus on using technology solutions to provide the most advantageous gas usage and India's first on-site Total Gas Management (TGM) service.

The deal with Indo Solar will see BOCI as the exclusive supplier of bulk nitrogen, silane and other specialty gases. BOCI will supply the facility with TGM services and install the distribution and monitoring systems. BOCI will lead the way for the development of a gas supply infrastructure in Fab City Hyderabad. Solar Semiconductor's new crystalline silicon cell plant in Fab City will use BOCI to expand its gas and chemical delivery to support future investments.

Finally, working with Euro Multivision in Gujarat, BOCI is supplying the bulk and special gases needed for their new 40MW crystalline cell manufacturing facility in Kutch.

AMG purchases 80 metric tons of solar-grade silicon from Timminco

Timminco has sold 80 metric tons of solar grade silicon to AMG Conversion, a wholly-owned subsidiary of AMG Advanced Metallurgical Group. The sale is estimated to be worth around US$3.1 million. The deal was accommodated by considering the price of the solar grade that has been negotiated for similar material with third parties. This was reviewed by the designated independent representatives of the boards of directors of each of Timminco and AMG.

Timminco will continue to focus on producing solar-grade silicon while AMG will use the silicon and furnace technology supplied by AMG's Engineering Systems division to produce solar-grade ingots and bricks for the solar wafer market. AMG also owns a 47.9% equity interest in Timminco.

Linde to supply Bosch Solar with bulk oxygen and nitrogen

A long-term contract to supply high purity nitrogen from an on-site air separation unit and bulk oxygen for Bosch Solar's new manufacturing site in Erfurt, Germany has been signed with Linde Nippon Sanso (LNS), a subsidiary of The Linde Group. LNS already supply specialty gases to both Bosch's crystalline and thin-film operations. The Bosch Erfurt facility (formerly ersol) is currently ramping. At full capacity the facility is expected to have the ability to produce 630MW of crystalline solar modules per annum.

the Zibo TCS production facility. The facility currently has an annual production capacity of 25,000, SunSi aims to double this capacity within the next 12 months.

The joint venture agreement states that all of the assets, including permits, rights, land usage, as well as the entire labor force and management team of the Zibo TCS producer, will be transferred into Zibo SunSi Chemical upon closing of the transaction.

SunSi Energies also announced that Child, Van Wagoner & Bradshaw, PLLC (CVB), its US-based auditors with offices in China, has completed the audit of the Chinese company's financial statements for the last two fiscal years under U.S. GAAP.

"We are pleased to have completed our due diligence and review of the Chinese company and its operations. While conducting our review over the past 9 months, we have built a solid relationship with the corporation, while integrating ourselves in the management of the Chinese company. The Chinese team will be integrated into the newly formed entity as its members are not only well respected in the industry, but also the leaders in TCS production. We can now focus on the expansion and economic growth of the company," said Richard St-Julien, vice president of SunSi Energies and president of SunSi Energies Hong Kong.

Other News

Nitol Solar joins SEMI as corporate, PV Group member

Nitol Solar, whose current and future product groups include the value chain from trichlorosilane to polycrystalline silicon and monocrystalline and multicrystalline silicon wafers, joined SEMI as a corporate member and a member of the PV Group.

"Joining SEMI is a next step of cooperation between Nitol and SEMI association. SEMI membership will reinforce the development of Nitol Solar and the entire PV industry in Russia, and will invest into growing integration of the global PV societies," said Dmitry Kotenko, Nitol Solar CEO.

Nitol's production is based at their factory in Usolie-Sibirskoe, Irkutsk region, Russia, with their products being sold to international customers, primarily in Europe and South-Eastern Asia.

China Sunergy renegotiating silicon ingot/wafer supply deal with REC

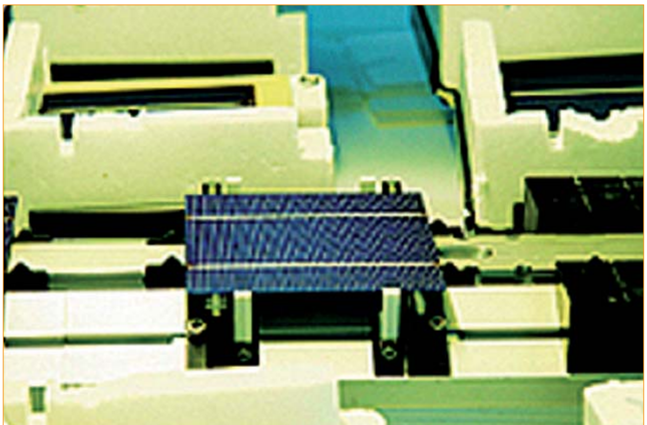

Silicon in raw state.

Solar cell manufacturer China Sunergy has started renegotiating its monocrystalline-silicon ingot and wafer supply agreement with REC. The original seven-year deal (for the 2009-15 period) was signed June 2008 with REC's SiTech unit, which has since been dissolved as a result of a merger earlier this year.

China Sunergy says it has entered into good-faith renegotiations with REC in respect to the overall arrangement of the supply deal and hopes to reach a mutually beneficial agreement between both parties. Such renegotiations between solar PV materials suppliers and their customers have become common since the dramatic drop in polysilicon prices and increase in poly supply that have changed the market's supply-demand dynamics since the fourth quarter of 2008.

During its announcement of its second-quarter financial results the end of last week, China Sunergy said that its quarterly blended wafer cost, as a part of production costs, declined to US$0.96 per watt compared to US$1.61 per watt in the first quarter. As the company fully consumed its higher cost inventory at the end of 2008, it said that its procurement flexibility facilitated the continued purchase of more raw materials on the spot market, which helped reduce blended wafer cost.

Wafer cost continued to decline as a percentage due to lower wafer pricing in the second quarter, the company said. Wafer cost per watt as a percentage of total production costs per watt declined from 81.4% in the first quarter of 2009 to 75.2% in the second quarter, according to China Sunergy. The company saw its quarterly revenues rise to US$70.1 million, an 89.5% increase over the previous quarter, and its non-GAAP net come in with income of US$1.2 million.


Source: China Sunergy

China Sunergy module production.

Product Briefings

Applied Materials

Applied Materials uses diamond wire technology in new ingot squarer system

Product Briefing Outline: Applied Materials has launched the 'Applied HCT Diamond Squarer' system. This new system is claimed to reduce the cost of squaring silicon ingots by up to one third while offering at least twice the cutting speed of conventional squaring processes, due to the use of novel diamond wire technology. The diamond wire technology is also available for its currently-installed HCT Squarer systems as an upgrade kit.

Problem: In the conventional squaring process, a rapidly moving wire, carrying abrasive slurry, is used to cut monocrystalline or multicrystalline silicon ingots into standard sized bricks which are then sliced into wafers for photovoltaic applications. The slurry and electrical energy used delivers a significant cost disadvantage.

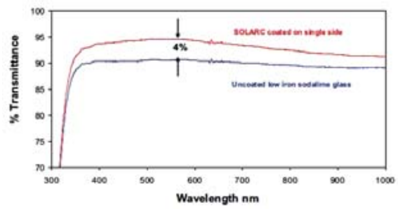
Solution: The HCT Diamond Squarer system uses diamond particles bonded to a metallic wire core to cut the ingot more quickly. In addition to increasing machine capacity and lowering energy consumption, this technology simplifies the squaring process by eliminating the complexity and expense of slurry management.

Applications: Cast multicrystalline silicon ingots into bricks, or pulled monosilicon ingots into pseudo-square bricks.

Platform: The system is the latest addition to Applied's production-proven suite of solutions for manufacturing silicon wafers for solar PV cells, which includes the Applied HCT MaxEdge wire saw for slicing ingots into ultra-thin wafers. The system has a load capacity of one cast ingot or 16-25 mono ingots. The diamond wire technology is also available for its currently-installed HCT Squarer systems as an upgrade kit.

Availability: Currently available.

Honeywell Electronic Materials



Honeywell's transparent coating material improves light transmittance

Product Briefing Outline: Honeywell Electronic Materials has launched a new material called Honeywell SOLARC that improves the efficiency and power output of PV modules. The new product is a transparent coating material that improves the light transmittance through the glass covering the solar cells.

Problem: Most commercially available PV panels today lose approximately 4% of their potential power output due to light reflection from the front surface of the cover glass. Also, solar panels lose on average 7% of their power output as a result of particulate contamination, according to the California Energy Commission.

Solution: SOLARC coating reduces reflection significantly, resulting in more light reaching the solar cell, which translates into higher electricity output. Demonstrating a 4% increase in transmission at 550nm, Honeywell's SOLARC has demonstrated a very good response across a broad solar spectrum that is relevant for PV cell operation, from 350nm through 1,100nm. The coating has also demonstrated superior durability in a broad variety of accelerated tests designed to imitate harsh environmental conditions to which a PV panel is likely to be exposed during its lifetime. Honeywell clams that environmental testing of the coating has shown that it provides additional protection to the glass, which can be prone to gradual deterioration especially under hot and humid conditions. The coating has been further optimized to enable anti-soiling and self-cleaning functionality that prevents dust accumulation.

Applications: Honeywell's SOLARC is a liquid-based coating, can be used by all common types of PV modules and can easily be adapted to a broad range of coating techniques including dip, roller, slot die, spray and spin-on.

Platform: Unlike other commercially available ARCs, it does not require mixing of two components prior to deposition, and has at least a six-month shelf life.

Availability: Currently available.

Siemens

Siemens new Gas Chromatograph optimizes polysilicon quality and output

Product Briefing Outline: Siemens has introduced a new Gas Chromatograph (GC) that can be used in the very demanding polysilicon production process. The MAXUM II PGC will help to maximize the polysilicon output to ensure stable and high quality material, minimizing off-spec products. This results in significant cost reductions with a typical return on investment of less than one year for a typical plant, according to the company.

Problem: The challenging polysilicon production process with its extremely high product quality requirements along with the difficult-to-handle trichlorosilane (TCS) substance require advanced analysis techniques to reliably control safe and correct operation of the process as well as product quality.

Solution: The MAXUM II PGC is directly connected to the process and can be installed within hazardous areas. They have a very short analysis time, typically 5 to 10 minutes and a high availability, in excess of 98%. Each measurement cycle generates reliable results for the key components such as DCS, TCS, STC, HCl and H_2. Every MAXUM PGC is able to monitor several sampling points by automatic stream selection, either successively or even simultaneously. The process data is continuously fed into the DCS either through analogue outputs or serial/ethernet communication, enabling the plant to run in the most optimized and efficient way. It also eliminates the need for disconnecting and connecting sample cylinders, exposing it to ambient air and risk of contamination.

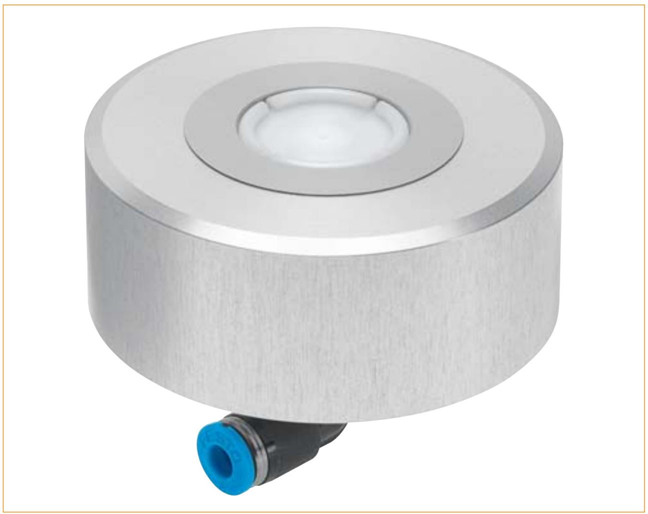
Applications: Polysilicon production plants.

Platform: Multiple oven options (airless, airbath, single, double); different detector types (TCD, FID, FPD, HID, ECD); various valve and column switching techniques as well as different column types (capillary, micro-packed, packed). Special detectors can trace components like BCl_3, PCl_3, hydrocarbons, CO, CO_2, and N_2 can be detected at ppb levels, e.g. in recycled gases.

Availability: Currently available.

Product Briefings

Festo



Bernoulli Gripper from Festo generates powerful suction effect with air cushion that enables 'contactless handling'

Product Briefing Outline: Festo has introduced a Bernoulli Gripper for transporting delicate work pieces such as solar cells and wafers. The most beneficial aspect of the gripper is the minimized air consumption that reduces the energy costs. Other essential aspects are little swinging power, high grip force, low-pressure applications and a constant area load.

Problem: During the production of solar cells the wafers have to be transported frequently and with high speed. Due to the fact that wafers are very thin and delicate, gripping is a critical point. Vacuum grippers' material composition can leave shadows on the wafers, which reduces the output of the solar cell. Meanwhile the suction has to be secure to resist forces of speed without breaking the delicate wafer.

Solution: The Festo Bernoulli offers a contactless suction force. Minimum contact of the wafer with the gripper insert provides the friction needed to guarantee high-speed transport without losing the wafer. The gripper offers a variable fine-tuning of the air consumption and suction force so that the wafer does not suffer stress during transport. The gripper does not leave residuals on the surface which could influence the output of the solar cell. The gripper offers high suction forces (>30N on request) and with low noise. The design can be easily customized on request to individual requirements and so optimized for each application. The optimized air consumption of the gripper increases the energy efficiency by reducing the energy costs.

Applications: Solar cell and wafer transport.

Platform: Festo offers complete solutions for wafer gripping and transport. The portfolio includes all the components needed from clean air preparation units and valves to handling solutions such as the high-speed H-Portal – customized to the application.

Availability: Currently available.

Understanding the role of abrasives used in the multi-wire sawing process

Oliver Anspach, PV Crystalox Solar Group, Erfurt, Germany; **Alexander Lawerenz**, CiS Forschungsinstitut für Mikrosensorik und Photovoltaik GmbH, Erfurt, Germany

ABSTRACT

Multi-wire sawing is currently the most efficient slicing technology for silicon wafers in the photovoltaic industry. Nevertheless, the wafer producers are faced with major cost reductions in the production process and the demand for high-quality, very thin wafers with a total thickness variation less than 10% of the average wafer thickness. One approach to this is the understanding of the role of slurry, specifically the abrasives used in the multi-wire sawing process. In the past few years, more and more scientific investigations have been conducted and are summarised in this article.

Introduction

The main goal for the entire solar industry is to achieve grid parity for solar power – and soon. This is only possible by minimising the cost per Watt peak and ultimately the cost per kWh. The industry realises this task by reducing the production cost throughout the manufacturing chain on the one hand and by increasing the efficiency of photovoltaic systems on the other hand. Within the wafering part of the value chain for crystalline silicon-based solar cells, which will play a dominant role in the years to come, a main goal is to increase the number of wafers produced per kilogram of silicon. Reducing the wafer thickness and minimising kerf loss are two approaches that have emerged with the development of the wire-sawing process. In the last five years, wafer thickness decreased from 300µm down to 160µm in wafer production and wafers with thicknesses of around 100µm have been achieved by R&D demonstrations [1]. In the same way, kerf loss (sawing slot width) decreased from 240µm early this decade to around 140µm. Again, slot widths below 100µm have been achieved by several research groups [2,3]. In any case, next generation solar cells with exact adapted production processes (e.g. thermal process steps) will require very thin wafers with well-defined geometries.

Among other factors, the total thickness variation (TTV) of a wafer is important. The TTV depends only on the way the kerf is removed and is independent of the wafer thickness reduction [4,5]. The mechanism of abrasion in the slot during the wire-sawing process remains the same. Today the TTV is in the tens of micrometers range. As the thickness of a wafer decreases, it becomes clear that compared with its thickness the wafer's TTV plays a more and more important role. Fig. 1 shows the percentage of the total thickness variation compared to wafer thickness for four given TTV values.

For future reference, the percentage of TTV compared to the wafer thickness should not exceed 10%, implying a TTV below 10µm for wafers with a thickness of 100µm.

Reduction of the dimensions of the slots between the wafers and efforts to run the wire-sawing process more efficiently still relies on a 'trial and error' approach of adjustment of sawing parameters. The role of abrasives – and more importantly, carrier fluids – as the slurry formulation in this complex and highly dynamic multi-wire sawing system is still underestimated and underlies special interest at R&D at PV Crystalox Solar.

The following section presents an overview of the role of abrasives, which, with carrier fluid form one part of the slurry formulation, on the dimensions of the slots and the wire-sawing process.

Silicon carbide abrasives

Within the multi-wire sawing process, the use of loose abrasives in a carrier fluid is well established. Nevertheless, the process is not fully understood and is probably not at its optimum level of operation. Silicon carbide powder is by far the most cost effective choice for abrasives. Other abrasives are diamonds or minerals, which are harder than silicon. The carrier fluid consists of polyethylene glycol (mostly common in industry), oil or water with additives.

Production

Silicon carbide is typically a synthetic mineral. Minor quantities occur naturally in the mineral Moissanite. Silicon carbide is used mainly as abrasive powder, but also in ceramic materials and more and more in semiconductor applications.

The production for abrasive powder starts with the Acheson process, where quartz sand and petroleum coke are reacted in a graphite electrical resistance furnace at temperatures up to 2500°C. After the chemical reaction to SiC crystals, the product is crushed, magnetically separated, sieved and classified. The final product, which is suitable for the wire-sawing process, is a green or black silicon carbide powder with different particle sizes. The green SiC has a higher purity

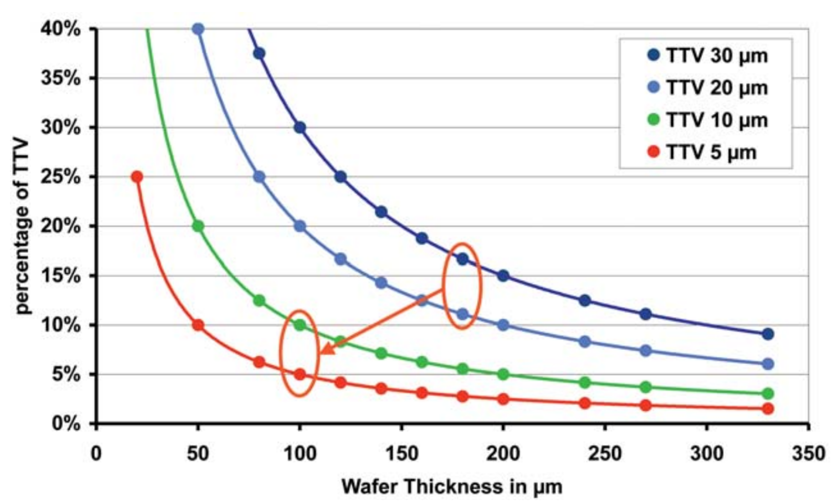


Figure 1. Percentage of TTV versus wafer thickness. The decrease in percentage TTV for wafers of 180µm to 100µm is marked in red [12].

than the black one, which contains a higher impurity level mainly of nitrogen and aluminium. Green SiC is at this time commonly used by wafer producers in Japan, while the black SiC is used in Europe and America. There is a lack of scientific investigations to highlight the differences in the use of black and green SiC in the multi-wire sawing process.

Size and shape characterisation methods

The most important property of abrasives that must be determined before the sawing process starts is their size distribution. To this end, there is a number of measuring methods available, some of which are also capable of measuring the shape of particles. Many of these methods serve to keep the abrasives in suspension, bringing with it the advantage that a suitable dilution can be adjusted to avoid an overlapping or even an agglomeration of particles. Some of the most widely used methods are discussed here.

Light microscopy is commonly used to analyse size and shape distributions of abrasives simultaneously. During measurement, the particles are illuminated and flow in a suspension in the focal plane of a camera. In the case of abrasives mixed with abrasive wear being measured in water suspensions, much care has to be taken to avoid the agglomeration of particles. The addition of special dispersing agents like sodium pyrophosphate and the application of ultrasound is helpful in such a situation (a special treatment is proposed in [6]). Depending on the pattern recognition, which takes place after particle image capture, a large variety of shape features can be analysed. Because these features are obtained from two-dimensional images, one must be mindful that the imaged particles are not oriented in a specific direction. Light microscopy cannot resolve particles that are much smaller than ca. 1µm. Because of its much better lateral resolution (down to ca. 5nm), scanning electron microscopy (SEM) might be an alternative to light microscopy. Scanning electron microscopes are used to get a qualitative picture of abrasives' sizes and shapes but until now there has not been an easy-to-handle preparation procedure which allows the quick analysis of large particle ensembles to obtain the size and shape distributions of abrasives, although efforts are being made to reach this goal. Because it is impossible to observe abrasives in suspension in electron microscopy, the particles have to be kept or transferred into a powder state. The main obstacles for the measuring of size and shape distributions of abrasives lie in the homogeneous and overlapping-free spreading of particles on the sample holder and in the scanning of a sufficiently large number of particles. If the abrasives are mixed with the abrasive wear containing a large amount of small particles, these obstacles will increase.

"Depending on the pattern recognition, which takes place after particle image capture, a large variety of shape features can be analysed."

Another popular method for ascertaining the size distribution is laser diffraction, where the abrasives – similar to light microscopy – are kept in suspension. The diffraction pattern of the scattered laser light is usually detected by an array of photodiodes. This method is capable of measuring small particles (down to ca. 50nm), but for small particles with diameters smaller than the laser wavelength the analysis of the particle size is dependent on the refractive index of this particle. Today's laser diffractometers are not able to measure the shape properties of particles (which is in principle possible by aligning the particles within the fluid using a two-dimensional array of photo detectors). It should be mentioned that the use of laser diffraction needs a careful calibration, otherwise results obtained with different diffractometers tend to diverge greatly. Obtaining the correct fine structure of size distributions is another challenging task. On the other hand, today's diffractometers are easy to use and do not require a complicated sample preparation.

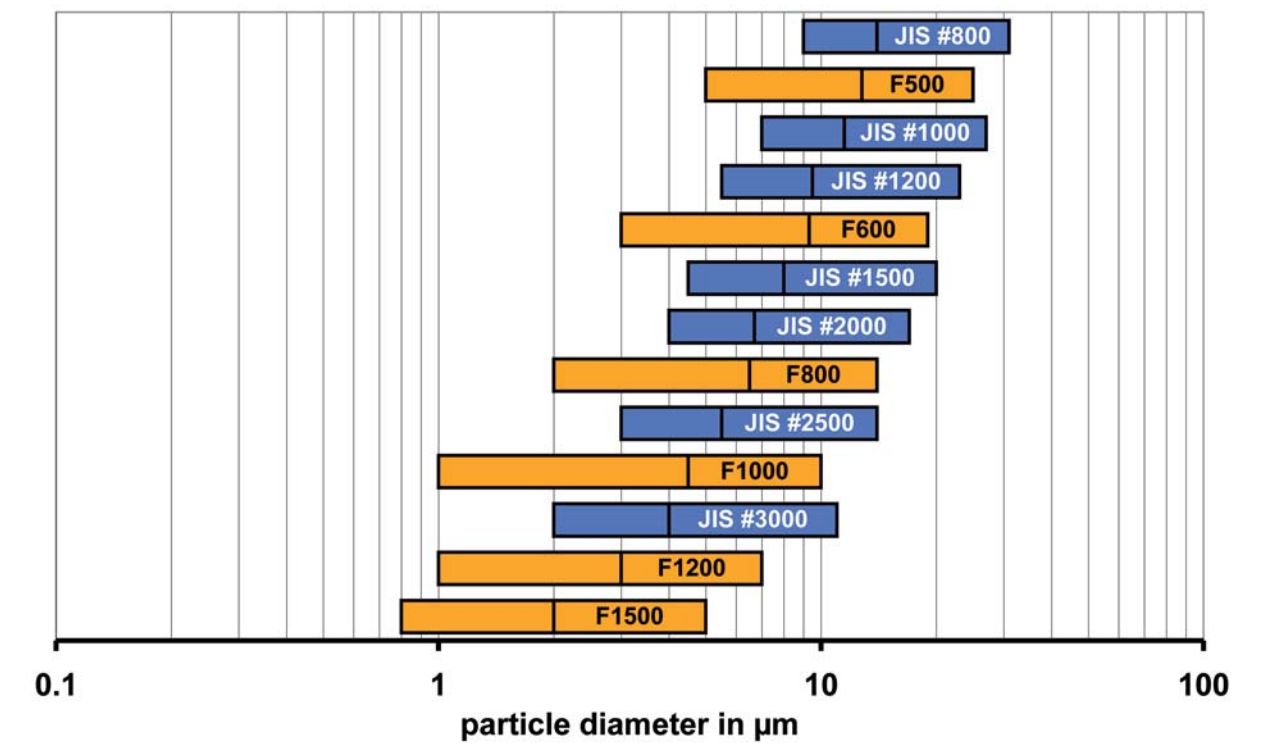


Figure 2. Overview of several classes of SiC powders according to the FEPA and JIS norm. The left end of the bar represents the ds94 value, the middle line the ds50 and the left end the ds3 value of the particle size distribution.

The electrical resistance method, often encountered as Coulter Counter, is also widespread partly because it has to be used for the specification of size distribution by the ANSI standard [7]. Particles are suspended in an electrolyte solution and have to pass a tube with a hole at its end (with an inner diameter somewhat larger than the particle's diameter). Whenever a particle passes the hole, a change in current measured between two electrodes occurs. This change is proportional to the volume of the particle. Therefore no shape distributions can be obtained.

"The ratio of half-width to modal diameter is advantageous because it allows the comparison of the narrowness of the size distribution."

In a sedimentometer the particles are filled into a vertically oriented tube, which is filled with a liquid. The measurement of the size distribution is based on the fact that larger particles settle to the bottom of the tube faster than smaller ones according to Stoke's Law. In the bottom of the tube, scaling enables the measurement of the amount of particles that have settled after a certain time. If small particles (in the micrometer range) are to be measured, this time can extend to several hours. This method needs a very careful preparation and filling of the abrasives into the sedimentation tube, otherwise a cluster sedimentation, where large and small particles are not separated, occurs – especially for abrasives with diameters below a few micrometers. Because of these drawbacks, other methods are replacing the sedimentation although sedimentation is still mandatory if the size distribution is to be measured according to the FEPA standard [8]. The tube must then be filled with methanol.

Measurement categories

Silicon carbide powders are most often specified by the FEPA, ANSI or JIS standards (FEPA: Fédération Européenne des Fabricants de Produits Abrasifs; ANSI: American National Standards Institute; JIS: Japanese Standardization Organization). The specified value of a certain powder (for example FEPA F600) is determined by the particle size distribution whereby a larger number indicates smaller particles. To be specified by a certain FEPA, ANSI or JIS standard value the size distribution of the powder

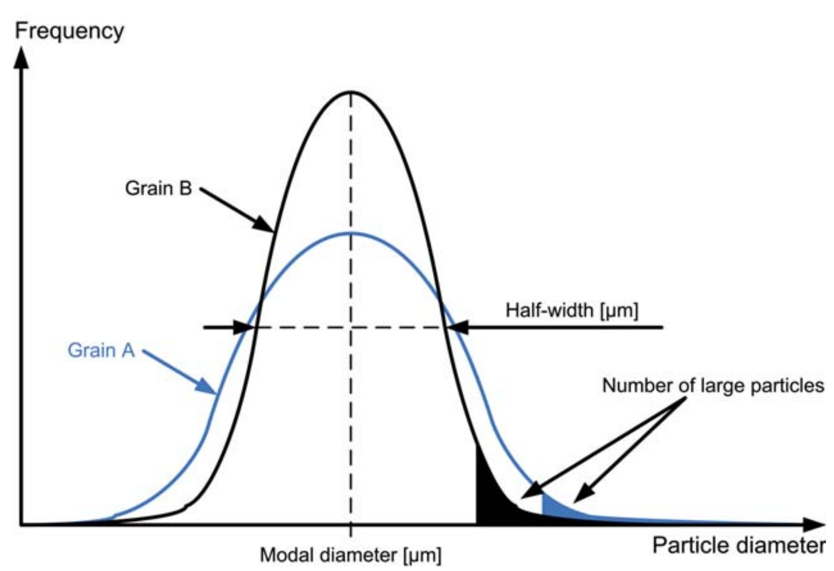


Figure 3. Sketch of a volume-based distribution of two abrasives, indicating the half-width and modal diameter.

has to fulfil some requirements, referred to as the ds3, ds50 and ds94 values. In a volume-based size distribution, a ds3 value is the diameter for which 3% of all particles are larger than the ds3 value (naturally, the ds50 and ds94 values are defined in the same manner). An example of the defined values for several particle size distributions according to the FEPA and JIS standards is depicted in Fig. 2.

It is difficult to compare different powders that are specified by different standards as these standards stipulate different measurement methods. In the ANSI standard, for example, the electrical resistance method is required [7] whereas in the FEPA standard, sedimentometers are used [8].

The ds3, ds50 and ds94 values are not the only useful values that can be taken to describe size distributions of abrasives. Other values include the mean diameter and the modal diameter (both measured in µm). The latter is especially beneficial if slurry particles, which contain abrasives as well as the much smaller abrasive wear particles, are to be characterised. In describing the narrowness of the size distribution, the full width of half-maximum (or half-width, measured in µm) can be used (see Fig. 3). It is also possible to normalise the half-width to the modal diameter. This dimensionless number is advantageous because it allows the comparison of the narrowness of the size distribution if abrasive particles with different modal diameters are to be compared. An example is shown in Fig. 4, where particles with the same normalised diameter lie on a line intersecting the origin. One of the SiC powders (F600 No. 2) has a smaller half-width (compared to powder F600 No. 1), although its normalised narrowness is larger. Another powder (F800 No. 4) has a larger modal diameter although its normalised narrowness is smaller in comparison with the F800 No. 3 powder.

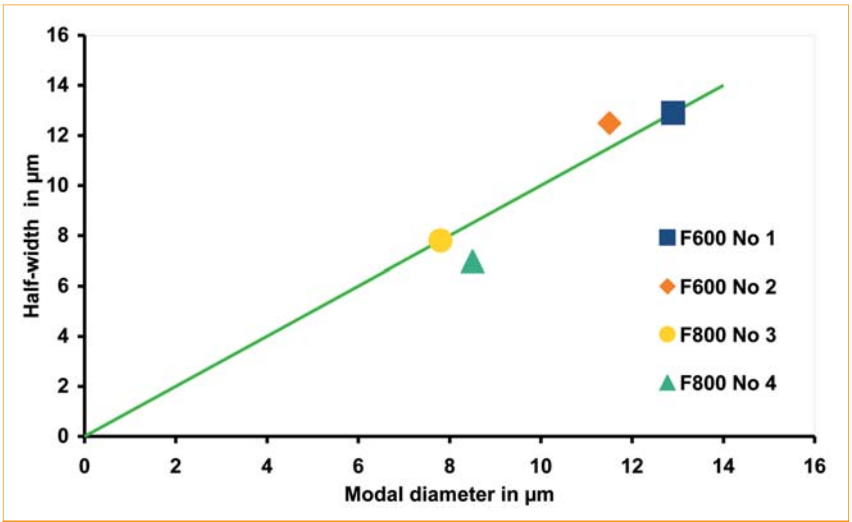


Figure 4. Half-width-modal diameter diagram. The green line indicates a reference line where all size distributions have the same normalised narrowness.

The shape of abrasives also influences sawing efficiency. All of the methods currently in use to measure shape properties are based on pattern recognition analysing only the two-dimensional images of the particles. The most common characteristic, which describes the shape of an abrasive, is the circularity, defined as the ratio of the

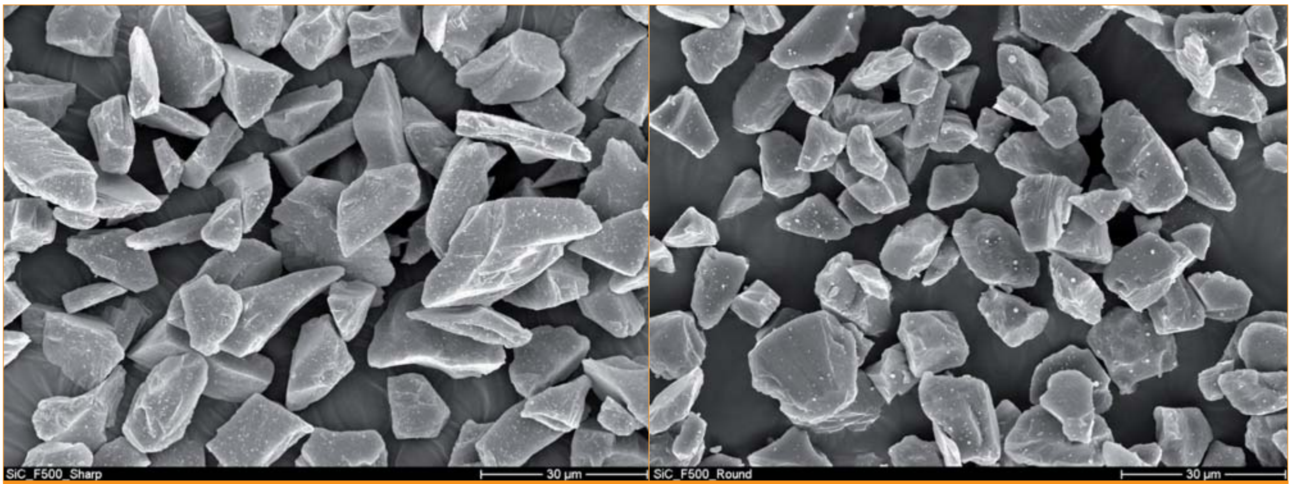


Figure 5. SEM images of SiC particles showing low circularity (SiC_F500_Sharp) and high circularity (SiC_F500_Round).

perimeter of a circle (with the same area as the respective particle) to the perimeter of the particle. The longer a particle is, the smaller the circularity. A perfectly round particle has a circularity of 1.00. Two samples of silicon carbide particles with a high and low circularity are depicted in Fig. 5. Today's instruments are capable of ascertaining a large number of shape features such as area, perimeter, circularity, feret diameter, aspect ratio, circularity, and convexity.

However, to our knowledge there is no single characteristic that specifies the sharpness of a particle. In contrast to the circularity or convexity, this demands the examination of the local proximity of the perimeter. A possible definition for the sharpness of a particle could be the minimum of all radii of curvature of the particle's perimeter.

Experimental setup

At PV Crystalox Solar, a standard industrial wire saw is set up to investigate the highly dynamic, fast and complex wire-sawing process. The wire web is separated to isolate a single wire winding to obtain single slots. An extra slurry tank provides the ability to manipulate and even replace small amounts of slurry during cutting (see Fig. 6). Temperatures of the silicon block and of the slurry can be set at constant in order to approach conditions, which are common in an industrial wire-sawing process. Furthermore, temperatures and forces that work on the silicon block can be measured [9].

In order to evaluate the performance of particular silicon carbide abrasives, slot width dimensions at the wire entry and exit side and the resulting TTV, roughness and surface damage of the side walls of the slot and the vertical force, measured during the experiment, are characteristic values [10-12]. The vertical force, which is parallel to the table drive direction and which occurs when the silicon block is forced through the wire web, indicates the 'abrasive performance' or how well the wire goes through the silicon during

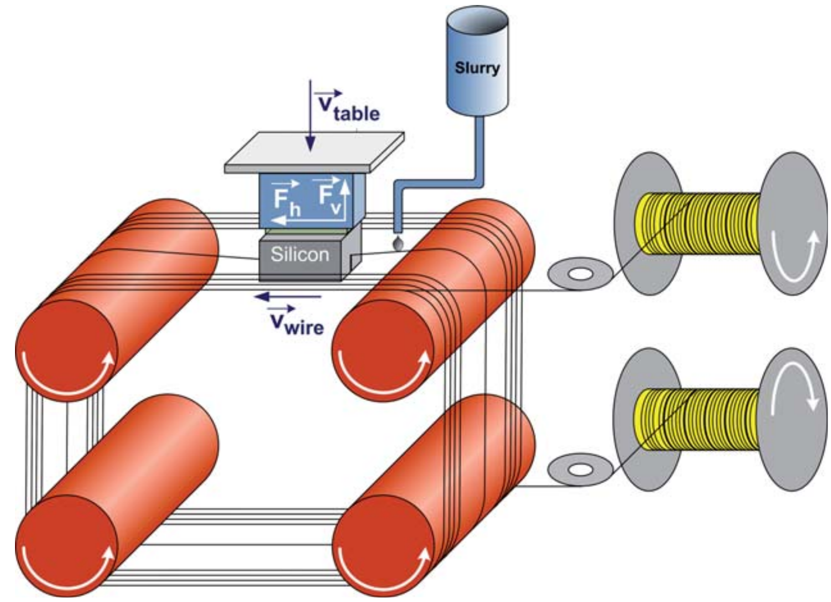


Figure 6. Sketch showing the single-wire experimental setup.

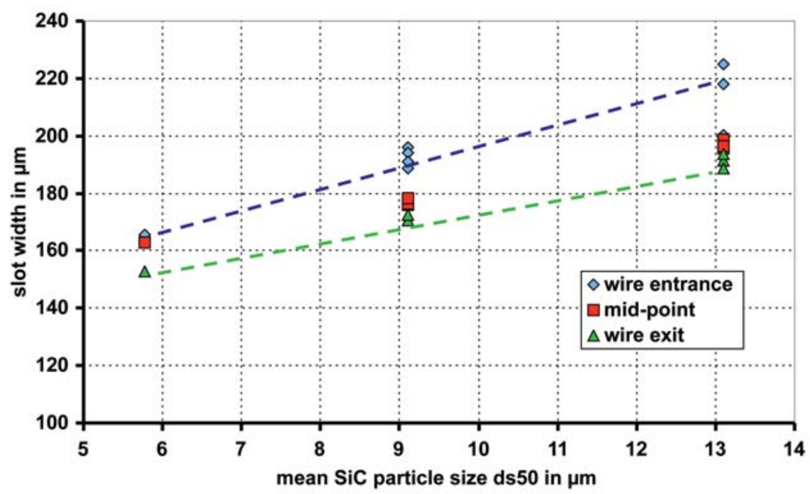


Figure 7. Slot width at the wire entrance and exit and at the mid-point of the Si block versus mean SiC particle size [11].

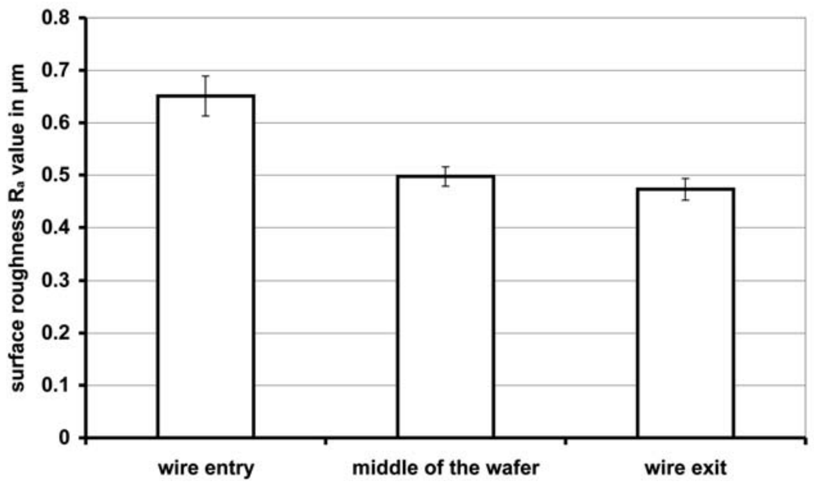


Figure 8. Mean results of the average surface roughness R_a given for the measurements at the wire entry and exit side and at the middle of the wafer [12].

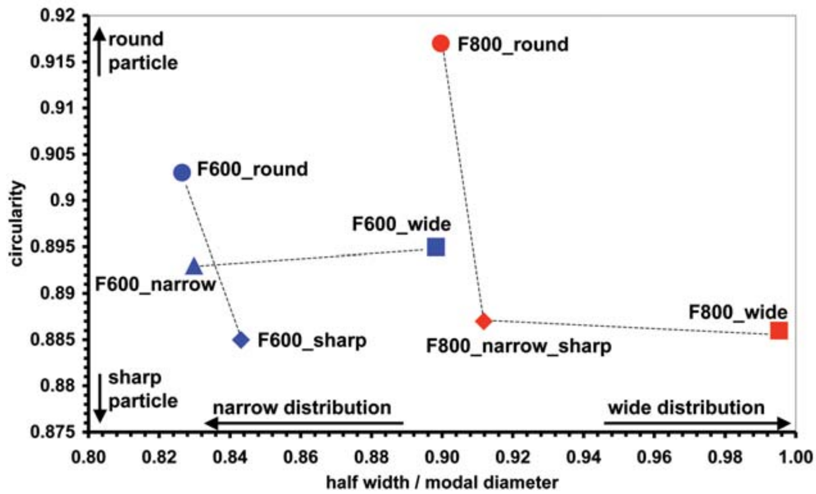


Figure 9. Circularity versus ratio between half-width and modal diameter. For the experiments chosen, F600 abrasives are marked in blue; F800 abrasives are marked in red [12].

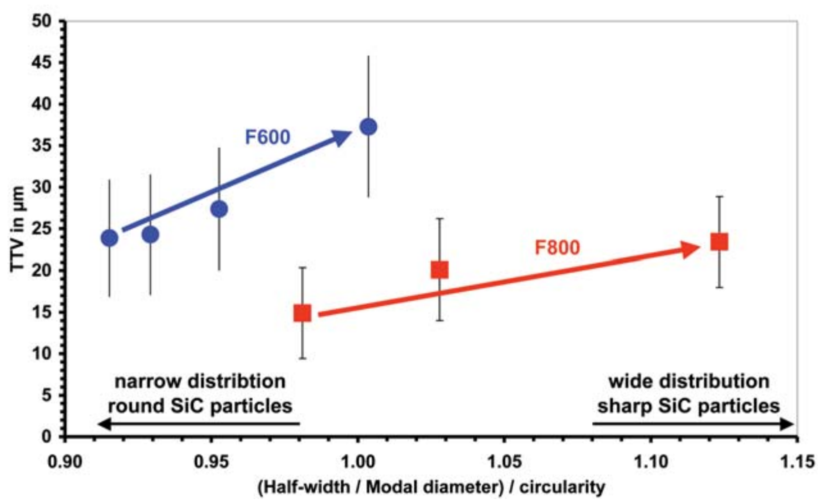


Figure 10. TTV versus ratio between half-width and modal diameter and the circularity [12].

cutting. The lower the vertical force, the 'better' the cutting process. Nevertheless, measurements of e.g. thickness, TTV, roughness and sub-surface damage can be also performed on the wafers cut with the multi-wire sawing process themselves, as found by other research groups [1,3-5, 13-25].

Influence of abrasives

Size

It is obvious that with increasing mean particle size of SiC in slurry, the slot width increases and therefore the wafer thickness decreases, a finding that has been well described in literature [1,3,11,20,26]. This correlation is also shown in Fig. 7, where the average of slot width at wire entry and exit and in the middle of the slot is plotted versus the mean particle size [11]. The slots measured were cut using three slurries, each with different mean SiC particle sizes. This diagram shows also that within the same slurry the slot width at the wire entry is larger than the slot width at the wire exit. Hence, this means that using a unidirectional wire-sawing process, the wafers on the wire entry side show a lower thickness than on the wire exit side.

Regarding the vertical force, it is known that the larger the mean particle size, the lower the vertical force on the silicon block, resulting in lower wear on the wire [2,19,20]. In other words, larger particles cut more easily through silicon and show a higher 'abrasive performance.'

> "Using a unidirectional wire-sawing process, the wafers on the wire entry side show a lower thickness than on the wire exit side."

The interaction between abrasive particles and silicon during the sawing process leaves a certain roughness at the wafer's surface. The literature states a correlation between the mean particle size of the used abrasives in the slurry and the surface roughness on wafers: with larger particle sizes comes more surface roughness [13,14,20,24-28]. Again, however, it became obvious that the surface roughness varies within one wafer depending on whether the measurement is carried out at the wire entry, the wire exit side or at the middle of the wafer. Fig. 8 shows the mean results of average surface roughness measurements on 42 wafers at three positions [12]. The fact that the surface roughness is higher at the wire entry side than at the middle of the wafer and at the wire exit side is in good agreement with the results of [2,27]. A correlation between the mean particle size and sub-surface damage, which is indicated

Figure 11. Collage of a wire beneath silicon and SiC particles in between the wire entry side (left) and the wire exit side (right) [12].

by the crack depth distribution on wafers, is discussed in the literature [13,14,19,28]. Larger slurry particles result in deeper sub-surface damage.

After all, the data in the literature show dependencies on the mean particle size of SiC in slurry. But one must bear in mind that correlations between different particles should also take into account that the correlations shown above also depend on particle size distribution and shape. Hence, we performed wire-sawing experiments at different table forward and wire speed conditions using slurries containing silicon carbide particles with extreme shape and size distributions. Fig. 9 shows the chosen SiC samples with narrow and wide size distribution (nearly the same circularity) and sharp and round particles (nearly the same particle size distribution) within two size classes, F600 and F800 [12].

Particle size distribution and shape

The results of the slot width measurements show that the wider the particle size distribution and the sharper the abrasives in slurry, the larger the slot width at the wire entry side. The slot widths at the wire exit side show no dependency on shape nor on size distribution [12]. A very interesting fact is observed when the difference between the slot width at the wire entry and exit side (respectively the TTV) was plotted versus the ratio between half-width to modal diameter and circularity (see Fig. 10). On the one hand, the slot widths cut with slurries with smaller particles (F800) show lower TTV than slots cut with slurries containing larger particles (F600), which is in good agreement with [11,20]. On the other hand, a direct correlation between the ratio of half-width to modal diameter and circularity can be observed in this case. In other words it can be stated that the narrower and rounder the particles in slurry, the lower the TTV of the slot cut with this slurry. It was also observed that the vertical forces, which were applied to the silicon block using slurries with sharper particles (low circularity), were lower than the forces with other slurries [12]. This means that the 'cutting performance' of sharper particles is higher than for round particles. Such a dependency intensifies with higher ratios between table forward and wire speed.

> "Larger particles are cutting at the wire entry, smaller particles at the wire exit side."

Bearing in mind that a) larger particles cause higher surface roughness, deeper sub-surface damage and larger slot widths, and that b) this can be observed not only on wafers cut with different particle sizes but also along one slot cut with one particular slurry, a new approach to classification of the participating particles along the whole length of the slot was pursued. In other words, larger particles were cut at the wire entry side and smaller particles were cut at the wire exit side regardless of the mean size of the particles (e.g. F600 vs. F800). Fig. 11 gives an idea of these dimensions. This mechanism of classification along the slot was observed by [29], where the researchers captured large particles pushed aside in a large-scale experiment. Nevertheless, although the mechanism remains unclear so far, a complex interaction between wire, particles and slot wall (silicon) can be presumed.

Silicon versus silicon carbide particles

During the wire-sawing process, silicon particles are abraded. The mean particle size of these silicon particles ranges between 2 and 5µm. Scientific experiments are required to investigate the correlation between the mean particle size of silicon carbide and the mean silicon particle size resulting from the wire sawing process.

Nevertheless, it becomes clear that with increasing the silicon load of the slurry, more and more silicon particles, among the silicon carbide abrasives, enter the slot. Since silicon particles compete against the silicon carbide particles in the very narrow space between wire and slot walls, at a certain silicon content the slurry is unable to cut the silicon block, as observed in the industrial wire-sawing process.

Recycling

For this reason, the slurry needs to be replenished and should also be recycled by separating the larger, still useable, silicon carbide particles from the smaller silicon particles (fines). Two main processes have been established in the past years: the centrifuge and the hydro-cyclone technique. Both techniques separate more or less efficiently the larger silicon carbide particles from the fines. However, it should be made clear that these fines also contain small silicon carbide particles, which results from the abrasion and breaking of larger silicon carbide particles. The abrasion rounds the edges of the SiC particles; the breaking minimises the amount of larger particles. Both processes result in a higher amount of fine fraction, which is an indicator for the breakability of SiC. This breaking and abrasion of silicon carbide particles during the wire-sawing process needs to be subject to further investigations.

Conclusion

Besides the carrier fluid, abrasives are a crucial component for the improvement of wire-sawing conditions and the subsequent production of high-quality wafers. However, to obtain such quality wafers (low TTV, low surface roughness) with high cutting rates (low vertical force per wire), a balance between slurries containing small and round particles with narrow distribution on the one hand and larger and sharp particles with narrow distribution on the other hand must be found. In fact, the 'narrowness' of the particle size distribution plays an important role in minimising the total slot width variation and therefore in achieving the goal of TTV less than 10% of the wafer thickness. Nevertheless, even the best silicon carbide particle suitable for multi-wire sawing shows its properties only after the recycling steps and usage in several wire-sawing runs.

Acknowledgements

The authors would like to thank **F.-W. Schulze** for fruitful discussions and **W. Büchner**, **B. Hurka** and **J. Zeh** for research done at PV Crystalox Solar. We would also like to thank **A. Grün** for preparing and analysing abrasives at CiS Forschungsinstitut für Mikrosensorik und Photovoltaik.

References

[1] Beesley, J.G. & Schönholzer, U. 2007, "Slicing 80 Micrometer Wafers-Process Parameters in the Lower Dimensions", *Proceedings of the 22nd European PVSEC*, pp. 956-962.

[2] Kaminski, S., Rietzschel, R., Wagner, T., Funke, C. & Möller, H.J. 2009, "Multi wire sawing of silicon with thin wires down to 80µm", *Proceedings of the 24th European PVSEC*, submitted.

[3] Schumann, M., Singh, M., Perez, T.R. & Riepe, S. 2009, "Reaching a Kerf Loss below 100µm by optimizing the Relation between Wire Thickness and abrasive Size for Multi-Wire Sawing", *Pre-Print of the 24th European PVSEC.*

[4] Müller, A., Cherradi, N. & Nasch, P.M. 2003, "The Challenge to implement Thin Wafer Potential with Wire Saw Cutting Technology", *Proceedings of the 3rd World Conference on Photovoltaic Energy Conversion*, pp. 1-4.

[5] Nasch, P.M., Cherradi, N., Müller, A., Seifert, C. & Geyer, B. 2004, "The Way to High-Efficiency, Low Cost Solar Cells through Thin Wafer Slicing by means of Wire Saw", *Proceedings of the 19th European PVSEC*, pp. 1118-1122.

[6] Lawerenz, A., Grün, A., Porytskyy, R. & Anspach, O. 2007, "Preparation methods and survey of optical measurements of slurry abrasives", *Proceedings of the 24th European PVSEC*, submitted.

[7] ANSI B74.10-2001

[8] FEPA, 2006, "Körnungen aus Elektrokorund, Siliziumkarbid und anderen Schleifmitteln für Schleifkörper aus gebundenem Schleifmittel und für allgemeine industrielle Anwendungen", FEPA standard 42-2:2006(de).

[9] Anspach, O., Berg, M. & Schulze, F.W. 2006, "Experimental Setup for investigations on the wire sawing process", *Proceedings of the 10th Scientific and Business Conference SILICON*, pp. 57.

[10] Anspach, O. & Schulze, F.W. 2007, "Glycol to Water-Based Slurry, Investigation on the Wire Sawing Process", *Proceedings of the 22nd European PVSEC*, pp. 952-955.

[11] Anspach, O., Stabel, A., Lawrenz, A., Riesner, S., Porytskyy, R. & Schulze, F.W. 2008, "Investigations on Single Wire Cuts in Silicon", *Proceedings of the 23rd European PVSEC*, pp. 1098-1103.

[12] Anspach, O., Hurka, B., Zeh, J. & Schulze, F.-W. 2009, "Influence of abrasive shape and size distribution on the wire sawing process", *Proceedings of the 24th European PVSEC*, submitted.

[13] Bidiville, A., Wasmer, K., Michler, J., Ballif, C., Van der Meer, M. & Nasch, P.M. 2007, "Towards the Correlation of Mechanical Properties and Sawing Parameters of Silicon Wafers", *Proceedings of the 22nd European PVSEC*, pp. 1130-1134.

[14] Bidiville, A., Wasmer, K., Michler, J., Ballif, C., Van der Meer, M. & Nasch, P.M. 2008, "Influence of abrasive concentration on the quality of wire-sawn silicon wafers", *Proceedings of the 23rd European PVSEC*, pp. 1311-1314.

[15] Funke, C., Sciurova, O., Kiriyenko, O. & Möller, H.J. 2005, "Surface Damage from Multiwire Sawing and Mechanical Properties of Silicon Wafers", *Proceedings of the 20th European PVSEC*, pp. 1128-1131.

[16] Funke, C., Sciurova, O., Möller, H.J., Stephan, M., Fröhlich, K.J., Seifert, C., Bachmann, A. & Müller, A. 2004, "Towards Thinner Wafers by Multi-Wire Sawing", *Proceedings of the 19th European PVSEC*, pp. 1226.

[17] Ishikawa, K.-I., Suwabe, H., Itoh, S.-I. & Uneda, M. 2003, "A basic study on the Behavior of Slurry Action at Multi-Wire Saw", *Key Engineering Materials*, Vols. 238-239, pp. 89-92.

[18] Kray, D., Schumann, M., Schultz, O., Bergmann, M., Ettle, P., Rentsch, J., Eyer, A. & Willeke, G.P. 2006, "Experimental Investigation of Wire Sawing Thin Multicristalline Wafers", *Proceedings of the 21st European PVSEC*, pp. 885-888.

[19] Möller, H.J. 2004, "Basic Mechanisms and Models of Multi-Wire Sawing", *Advanced Engineering Materials*, Vol.6, No.7, pp. 501-513.

[20] Québatte, L., Popa, A.M., Bakshi, A.K., Boussant-Roux, Y. & Nasch, P.M. 2008, "Influence of Shape and Size of Silicon Carbide Grits on Wire Saw Cutting Efficiency", *Proceedings of the 23rd European PVSEC*, pp. 1094-1097.

[21] Rietzschel, R., Wagner, T., Funke, C. & Möller, H.J., 2008, "Optimization of the wire sawing process using force- and temperature-measurements", *Proceedings of the 23rd European PVSEC*, pp. 1301-1304.

[22] Schmidt, D., Hagendorf, C., Werner, M., Altmann, F & Bagdahn, J. 2008, "Analysis of micro cracks in silicon material using ion beam polishing techniques", *Proceedings of the 23rd European PVSEC*, pp. 1493-1496.

[23] Schumann, M., Bergmann, M., Haas, F., Orellano, T., Mayer, K. & Eyer, A. 2007, "Slurries for Multi-Wire Sawing – An experimental Approach", *Proceedings of the 17th International Photovoltaic Solar Energy Conference*, pp. 721-722.

[24] Wagner, T. & Möller, H.J. 2008, "A 3D Wire Saw Model of the Slurry Flow to Predict Forces Exerted Upon Silicon Ingots During Cutting", *Proceedings of the 23rd European PVSEC*, pp. 1315-1320.

[25] Weber, B., Bierwisch, C., Kübler, R. & Kleer, G. 2008, "Investigation on the Sawing of Solar Silicon by Application of Wires of 100µm Diameter", *Proceedings of the 23rd European PVSEC*, pp. 1285-1288.

[26] Nasch, P.M. & Schneeberger, S. 2005, "A Theoretical Modelling of Consumables Usage as a Tool for Cost Reduction in Silicon Wafering using Multi-Wire Slurry Saw", *Proceedings of the 20th European PVSEC*, pp. 1139-1144.

[27] Wasmer, K., Bidiville, A., Jeanneret, F., Michler, J., Ballif, C., Van der Meer, M. & Nasch, P.M. 2008, "Effects of Edge Defects Induced by Multi-Wire Sawing on the Wafer Strength", *Proceedings of the 23rd European PVSEC*, pp. 1305-1310.

[28] Wasmer, K., Bidville, A., Ballif, C., Van der Meer, M. & Nasch, P.M. 2009, "Study of the influence of Feed rate and Wire Tension on the mechanical stability of wire-sawn Silicon Wafers", *3rd International Workshop on Crystalline Silicon Solar Cells SINTEF/NTNU*, pp. 1-4.

[29] Noca, F., Monkewitz, P., Alhosseini, B.H. & Nasch, P.M. 2009, "Fluid Mechanics of Wire Sawing", *Proceedings of the 24th European PVSEC*, submitted.

About the Authors

Oliver Anspach studied geology at the University of Jena and the University of Edinburgh. He received his Ph.D. degree at the Otto-Schott-Institute for glass chemistry at the University of Jena working on textured glass ceramics. Since 2005 he has been working for PV Crystalox Solar PLC, and for the past two years has been responsible for research and development in the field of multi-wire sawing.

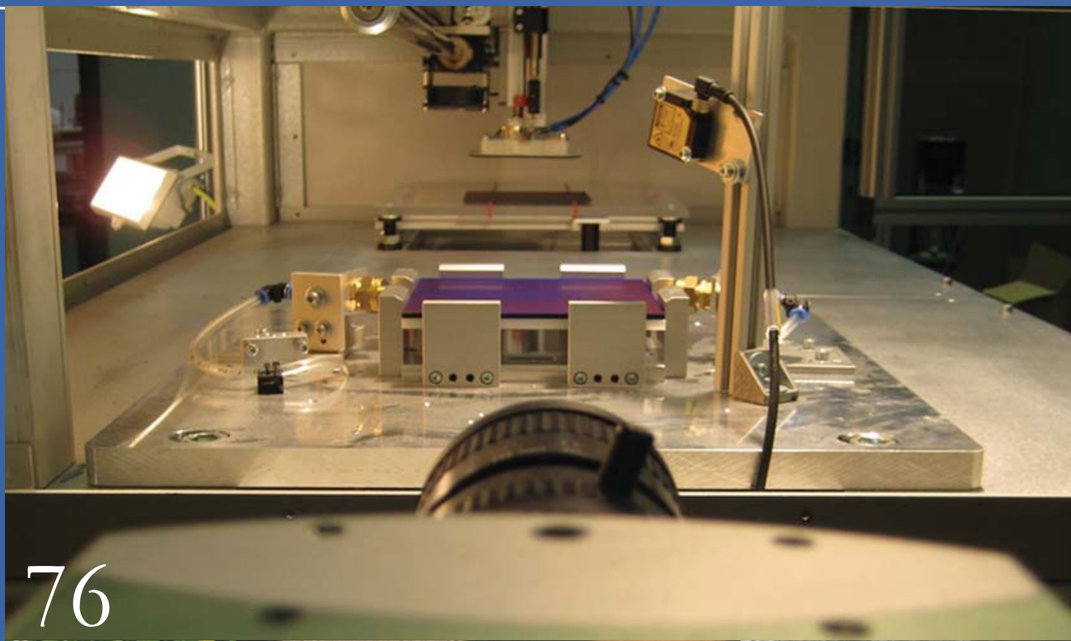
Alexander Lawerenz is head of the Photovoltaics Department at the CiS Forschungsinstitut für Mikrosensorik und Photovoltaik GmbH in Erfurt, Germany. He studied physics in Konstanz and Hamburg and received his Ph.D. degree from the Technische Universität Bergakademie Freiberg. He joined the CiS Forschungsinstitut in 2003, starting his work in the field of characterisation of solar silicon materials.

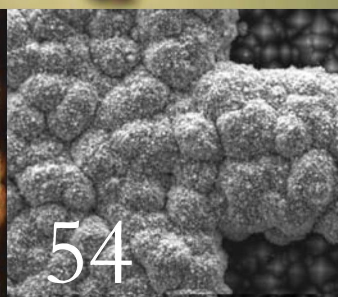
Enquiries

PV Crystalox Solar Group
Wilhelm-Wolff-Str. 25
D-99099 Erfurt
Germany

Email: oliver.anspach@pvsilicon.com
Website: www.crystalox.com

Cell Processing





OTB Solar, Arise make progress in development of inkjet-print-based selective emitter process

Arise's PV cell production fab in Bischofswerda, Germany.

OTB Solar and Arise Technologies say they have made "significant progress" in the development and deployment of OTB's inkjet deposition-based single-pass selective emitter process, in combination with a conventional diffusion furnace, to produce high-efficiency silicon-based photovoltaic cells. The process enables the deposition of the area emitter and selective emitter dopants in a single-pass sequence, thus reducing and eliminating the need for additional costly emitter forming equipment, processes, and materials.

The emitter-forming process under development at OTB Solar's Eindhoven Technology Center and Arise's PV cell production fab in Bischofswerda, Germany (pictured), uses OTB's industrial-scale Elements inkjet printing deposition platform, which can be adjusted toward the different throughput requirements of cell makers.

"Recent developments indicate that a significant improvement in cell effect can be attained by way of a single-pass selective emitter process," says OTB Solar CEO Paul Breddels. "The process is simple, cost effective and can be easily integrated into existing cell production operations."

Ian MacLellan, vice chairman and president of Arise's systems division and corporate CTO, explains that the Waterloo, Ontario-based company has "been looking at various selective emitter approaches and like this one because it is simpler to implement in production while keeping existing throughput on our production lines.

"These low-volume results also demonstrate that we can implement this technology on our existing production lines," he continues. "We look forward to working with OTB to develop a high-volume solution to complement our strategy of a step-by-step approach to delivering on our high-efficiency program for our customers and shareholders."

Earlier this year, OTB Solar finished installing a turnkey inline cell production line at Arise's factory in Germany. The equipment company also had a high-throughput inkjet printing toolset installed at Innovalight's fab in Sunnyvale, CA—said to be the first industrial-scale IJP system of its kind in a solar PV facility.

News

Cell Production News Focus

Neo Solar starts volume production of the 'Perfect Cell'

Solar cell manufacturer Neo Solar Power has begun volume manufacturing of what it is calling the 'Perfect Cell' – a monocrystalline silicon cell that yields a conversion efficiency of 17.8%. The company has started volume production, which will see 60 of these Perfect Cells formed into a module that is theoretically capable of producing more than 250W of power, compared to the current mono- and multicrystalline module yield of 220W. The company also produces 'Supercell,' a multicrystalline silicon cell that yields 16.8% conversion efficiency, currently in mass production.

Applied Materials will use its Baccini Esatto technology for back-end processing systems

Applied Materials' Baccini Esatto technology will be used for the company's Baccini back-end solar cell processing systems. The Esatto technology, featuring proprietary hardware and software innovations, is designed to increase the efficiency of c-Si solar cells by enabling the fabrication of advanced contact structures.

The technology's high precision, multi-step screen printing capability will be used initially for double-printed metal line deposition where it has apparently raised absolute cell efficiency by as much as 0.5%. This will allow manufacturers to print taller, narrower grid lines, reducing the shadowing effect caused by wider grid lines. This will also improve electrical conductivity. Results from the production environment show that Esatto technology allowed the replacement of single 120µm wide lines with two-layer, double-height lines less than 80µm wide on the finished cell. This will be the first of many applications for the technology.

The Esatto technology allows multiple layers of different materials to be overlaid with better than ±15µm repeatability. It was designed to enable advanced contact formation techniques such as double-printed front side metal lines and the multiple process flows required to create selective emitter structures.

Applied Materials' Baccini Esatto technology.

R & D News Focus

Roth & Rau starts Swiss unit, opens solar-cell technology development center at IMT

Roth & Rau has opened a technology center for the development of future-generation solar cells at the Swiss Institute for Microtechnology (EPFL/IMT), as part of a three-year agreement that the two organizations signed in May 2008. A Swiss subsidiary of Roth & Rau has been established in conjunction with the installation of the research line and siting of a team of scientists and engineers at IMT's Neuchâtel campus.

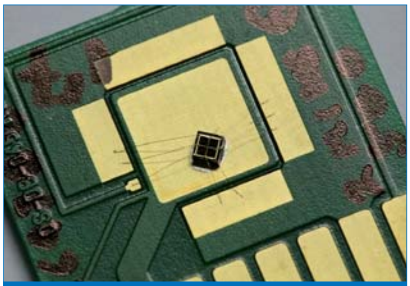
According to the partners, the facility will be used to develop equipment, technologies, and processes for the production of highly efficient crystalline silicon solar cells based on heterojunction technology.

"We are doing intensive research at Neuchâtel into the next-but-one generation of solar cells, which will achieve efficiency ratios of 20% and more," said Roth & Rau's CEO, Dietmar Roth. "We have already obtained the first promising results and are confident that the new manufacturing technologies including the required plant technology and processes will be ready for mass production in 2011."

Up to this point, heterojunction solar-cell technology has been used on an industrial scale by a single company – Sanyo. Heterojunction cells are based on a relatively simple low-temperature manufacturing concept; they are characterized by excellent passivation, which leads to very high efficiencies and excellent temperature behavior, the company said.

"We aim to consolidate our technology leadership with innovative products and hence to grow our company in the long term," explained Bernd Rau, managing director of Roth & Rau Switzerland and group R&D officer. "Comprehensive investments in research and development like here in Neuchâtel are the basis for this growth."

The IMT operation is not the only external technology center where Roth & Rau has become heavily involved over the past year. The company announced in July its intention to renew and expand its partnership with SVTC Technologies, including the establishment of a 30MW development and manufacturing line at SVTC's new Silicon Valley Photovoltaic Development Center in San Jose.



QuantaSol high efficiency cell.

QuantaSol seeks to increase manufacturability of its CPV solar cells

Having already demonstrated and had verified its record-setting strain-balanced quantum-well single junction cell with efficiency levels of 28.3%, Imperial College spin-out QuantaSol is seeking further cell efficiency gains and lower fabrication costs before entering volume production. The company is adopting a dilute nitride process under license from the University of Houston.

QuantaSol said that using dilute nitrides it will reduce the number of quantum well layers required for each junction, without sacrificing solar efficiency. Conversely the thickness of the device is reduced as are the process steps, lowering manufacturing costs. The company said it was planning to produce triple-junction CPV devices in 2010.

Canadian Solar to adopt MWT and EWT cell technology after new enhancements enter production in 4Q09

The race to higher conversion efficiencies in volume production for both mono- and multicrystalline cells continues with news that Canadian Solar plans to boost cell performance to 18.5% and 16.8%, respectively. This will be accomplished by using several advances that include improvements in screen-printing techniques, better texturization and a modified selective emitter process. These successful R&D projects will be migrated to production lines in the fourth quarter of 2009.

Canadian Solar also announced that it has partnered with the Energy Research Center of the Netherlands (ECN) to apply metal wrap-through (MWT) cell technology to Canadian Solar's production lines, which eliminates the need for front-side busbars, giving more surface area, further boosting conversion efficiencies. In further collaboration with ECN and Dutch equipment supplier Eurotron, Canadian Solar is targeting the introduction of emitter wrap-through (EWT) structures, which can further eliminate the front-surface grid to boost performance of the cell.

Module performance is also expected to be enhanced with these technologies as they enable the use of back-side

interconnect in module assembly. Specialized module assembly equipment is a specialty of Eurotron. Canadian Solar is also developing heterojunction intrinsic thin-layer cells and tandem junction cells that could see conversion efficiencies top 20%; however the company said that this could take several years to develop and enter production.

JA Solar working to commercialize Innovalight's silicon ink technology in 2010

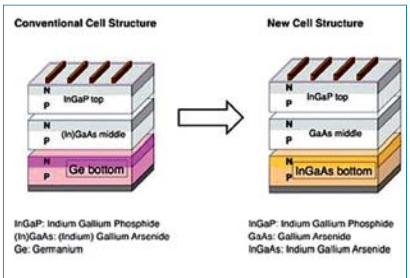
With a demonstrated and verified conversion efficiency of 18%, Innovalight has found a commercial partner in the form of JA Solar, which intends to use the ink technology and equipment required to enter volume production by the end of 2010. JA Solar said that is was already developing silicon ink-based high efficiency solar cells (on silicon) at its R&D pilot line in Yangzhou, China.

Innovalight has partnered with several equipment suppliers this year, notably Roth & Rau and OTB Solar, in an effort to have the tool and process infrastructure in place for future commercialization. The company said in 2007 that its liquid silicon process has the potential to reduce cells costs by more than 50% and expected commercial production of the ink to begin in 2009.

Efficiency News Focus

Sharp accomplishes 35.8% solar cell efficiency

Sharp has released reports of a solar cell conversion efficiency that reaches 35.8% using a triple-junction compound solar cell. The company reached its breakthrough as part of a research and development initiative supported by Japan's New Energy and Industrial Technology Development Organization on the theme of "R&D on innovative solar cells". Contrasting from the common used silicon-based solar cells, the compound solar cell uses photo-absorption layers, which are made from a composite of two or more elements such as indium and gallium. For the past nine years, Sharp has been researching and developing a triple-junction compound solar cell that reaches high conversion efficiency by stacking three photo-absorption layers.



Sharp's triple-junction compound solar cell.

When it comes to triple-junction compound solar cells, to improve their efficiency it is important to enhance the crystallinity in each photo-absorption layer. It is equally vital that the solar cell be made of materials that can maximize the effective use of solar energy. In the past germanium was used as a bottom layer because of its ease of manufacturing, but while germanium produces a large amount of current, the majority of what is produced is wasted and therefore not effectively used for electrical energy.

Sharp solved this problem by forming the bottom layer from indium gallium arsenide (InGaAs), a matter with high light utilization efficiency. While the process to make such an efficient bottom layer from InGaAs with high crystallinity was difficult, Sharp did just so by using its technology for forming layers. This resulted with the total wasted current being diminished while the conversion efficiency, which had previously been 31.5% in Sharp's cells, to be increased to 35.8%. The 35.8% conversion efficiency was confirmed by the National Institute of Advanced Industrial Science and Technology this past September.

1366 Technologies' cells entering a POCL3 furnace.

1366 Technologies unveils texturing, metallization schemes for more efficient multicrystalline cells

Silicon photovoltaics developer 1366 Technologies has come out with a pair of cell texturing and metallization technologies as part of its self-aligned cell architecture that the company believes will help deliver simpler, more commercially viable solutions for multicrystalline-silicon solar cell manufacturers looking to reach conversion efficiencies of 18%. The two innovations can be easily integrated into existing manufacturing lines, according to the Massachusetts-based company.

The first technology deals with cell texture, creating a distinctive honeycomb structure that introduces cross-textured surfaces to the cell that trap more light and enable up to 1% higher absolute efficiency overall than previous cell designs.

The second focuses on the front-side cell metallization, where the company has developed the world's finest metallization lines – just 30µm compared to the prevailing 120µm – and an innovative grooved ribbon busbar, which is licensed by Ulbrich and Schlenk.

Industry-standard thick fingers and flat busbars typically shade 9% of the surface of a cell. 1366 says that its front-side metallization approach only shades 2% of the cell, delivering 75% of the efficiency gains of back-contact cell designs without the high costs and process complexity. Earlier this year, 1366 won a cost-shared subcontract worth up to US$3 million for the development of its self-aligned cell approach, as part of the U.S. Department of Energy's Solar America Initiative.

Q-Cells to roll-out polycrystalline cells with 17% conversion efficiency in 2010

As part of its new strategy to focus greater effort and resources on technological advancements of its solar cells, Q-Cells will be launching a polycrystalline cell with a conversion efficiency of 17% in 2010, using existing production lines. The cells were developed at Q-Cells new €50 million 'Technikum' pilot line in Thalheim, Germany. Q-Cells claimed this was a new efficiency record for polycrystalline cells. The Fraunhofer Institute for Solar Energy Systems (ISE) has tested and certified that modules using the high-performance cells achieved efficiency of 15.9% and an output of 249W. Q-Cells also said that when the development phase has been finished further increases in the efficiency rating are expected when volume production is started.

BP Solar, IMEC Mono² silicon cell demonstrates 18% efficiency

IMEC and BP Solar have demonstrated 18% conversion efficiency for silicon solar cells developed using BP Solar's Mono² silicon. IMEC's processing techniques and BP Solar's low-cost substrates make it possible to produce a solar cell that is both efficient and low in price. The production process used by BP Solar for the Mono² offers a cheaper alternative to the more expensive Czochralski silicon substrates, as it offers low defect densities and high conversion efficiencies with production costs that are comparable to the costs of multicrystalline substrates.

The production of Mono² involves three extra processing steps to the standard industrially applied process of full aluminum back surface field, making it plausible to manufacture. This process involves a proprietary growth nucleation process for the casting of ingots used to produce single crystal bricks and wafers whereby preferred crystallographic

Amtech subsidiary receives multiple orders for diffusion processing equipment

Amtech Systems' solar subsidiary, Tempress Systems, has received a follow-on multi-system order for its diffusion processing equipment from an existing customer in Asia. The order for multiple systems is expected to ship by summer 2010.

The company also shipped one of its diffusion furnace systems to a solar research institute in Asia. A second system is set to be shipped in the March 2010 quarter to a solar research institute in Australia. Both orders were received in the 2009 fiscal year.

Manz Automation gains €5 million in bookings from EU PVSEC

In attending the 24th European Photovoltaic Solar Energy Conference and Exhibition in Hamburg, Manz Automation has said that it has secured orders and orders of intent worth €5 million. Manz expects the orders to be recognized in revenues and earnings in the coming fiscal year.

At the event held in Valencia last year and before the economic crisis was fully revealed, Manz has secured €20 million in direct new orders from the event. However, Manz noted that with its strategic alliance partner Roth & Rau, they had one of the largest stands at the exhibition and demonstrated three new thin-film and three new crystalline products at the event.

Despatch Industries ships first UltraFlex furnace to SERIS

Adding to its tally of over 8GW of firing furnaces shipped to customers worldwide, Despatch Industries has been tapped by SERIS (Solar Energy Research Institute of Singapore) for the first shipment of its fast firing furnace, the UltraFlex, which features Microzone Technology. SERIS will use the furnace with its R&D manufacturing line.

The company claims that the state-of-the-art dryer and firing furnace offers next-generation capabilities in performance, profile flexibility and reduced cost of ownership. The Microzone technology features special lamps configured to allow for tight control and is said to increase profile flexibility independent of belt speed.

Veeco's TurboDisc qualifies for CPV cell production at Azur

Azur Space has successfully qualified Veeco Instruments' TurboDisc Arsenic Phosphide (As/P) MOCVD system for use at its site. The system will be used for the production of CPV solar cells for terrestrial applications, and is reportedly the first of several TurboDisc systems to be installed at Azur's Heilbronn, Germany facility.

Applied Materials buys assets of Advent Solar: Emitter-Wrap Through technology provider

The struggling start-up, Advent Solar, which had already closed its solar module manufacturing line, conducted several rounds of layoffs and shifted its business model to Intellectual Property (IP) provider, has been acquired by Applied Materials for an undisclosed sum. Applied said that the assets of Advent Solar would be integrated with Applied's Energy and Environmental Solutions Group.

Advent had been started by a number of ex-Intel Corp engineers and managers, many coming from Intel's Albuquerque, New Mexico semiconductor facilities, where Advent was established in 2002. The start-up had developed several innovative module assembly techniques that were designed to improve the overall conversion efficiency of the finished model as well as reduce manufacturing costs compared to conventional process steps. The company had in particular developed what it claimed was the PV industry's first cell-to-module solar architecture – 'Ventura Technology.'

The Ventura Technology was said to design a platform-level design by combining Emitter-Wrap Through (EWT) back-contact cells with semiconductor device manufacturing methods, helping to eliminate efficiency losses inherent in string-ribbon processing to the final module power generation. Also by eliminating the front grid, more sunlight was made available for electrical conversion. The technology was also under development to be used for Upgraded Metallurgical Silicon (UMG).

Energy Focus signs $100,000 contract for solar research

Energy Focus signed a 12-month US$100,000 contract with DuPont-University of Delaware Very High Efficiency Solar Cell (VHESC) consortium as part of a defense advanced research projects agency (DARPA)- funded effort for the delivery of advanced solar research for high efficiency, low-cost photovoltaics. DARPA is creating the VHESC solar module technology for compact renewable energy power for permanent and mobile bases. It also intends to reduce the logistical conundrum of providing energy, such as batteries and fuel, to the U.S. military in the field.

The modules that are being developed by the VHESC team use an optical "spectrum splitting" system, which takes light from the sun into different paths corresponding to the colour of the light and in turn focuses the light onto PV cells that cover distinctive segments of the solar spectrum. DARPA and the VHESC recently entered the second two-year phase of the four-year program, which aims to raise the system power efficiency of a new class of solar modules to 40% and deliver engineering prototype modules that can be promptly put into production.

NREL selects Synopsys' solar cell simulation package

The U.S. National Renewable Energy Laboratory has adopted Synopsys' Sentaurus TCAD package for simulating solar cell characteristics to improve performance.

The simulations provide NREL scientists with valuable insight into the physical mechanisms that drive solar cell performance, thereby supporting the development of more efficient solar cell designs. The simulations include the definition of the solar radiation incident on the cell, its reflection and transmission through antireflective coatings and surface texturing, and the absorption of the light and conversion to electrical current within semiconductor regions of the cell.

"Solar cells are very complex, with many material layers and design trade-offs affecting major performance metrics such as efficiency," said Dean Levi, a principal scientist at NREL. "We view simulation as an important tool to understand the internal physics of our designs and to point toward ways to improve them."

NREL recently implemented Sentaurus to create polycrystalline thin-film CIGS, CdTe, and silicon solar cell models. These models have illustrated how material properties, grain boundaries, nonuniformity, and interdigitated designs affect both device performance and characterization.

"The photovoltaic industry is experiencing tremendous growth and continues to drive toward higher efficiency and innovative solar cell designs," said Howard Ko, GM/senior VP of the silicon engineering group at Synopsys. "Our Sentaurus TCAD tools offer many capabilities to simulate solar cell operation and performance characteristics to guide design improvements. Having NREL as a user of our tools enables us to better understand the challenges and new directions of the fast-changing photovoltaic field." Earlier this year Synopsys said it had established a relationship with the Solar Energy Research Institute of Singapore, its first public disclosure of a customer in this arena.

orientations can be achieved. This feature allows further improvement in cell efficiencies. BP Solar's Mono² was developed with support of the U.S. Department of Energy's Technologies Pathways Partnership.

RoseStreet Labs Energy demos first nitride/silicon tandem solar PV cell

RoseStreet Labs Energy says it has demonstrated the first known nitride/silicon tandem solar cell. Using the same nitride material technology as solid-state lighting and blue lasers, the Phoenix-based company fabricated and tested a working photovoltaic device that couples a silicon cell with a nitride thin-film.

RSLE says the hybrid cell should achieve practical conversion efficiencies of 25-30%. The company, which has a 0.5MW pilot line featuring a molecular beam epitaxy (MBE) tool, plans to begin production of this technology in the fourth quarter of 2010. The company (a unit of RoseStreet Labs) explains that its proprietary full spectrum technology is primarily based on nitride alloys, specifically indium-gallium-nitrides, which have a direct bandgap spanning almost the entire solar spectrum. Their large absorption coefficients facilitate the complete absorption of the photons in PV devices with a film thickness of 1μm.

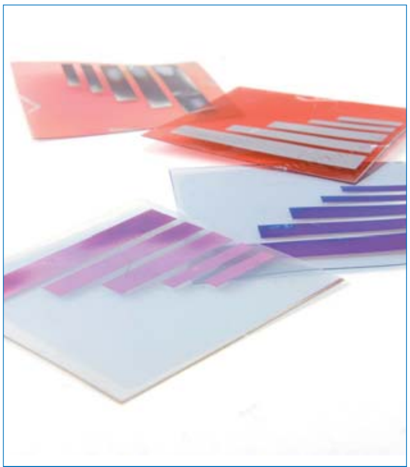
IMEC demonstrates solution-processed organic cell with spray-coated active layer

Alongside the news of IMEC and BP Solar's 18% Mono² silicon cell efficiency, IMEC has demonstrated a fully solution-processed organic solar cell with a spray-coated active layer and a metal top contact spray coated on top. The organic cell shows power conversion efficiencies above 3%, a performance comparable to organic solar cells produced by spin coating of the organic layer and vacuum evaporation of the top contact metal. This news marks an important step towards producing organic solar cells with cheap and large-area processes.

IMEC is working towards the promise that polymer-based, organic solar cells can achieve low-cost production and a high throughput. However, this can only be attained if all the layers of the cells can be deposited by solution-based, in-line compatible methods. IMEC's latest research shows that spray coating is a suitable deposition technique, and that it can be used to deposit all layers, including the metal top contact. IMEC has demonstrated that an active layer – a solution of P3HT and PCBM – deposited with spray coating shows power conversion efficiencies above 3%, a performance that is comparable to that of spin-coated devices.

For the metal top contact, IMEC spray coated a solution with silver nanoparticles. The difficulty lies in achieving this without dissolving the underlying layer, and without damaging it by the temperature needed to sinter the silver nanoparticles.

IMEC demonstrated that spray coating reduces the damage to underlying layers quite significantly compared to other techniques. The company was also able to sinter the silver nanoparticles at 150°C, a temperature that is compatible with processing on flexible substrates.



Source: IMEC

IMEC organic photovoltaic cells.

Product Briefings

Rehm Thermal Systems

Rehm's Visu2 software enables greater efficiency and yield in solar cell metallization

Product Briefing Outline: The RFS and RFS-D Fast Firing Systems and the RDS 2100 and 3000 drying ovens feature Rehm Thermal Systems' Visu2 software, which drives a range of advanced process features and thermal control to enable PV manufacturers to move their processes to greater levels of efficiency and yield. Visu2 incorporates process and product traceability tools, remote diagnostics and an extensive product library within an intuitively designed interface that is claimed to dramatically accelerate set-up time and reduces operator training.

Problem: PV manufacturers require increasingly detailed traceability of the process steps in order to increase efficiency and yield.

Solution: Process and product traceability are supported via barcode and data recording of all relevant process parameters with time stamps. With its CCS (Capability Control System), Rehm Thermal Systems offers the ability to monitor process capability during the production process. CCS is based upon the measurement of temperatures in all of the oven's heat zones for each individual cell, as well as measurement of conveyor speed. The system automatically translates the data into control charts where both momentary results and long-term trends are displayed as graphics. Extensive system documentation is available with a few keystrokes, and Visu2 offers password-protected security levels as well as multilingual operations, data recording and maintenance logging.

Applications: Solar cell metallization.

Platform: A complete lineup of thermal solutions for metallization now includes the RFS Firing System and RFS-D combination Drying and Firing System in addition to the model RDS series dryers.

Availability: Currently available.

Despatch Industries

Despatch Industries' UltraFlex dryer and firing furnace employs Microzone technology

Product Briefing Outline: Despatch Industries has introduced the 'UltraFlex' dryer and firing furnace with 'Microzone' Technology. This new tool is designed to provide next-generation capabilities in performance, profile flexibility and reduced cost of ownership.

Problem: Crystalline silicon solar cell manufacturing cost per Wp can be lowered by increasing production volumes and yield, producing higher efficiency silicon solar cells and by reducing silicon usage through reduced wafer thickness. Because silicon and aluminium have different thermal expansion coefficients, a bow is created in the wafer during the high temperature firing process. Tradeoffs in efficiency, breakage and yield have slowed the industry's natural migration to thinner wafers.

Solution: Despatch Industries has taken its current dryer and firing furnace and reengineered it from top to bottom to create a smarter, more efficient tool with a smaller footprint and a first-of-its-kind configuration. The UltraFlex system has a redesigned airflow system for increased efficiency. Despatch also developed new custom lamps that operate at optimal levels for extended life and enable maximum absorption of energy into each cell. Microzone lamps are configured to create the sharp divisions and tight control necessary to adapt to the industry's ever-changing pastes and cell architectures.

Applications: Crystalline solar cell metallization firing.

Platform: The UltraFlex incorporates the company's patented, push-button chamber design, and now features a smooth, easily cleanable interior to minimize maintenance time. The system can also achieve rapid thermal ramping and cooling rates of up to 200°C per second to create precise profiles and intervals above critical temperature thresholds. A new, patent-pending V_{OC} Thermal Oxidizer is integrated into the dryer to provide virtually maintenance free elimination of V_{OC}s at point-of-generation.

Availability: Currently available.

Essemsolar

Essemsolar's full convection oven for drying and curing processes at laboratories

Product Briefing Outline: Essemsolar is launching the new RO300FC-S full convection oven for drying and curing processes. The oven features a compact design, excellent process control and very small delta-T values that make the machine ideal for small batch manufacturing or process development in laboratories.

Problem: The RO300FC provides similar process conditions as larger ovens but in smaller dimensions. The oven can even be operated with nitrogen if a process requires an oxygen-free atmosphere.

Solution: RO300FC-S offers excellent process conditions for the manufacturing of high-quality products. The heating technology is 100% pure hot air convection – any infrared radiation is shielded from the substrates. Due to highly sophisticated air guidance inside the process tunnel, heat distribution is exceptionally homogeneous: Delta-T values are below 4°C all over the oven's width. In transport direction, three heating and one cooling zone ensure a proper temperature profile. The exact zone regulation enables profiles of a rectangular shape. The process width measures 300mm, with a 400mm transport width. The conveying speed is programmable. Depending on the installed drive configuration, the range spans from 2 to 180, 10 to 300, or 100 to 800mm/min. The transport system is optimized for handling sensitive substrates and devices. Chain or mesh belt conveyors are available. An SMEMA interface simplifies the integration into production lines.

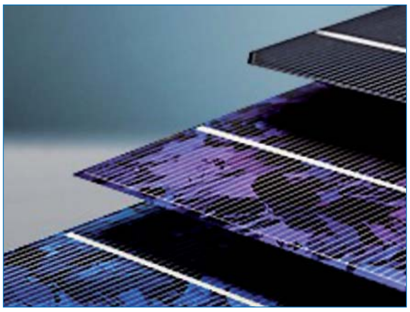
Applications: Drying and curing applications in laboratories.

Platform: It features a compact design and a footprint of only 2.00 x 0.71m, making the machine ideal for small batch and prototype production or laboratory applications.

Availability: Currently available.

Product Briefings

Heraeus



New front-side silver paste from Heraeus provides high printed aspect ratio for greater cell efficiency

Product Briefing Outline: The Photovoltaic Business Unit of Heraeus has developed a new front-side silver paste that is claimed to offer higher efficiencies along with superior contact quality and aspect ratios on both mono- and multicrystalline wafers and a wide range of sheet resistance emitters. The cadmium-free silver metallization paste (SOL9235H) is the newest in the series of Heraeus products introduced each year for the photovoltaic cell manufacturing market.

Problem: Silver thick-film contact paste is screen-printed on the ARC and forms a contact with the emitter after reacting with the ARC during contact firing. Correct aspect ratio and fine line resolution are required for optimum cell efficiency.

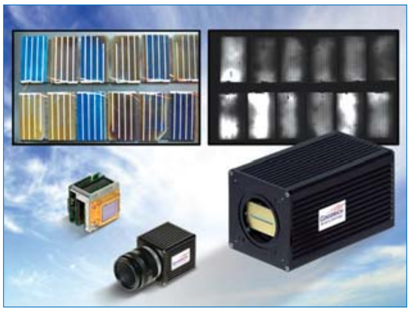
Solution: SOL953 is a front-side Ag conductor for mono- and multicrystalline silicon solar cell wafers with low-doped emitters. Optimized for high throughput processing, SOL953 provides fine-line (80-150µm) resolution for advanced cell designs. It easily penetrates the SiN_X:H anti-reflective coating during the firing process and provides low contact resistance. SOL953 can be co-fired with commercially available backside Al and Ag/Al pastes. Heraeus claims that customers who tested this new front-side paste during the development and scale-up phase reported increases of cell absolute output efficiencies in the 0.2 to 0.4% range. The paste also provides a very high printed aspect ratio feature.

Applications: Front-side Ag conductor for mono- and multicrystalline silicon solar cell wafers.

Platform: SOL953H paste is typically dried in an IR dryer with set points of 250-300°C in less than 20 seconds or 150°C for 10 minutes in a circulated air oven. It is fired in an IR Furnace with Actual Wafer Peak Temperature at 740-800°C. Material is guaranteed to meet specifications for 6 months from date of shipment.

Availability: Currently available.

Sensors Unlimited



Sensors Unlimited's SWIR-based cameras detect wafer defects and cell efficiencies

Product Briefing Outline: Sensors Unlimited's high resolution, shortwave infrared (SWIR) area and linescan cameras are being used to improve the manufacturing yield of photovoltaic cells. SWIR technology monitors the quality of solar thin films, concentrated PV and crystalline cells, to maximize efficiency of the solar cell manufacturing process through final assembly of the completed modules.

Problem: The wafering process can cause defects, hidden cracks or saw marks inside or on the opposite side of the wafer.

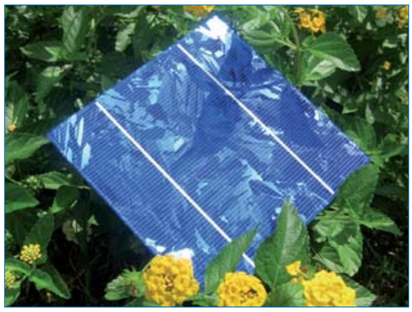
Solution: The InGaAs-based SWIR cameras, which operate between 0.9 to 1.7 microns, are ideal for inspecting silicon boules and wafers due to the material's transparency beyond 1.2 microns. The Goodrich cameras reveal voids in silicon boules, bricks, and ingots before they are sliced into wafers to produce mono- and multicrystalline solar cells. They can also detect hidden cracks by mapping stress in raw wafers, finished cells, and thin films made for solar electricity generating panels. SWIR cameras can also spot saw marks on the opposite side of a silicon wafer and/or defects inside the material. In addition, by applying forward bias to cells to generate electroluminescence, the SWIR cameras are used to gauge cell efficiency and uniformity. This aids improvement of cell manufacturing processes, and aids matching cells with similar efficiencies for assembly into modules.

Applications: Inspection of ingots, bare wafers and solar cells.

Platform: Both Goodrich linescan and area cameras can be used for photoluminescence inspection of photovoltaic solar cells. The area cameras provide convenient still images while the digital high-speed, 1024 pixel line cameras are ideal for providing higher resolution at lower cost when used with continuous production flow or with moving inspection stages.

Availability: Currently available.

DuPont Microciruit Materials



DuPont new lead-free front side metallization material gives improved electrical performance

Product Briefing Outline: DuPont Microcircuit Materials has launched 'Solamet' PV173 photovoltaic (PV) metallization paste, a new lead-free front side material for crystalline silicon solar cells. With its high performance and superior environmental properties, Solamet PV173 is targeted to PV cell and module manufacturers who are seeking technologies with a significantly reduced environmental footprint.

Problem: The aim is to develop narrower and taller grid lines that will precisely print in two or more layers, which allow more cell surface area, boosting cell efficiencies, while reduced environmental footprint of the process. Improved material performance is important while maintaining compatibility with other materials, especially in high-volume cell and wafer production environments.

Solution: Solamet PV173 is compatible with standard PV cell manufacturing processes, and features excellent electrical performance on both mono- and multi-wafers for flexible wafer selection. Solamet PV173 provides high adhesion, superior print speed, and enables advanced fine line designs down to 80 microns. It is also compatible with DuPont Solamet PV502 and PV505 tab silver pastes, and PV38x aluminum pastes, which are also lead-free.

Applications: Crystalline silicon solar cell metallization processing.

Platform: Lead-free silver paste.

Availability: Currently available.

Product Briefings

Xiris Automation

PVCI-1500 machine vision system from Xiris Automation tackles defect inspection of c-Si cells

Product Briefing Outline: Xiris Automation has released the PVCI-1500 Machine Vision Platform, targeted at crystalline silicon cell and wafer inspection. Optimized for inspection of solar cells as an incoming single-pass quality check, the PVCI-1500 combines specially designed optical components with fast analysis software, ensuring precise detection and classification of physical defects arising from shipping and handling.

Problem: In the final selection of cells to be assembled into modules, quality control checks are required to ensure that cells with cracks, pinholes, edge defects, geometry variances, global and localized colour variances and other visible surface anomalies are captured and binned.

Solution: Using a combination of visible and non-visible illumination sources and a unique single optical path dual-camera system, the PVCI-1500 can be configured for many common inspection requirements including crack detection, edge defect detection, surface inspection, print inspection, colour binning and colour homogeneity. Modular System design allows for performing standardized inspections in a single pass, reducing process variation and the need for multiple inspection stations. High Resolution Area Scan cameras allow for consistent measurement of solar cells in any orientation.

Applications: Crystalline silicon cell and wafer inspection.

Platform: The PVCI-1500 is initially offered in two variants: a low-cost configuration with high powered back illumination, front illumination and a high resolution monochrome camera targeting incoming cell inspection for module manufacturers; and a feature-rich version which adds multi-angle front illumination and an accurate colour camera to support cell classification.

Availability: Currently available.

BASF and Schmid

New laser transfer printing process from BASF and Schmid increases efficiency in wafer production

Product Briefing Outline: BASF and Schmid have together developed a new, contact-free laser transfer printing (LTP) process for metallizing the front and back of solar cells. At present, screen-printing is the most commonly used process for metallization. This printer and paste system is based on a contact-free laser process and not only offers customers advantages with regard to handling, but also increases the efficiency of cell production.

Problem: There is always a need in the industry to reduce cracking rates in ultra-thin solar cell production, while boosting performance and simplifying handling.

Solution: The LTP PV 1500 laser transfer printer was developed by the Schmid Group to completely replace the existing screen-printing process. It can be used for coating both the front of solar cells with silver and the backs with aluminium and aluminium/silver. The system can be integrated into existing production lines and is suitable for all types and sizes of cells. The LTP printer achieves a throughput of 1500 wafers per hour and works without actual contact to prevent any mechanical stress on the wafers. A wafer is held in place on a vacuum conveyor and then passed through under the laser, which then separates the metallization paste from the carrier film and transfers the paste to the wafer. The paste on the film is constantly replaced cyclically, while an integrated ink supply with viscosity control ensures that pastes with different compositions can be used.

Applications: Front- and back-side solar cell metallization.

Platform: BASF will be offering customized metallization pastes for mono- and multicrystalline solar cells that are designed specifically for the new LTP process and can also be used in conventional screen-printing. The portfolio will comprise both silver pastes for front-side printing and aluminum-based pastes for printing of back sides.

Availability: Market launch is planned for early 2010.

Schmalz

Schmalz's Wafer-Gripper SWG offers non-contact wafer handling

Product Briefing Outline: The Schmalz Wafer-Gripper SWG is applied in fully- or partially-automated production of highly sensitive wafers and solar cells with maximum process stability. A new handling concept provides minimum cycle times, precise positioning, reliable handling even of deformed and broken parts, breakage detection 'on the fly' and controlled air discharge.

Problem: The current technology for handling wafers and solar cells utilises conventional vacuum grippers or floating suction pads employing Bernoulli's principle. While conventional vacuum grippers allow robust handling, chemical contamination and high mechanical strain occur at contact surfaces.

Solution: Schmalz's offering grips the entire surface of the wafer without leaving a mark. Hundreds of suction holes reduce the stress impact on wafers to a minimum and avoid micro cracks. At the same time the SWG is said to meet the highest requirements with respect to acceleration and process speed. The large contact area between wafer and gripper with maximum holding force allows complex and high-speed handling cycles below one second without slippage. The large contact surface provides reliable gripping even of deformed and broken wafers, which ensures maximum process stability. Since the pressurized air and ultra-small particles are completely extracted, production can be carried out under cleanroom conditions.

Applications: Wafer pickup from stacks and belts, loading of tabber/stringers, sorting, high accuracy positioning during and after the visual inspection process and other tasks.

Platform: The Wafer-Gripper is available with suction surface geometries for the standard cell sizes of 125mm and 156mm. The contact surface made of PEEK (Polyetheretherketone), vacuum generator, blow-off unit, robot interface, sensors and optional features are of modular design.

Availability: Currently available.

Achievements and challenges in two-step metallization processes for crystalline silicon solar cells

Jonas Bartsch, **Christian Savio**, **Matthias Hörteis** & **Stefan W. Glunz**, Fraunhofer Institute for Solar Energy Systems (ISE), Freiburg, Germany

ABSTRACT

One-step screen-printing processes are still the most widely-used technique for the front-side metallization of crystalline silicon solar cells in the PV industry. This is because of the knowledge, stability and speed of the process, and despite some big disadvantages exhibited by the resulting contacts (relatively low conductivity and aspect ratio). Therefore, the metal contacts of high-efficiency laboratory cells are usually produced via advanced two-step metallization processes, which allow the application of optimized contact structures. In a first step, a narrow metal layer is applied to form the contact to the silicon wafer. Several different techniques have been developed for this first stage. In the second step, the seed layer is reinforced electrochemically with a dense layer of a metal of high conductivity, usually by light-induced plating. The transfer of such techniques into industrial scale has been pursued intensively, and may enter solar cell production lines in the near future. However, the process can still be improved based on a better process understanding, in order to benefit from the full potential of the technology.

Introduction

Industrially manufactured crystalline silicon solar cells still offer a lot of potential for economical and technical optimization. A standard solar cell which is produced on a monocrystalline wafer in a state-of-the-art production line will result in an efficiency of 17-18%, whereas laboratory cells will yield values greater than 20% on comparable material. However, the process used for the latter is usually much more complicated, expensive and in many cases not suited for the industrial scale. The transfer of laboratory cell technology into production lines with industrially viable processes is therefore desirable.

Many of the differences between such cells are due to their front-side structure. The laboratory cell collects the incident light much more effectively than the industrial cell. This is achieved by superior texture, low doping and a well passivated emitter, but even more importantly by a reduced amount of metallized area. This approach is very straightforward; the more light actually reaches the silicon surface, the better the efficiency will be, relatively independent of the substrate quality or other cell features. Typically, the very fine structures needed for these features will be produced by photolithography (Fig. 1).

"As the used pastes contain organic compounds and a glass frit system to enable the contact formation of the silicon substrate during the firing step, the metal lines are porous and feature a relatively low conductivity."

Industrial silicon solar cells are almost exclusively metallized by screen-printing and firing of metal pastes in current practice. The process is robust, well known and requires only two overall steps. The share of metallized area on these cells will typically be 7-10% of the total cell area (about 3-4% for a lab cell). Due to the limitations of the technique, a further noteworthy reduction of this value will be very difficult to achieve. As the used pastes contain organic compounds and a glass frit system to enable the contact formation of the silicon substrate during the firing step, the metal lines are porous and feature a relatively low conductivity. To lower the electrical losses caused by the series resistance of the metallization to an acceptable level, these contacts must consequently have a large cross-section. This demand becomes more pronounced with increasing cell areas (meaning longer distances between the busbars). As the aspect ratio of the contacts is limited

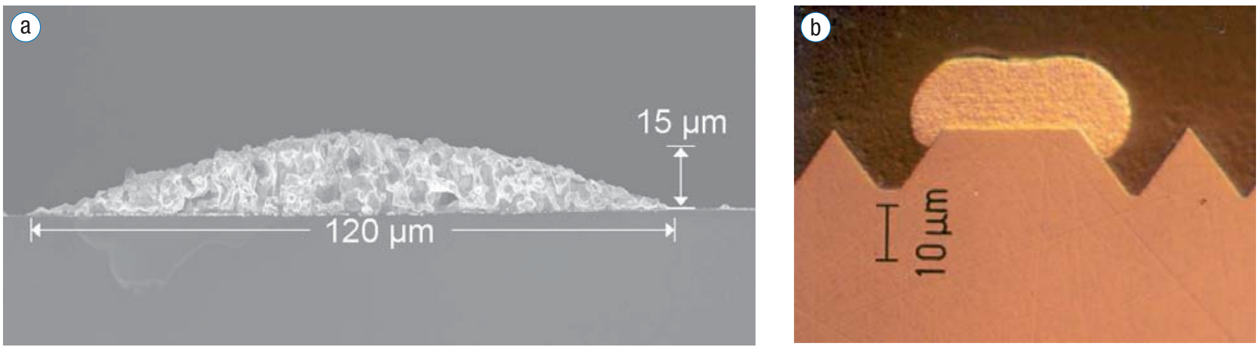


Figure 1. Cross-section of standard screen-printed solar cell contact, typical for industrial production (left) and lab-type solar cell front side, structured photolithographically (right).

due to the printing techniques and the rheological properties of the metal pastes, this is at the expense of increased shading.

Novel metallization techniques are needed, for which the well-known laboratory processes can be used as guidelines. The latter usually comprise two steps: a very fine seed layer is first evaporated onto the wafer (which is usually structured photolithographically), and then reinforced electrochemically with a dense and highly conductive metal layer in a second step, mostly by light-induced plating. The conductivity and aspect ratio of these contacts are much higher. Optically, the shading is reduced even below the geometrical shading of the contacts, as the roundly shaped and bright contact reflects light onto the cell surface directly or via the encapsulation glass [1]. Furthermore, as the seed layer can be optimized separate from the conductive layer, the contact resistance may also be reduced. The reduced area of silicon-metal interface leads to less recombination in the emitter. Also, the use of copper instead of silver as the conducting material, together with a diffusion-preventing seed layer (e.g. nickel) has the potential to drastically reduce the metallization costs [2].

A transfer of this technology into industrial scale requires seeding technologies independent of photolithography. Several suitable techniques have been developed and transferred into industrial scale in the past few years [3, 4], such as fine-line screen-printing [5], metal aerosol-printing [6], metal inkjet-printing [7], and recently thick-film stencil-printing [8], which are all based on the direct printing of metal pastes or inks onto the cell and the contact formation in a firing step. Other techniques, like electroless nickel plating [9] or high-rate inline evaporation processes of different metals [10] make contact in a thermal step at moderate temperature and need an additional step for the structuring of the cell. This can be performed by laser ablation [11] (for electroless plating) or inkjet-masking [9], for example. With the exception of screen- and stencil-printing, all mentioned seeding techniques are contactless, which simplifies wafer handling and may increase yields, especially for ever thinner wafers entering the production lines. Together with the development of devices for industrial-scale plating of solar cells [12] for the second step, the process is ready to enter industrial production lines.

Potential of plated contacts regarding conductivity

As mentioned, the conductivity of screen-printed contacts is limited because of their porosity. Electrochemically deposited layers have the potential to reach the conductivity of the bulk material that is plated. This is achieved if the deposit is dense, homogenous and shaped in such a way that all of the material contributes to the conduction. In practice, the conductivity of bulk silver is difficult to achieve.

The properties of the metal layer depend much on the chemical basis of the process. In an experiment, we compared several electrolytes for silver deposition regarding the conductivity of the plated contacts. For comparison, we used an electrolyte which has been long been used industrially and is consequently very well optimized. This cyanide-based (CN) electrolyte is also used for contacts of high-efficiency cells, where conductivity values close to bulk silver could be achieved. However, alternatives are necessary to the PV industry as the CN electrolyte is very toxic. The two other electrolytes were commercially available solutions on a different chemical basis. After measuring the contacts "as plated", a tempering step was carried out to check for any positive influence on the contact properties (e.g. by micro-sintering of grain boundaries).

As can be seen in Fig. 2, the first tested electrolyte (NCN1) gave only moderate conductivities and required a tempering step to achieve a value comparable to a very good screen-printed contact. This additional step would make the process less attractive. Using a different commercial electrolyte (NCN2) led to far better results, even before the thermal treatment. Conductivities close to the high-efficiency reference could be achieved in an industrial inline machine. The differences can be

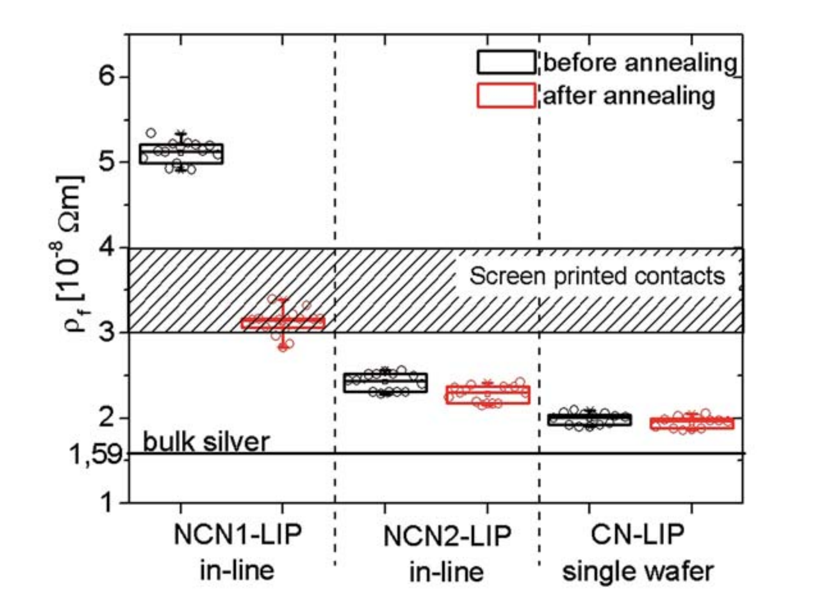


Figure 2. Conductivity of solar cell contacts plated with different electrolytes.

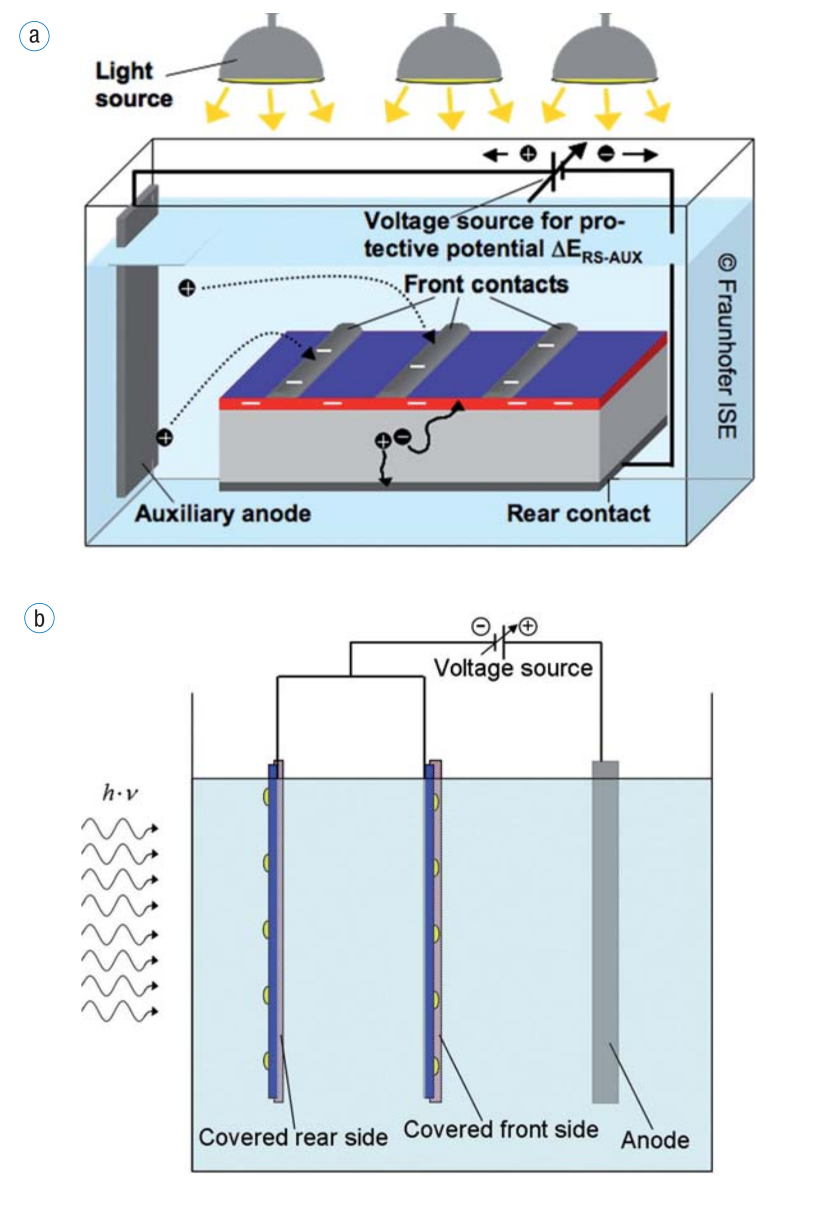


Figure 3. Usual setup for light-induced plating (top) and setup for the separated consideration of rear-side and front-side processes (bottom).

explained by the different microscopic contact structures [13].

Seeding technologies and plating behaviour

Most investigations on the plating process so far have been carried out on screen-printed or fine-line screen-printed seed layers [14, 15]. It has been shown that significant efficiency gains can be achieved compared to one-step screen printed contacts, even despite the fact that the initial contacts still feature most of the same unwanted properties. The full benefit of the two-step process will only be obtained using narrow advanced seed layers, which make the contact to the silicon, while the conduction is realized by the dense plated metal layer.

The conditions needed to achieve metal layers of high quality for plating processes depend on the properties of the used substrate, and are very different for various materials and seeding technologies. For plating, the current density (current per metal surface area) and the local field density play key roles.

The current density can be estimated with the metal area and the current. However, the current over the front side is not accessible by direct measurement. We developed an experimental setup to measure it indirectly, via weight gain [16]. This setup enables a separate consideration of the rear and the front side of the solar cell (Fig. 3, bottom). The difference in current density for such contacts has been calculated to be of a factor of approx. 1.1 for early stages of the deposition and up to 1.9 in the maximal case, compared to current densities on screen-printed seed layers [17].

Fig. 4 shows silver disc electrodes that have been plated at different current densities in the electrolyte also used for silver deposition onto solar cells. The plating conditions have been controlled galvanostatically. The effect of the increasing current density on the deposition quality is clearly visible.

The local field density is difficult to quantify, but qualitatively, the different seed layers show important differences. Thick-film seed layers like screen-printing are relatively wide and shaped like a segment of a circle, with a relatively smooth, porous surface. The texture of the silicon substrate is levelled out by the seed layer. In contrast, very thin seed layers (e.g. aerosol-printed metal lines) keep the surface features of the silicon substrate. This is expected to lead to locally increased field densities, especially at sharp edges, which will result in higher local deposition rate and possibly disordered growth.

Experimental results

To experimentally validate these expectations, we made a series of experiments on two different seed layers. Test cells (5 x 5cm²) were created on

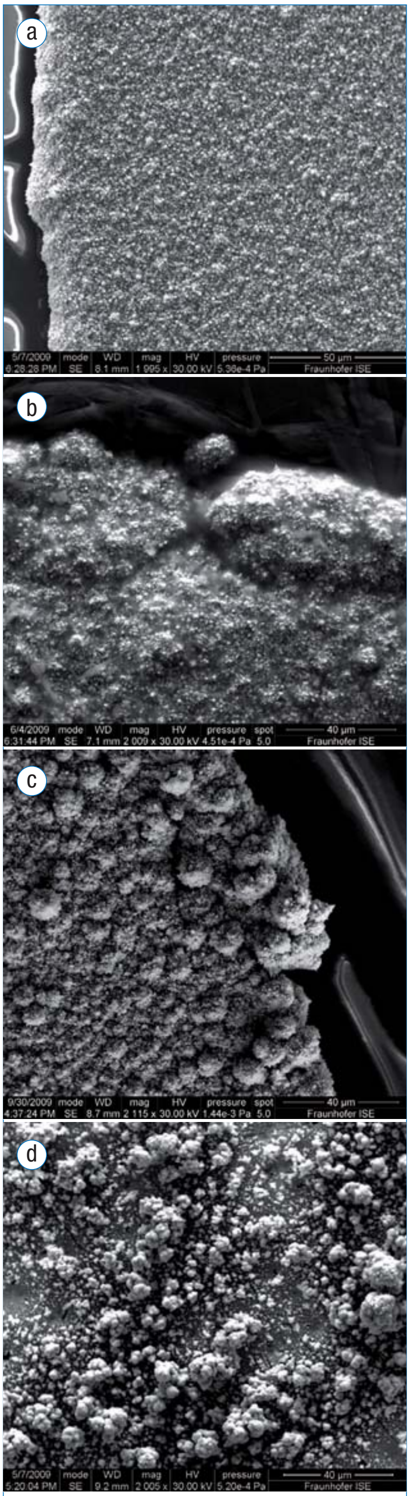


Figure 4. Silver disc plated at current densites of 0.6, 2, 4 and 6A/dm^2 (from top to bottom).

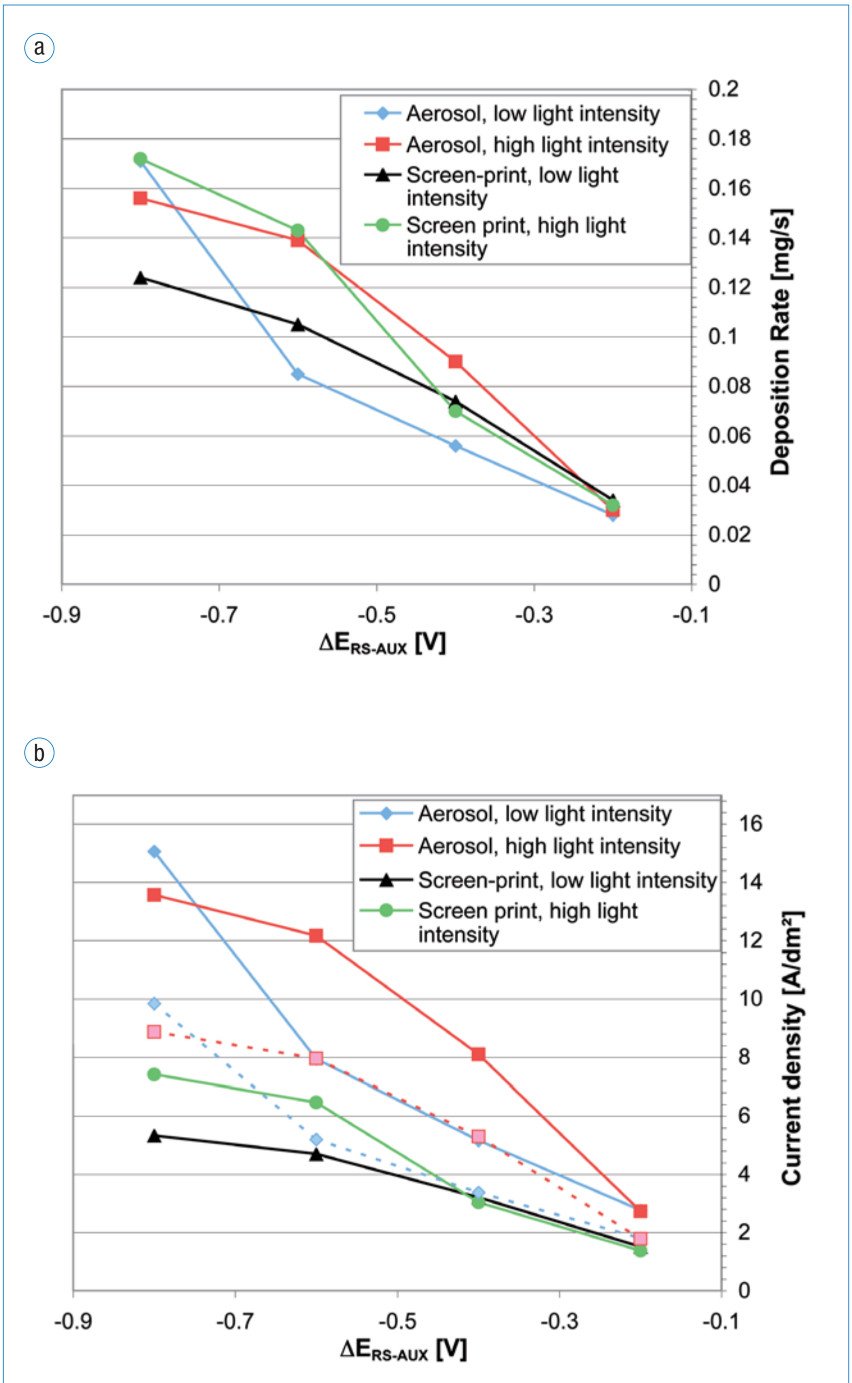


Figure 5. Deposition rates (top) and current densities (bottom) for different plating conditions (light intensity, $\Delta E_{RS\text{-}AUX}$).

monocrystalline precursors (55Ω/sq sheet resistance, random pyramid texture, SiN_X-ARC, full rear-side Al-BSF) with screen-printed and aerosol-printed seed layers (20 fingers, two busbars of 1mm at the edges). These were plated at different conditions of rear-side potential ($\Delta E_{RS\text{-}AUX}$) and light intensity. As can be seen in Fig. 5 (left), the deposition rate increases as light intensity and absolute $\Delta E_{RS\text{-}AUX}$ are increased, independent of the seed layer. Calculating the geometrical area of the initial contacts based on a microscopic evaluation, this leads to higher calculated current densities for the aerosol-printed seed layers (Fig. 5, right).

"However, screen-printed seed layers proved to be less sensitive to higher deposition rates, as can be seen at $\Delta E_{RS\text{-}AUX}$ = -0.6V."

The resulting contacts were comprehensively characterized with respect to their optical and electrical properties. The contact fingers of our sample cells were separated with a dicing saw. Thus, the resistance from busbar to busbar for single fingers could be measured with the four-point probe method. The cross-sectional area of the contacts was evaluated with a confocal microscope, where profiles of the contacts were averaged over a length of 560µm at several different spots of each cell (Fig. 6). With length, resistance and cross-sectional area, we could calculate the conductivity of the contacts.

The measured values show the electrical properties of the plated metal layer improving with decreasing plating speed (Fig. 7). However, screen-printed

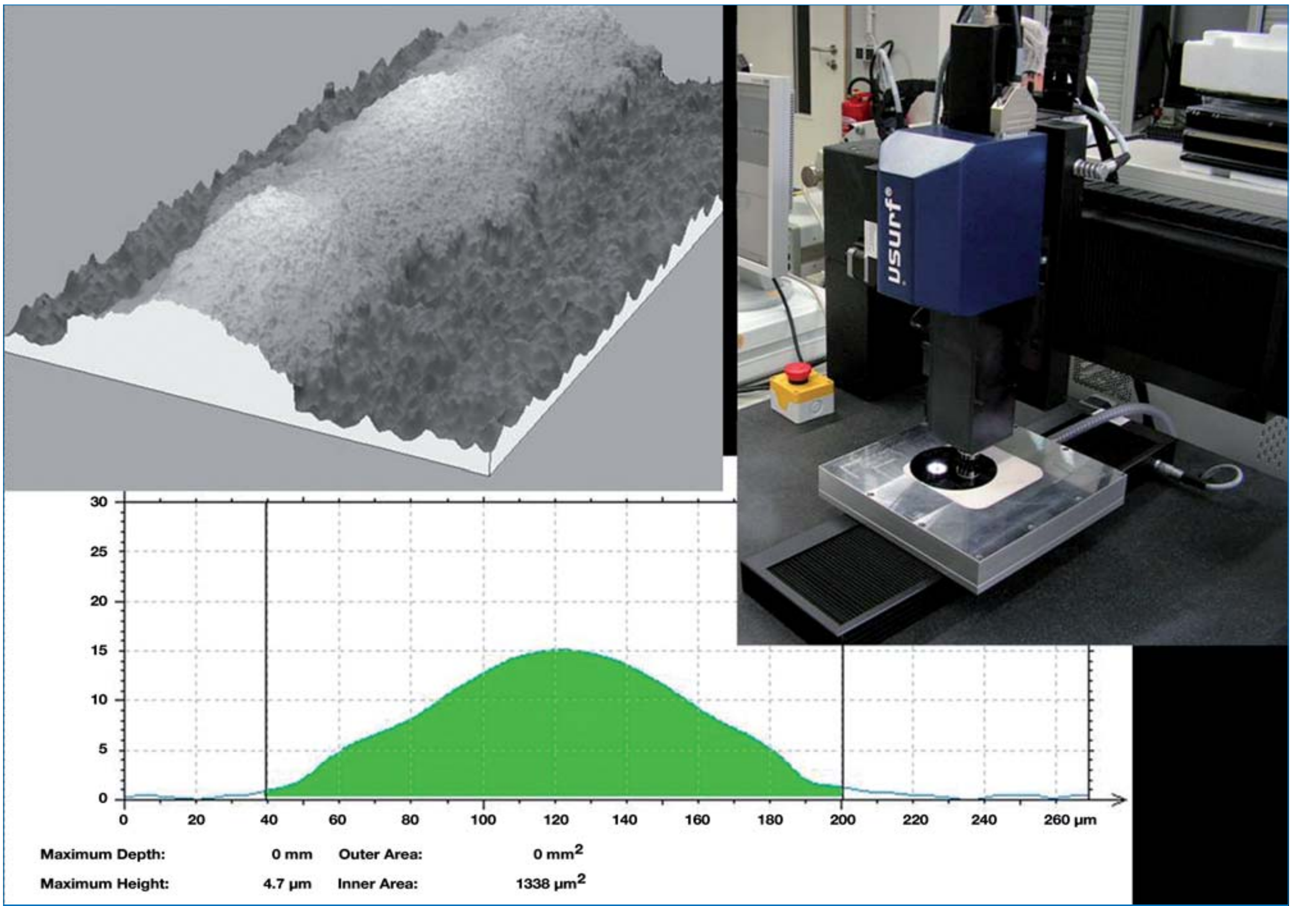


Figure 6. Contact property evaluation with the confocal microscope.

seed layers proved to be less sensitive to higher deposition rates, as can be seen at $\Delta E_{RS\text{-}AUX}$ = -0.6V. The conductivity is already improved for these conditions, and not far below the best values which have been realized. This can be explained by the lower current density and the relatively smooth surface. For aerosol-printed seed layers, the conductivity is far lower at the same conditions. It starts to increase at $\Delta E_{RS\text{-}AUX}$ = -0.4V and reaches the highest values (three times higher than a standard screen printed contact) only for $\Delta E_{RS\text{-}AUX}$ = -0.2V.

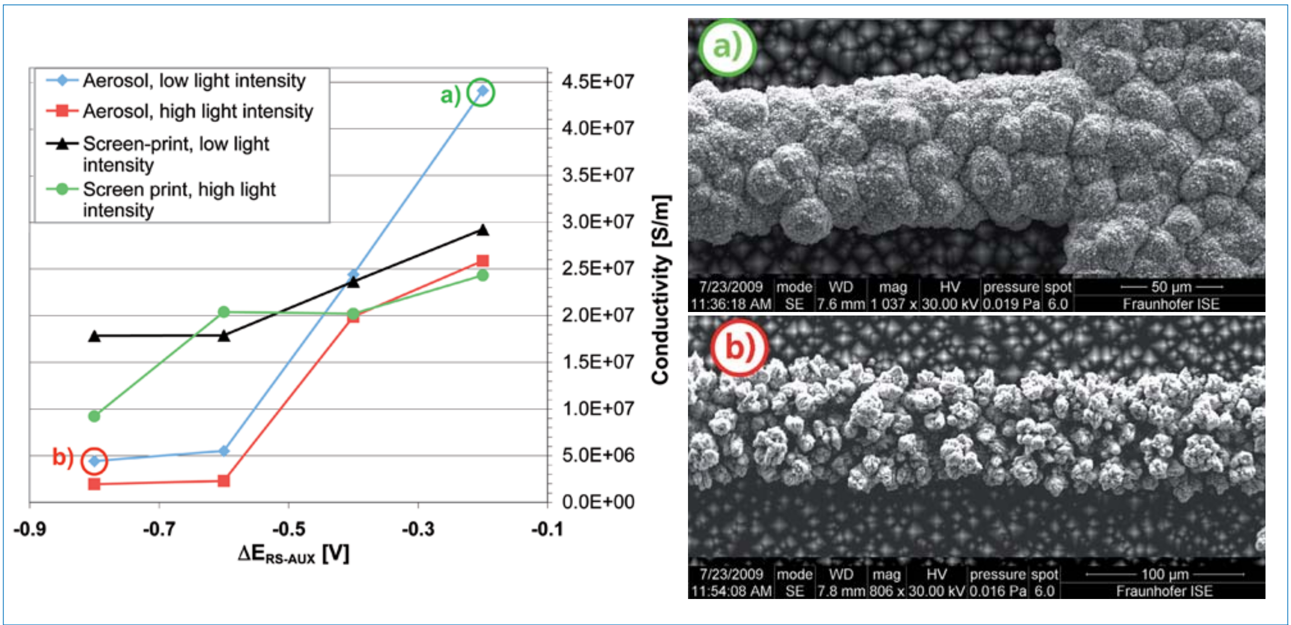


Figure 7. Electrical properties of the resulting contacts (left); SEM images at two extreme deposition rates (right).

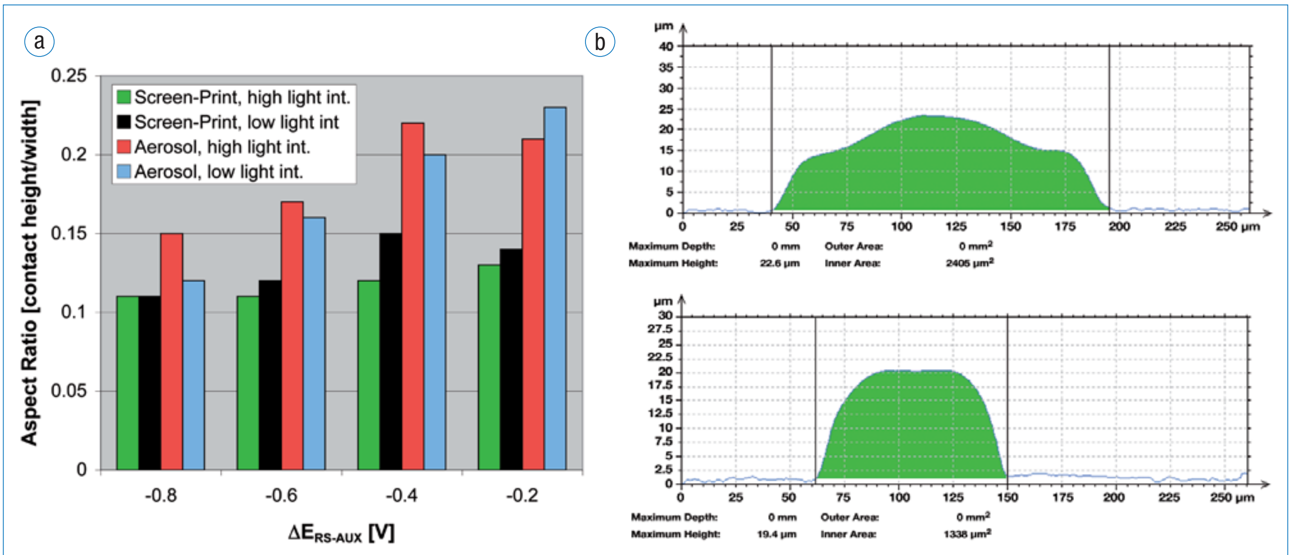


Figure 8. Aspect ratios of the contacts for different plating conditions (left); averaged cross-sections for a screen-printed and plated and an aerosol-printed and plated contact (right).

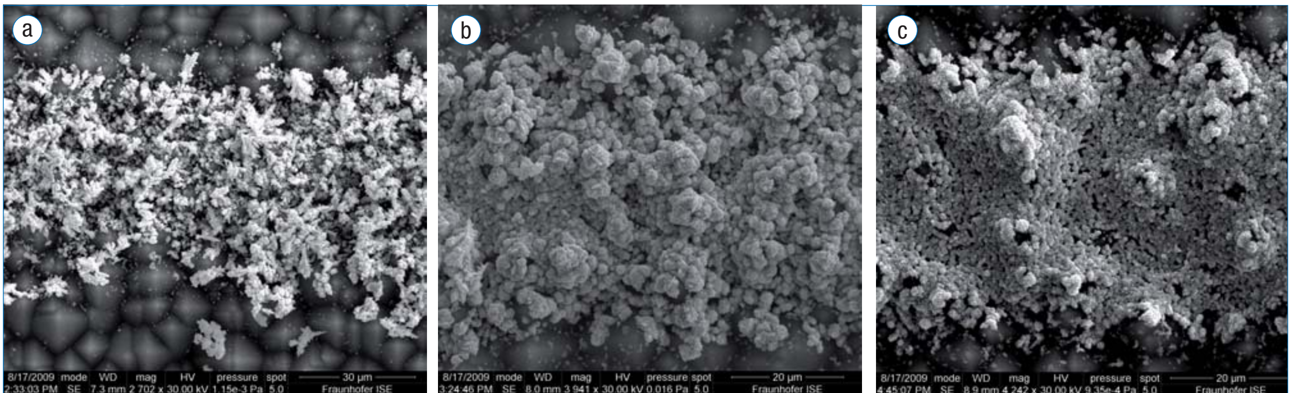


Figure 9. Metal layers after 10 seconds of depostition at -0.8V, -0,6V and -0.4V $\Delta E_{RS\text{-}AUX}$ (from left to right).

Looking at SEM images of the resulting contacts, this behaviour is understandable. The metal layer grown at higher deposition rate looks porous, silver columns have been created that are not interconnected and thus unsuitable to conduct current laterally. The layer grown at lower deposition rate appears homogenous and dense. In our evaluation of the optical parameters (confirmed by light microscope measurements) we found that these contacts are also superior in terms of aspect ratio and thus shadowing losses. The disordered growth that appears at high deposition rates seems to be less directed, whereas the good contacts grow comparably in height and less in width (Fig. 8).

As process speed is a key factor for industrial applicability, we took a look at process times that are to be expected per wafer for the best plating conditions. As can be seen in Fig. 5, the deposition rate is about 0.03mg/s for these conditions. Experimentally, we found that the optimal mass of silver per wafer (156 x 156mm^2) is around 200mg. Such a wafer is about nine times larger than our test cells, so the deposition rate should be larger in the same order of magnitude. (The optimal mass on our test structures is between 20-25mg, which was also the desired mass in our experiment.) This leads to a deposition of 0.27mg/s per wafer, which means that the process time for one wafer would be about 740 s for 200mg of silver plated. Such a process time is perfectly acceptable for industrial production. A slightly higher deposition rate will still lead to very good contacts, and an inline machine with a fitted size can grant an industrially compatible throughput. Furthermore, advanced plating techniques and an optimized mass transport to the wafer surface may support the deposition quality even at higher deposition rates.

To improve our understanding of the mechanisms that induce the described behaviour, we took a look at the first seconds of the deposition process. Test cells with aerosol printed seed layer were plated for 10 and 60 seconds for all plating conditions. The plating mechanism was evaluated with SEM images (Fig. 9). For the highest deposition rate, a localized deposition was found at the pyramid tips. The silver crystals show a typical dendrite-like appearance and multi-directional growth. This result fits well with the expected high field density at these spots. This behaviour was strong for -0.8V $\Delta E_{RS\text{-}AUX}$. For -0.6V, the surface structure was found to be rather rough, but already the valleys show a lot more deposition. However, the pyramid tips still show the beginnings of a columnar growth with a rough surface structure that may be caused by the high current density. The metal layer deposited at -0.4V looks quite homogenous.

“Advanced plating techniques and an optimized mass transport to the wafer surface may support the deposition quality even at higher deposition rates.”

We expect a comparable behaviour for differently created seed layers with similar geometrical properties. The effect of high field density should not be as pronounced for multicrystalline wafers with acidic texture.

Evaluation on an industrial scale

To evaluate the capability of this two-step front-side metallization on an industrial scale, solar cells were produced in our inline plating machine in the PV-TEC pilot line (Fig. 10). In a first experiment, we evaluated the optimal mass of silver to be deposited onto an aerosol-printed seed layer. We used multicrystalline solar cells and successively increased the plated silver mass in multiple deposition steps. After each step, the

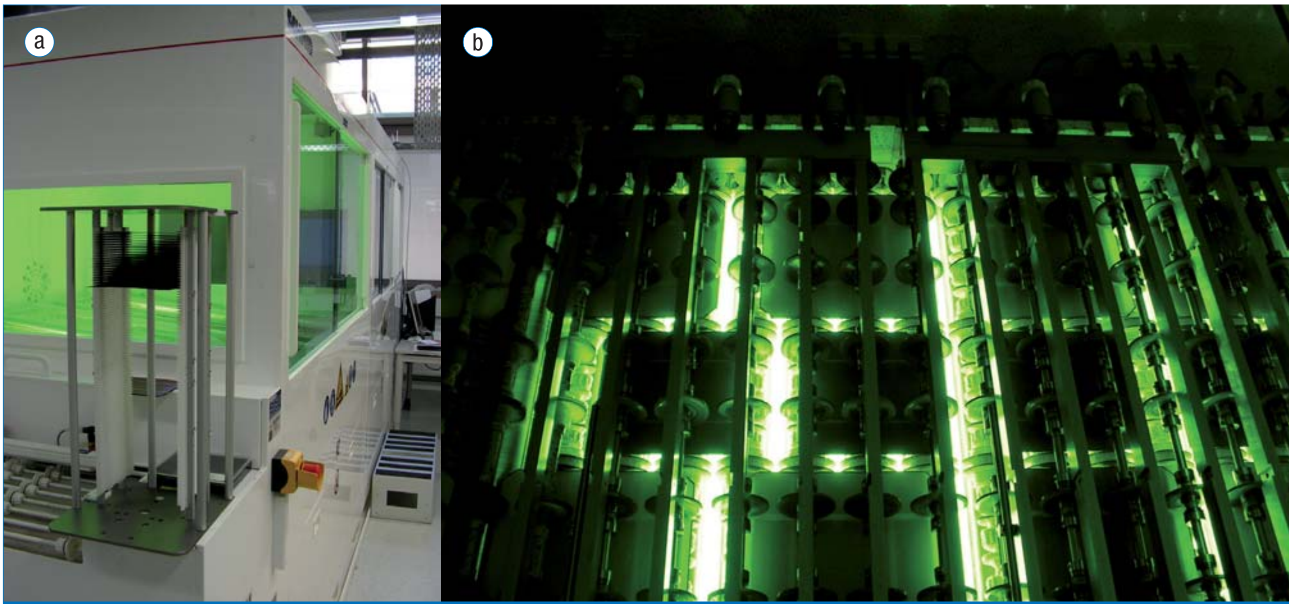


Figure 10. Inline plating machine in PV-TEC at Fraunhofer ISE (left), cells during the plating process (right).

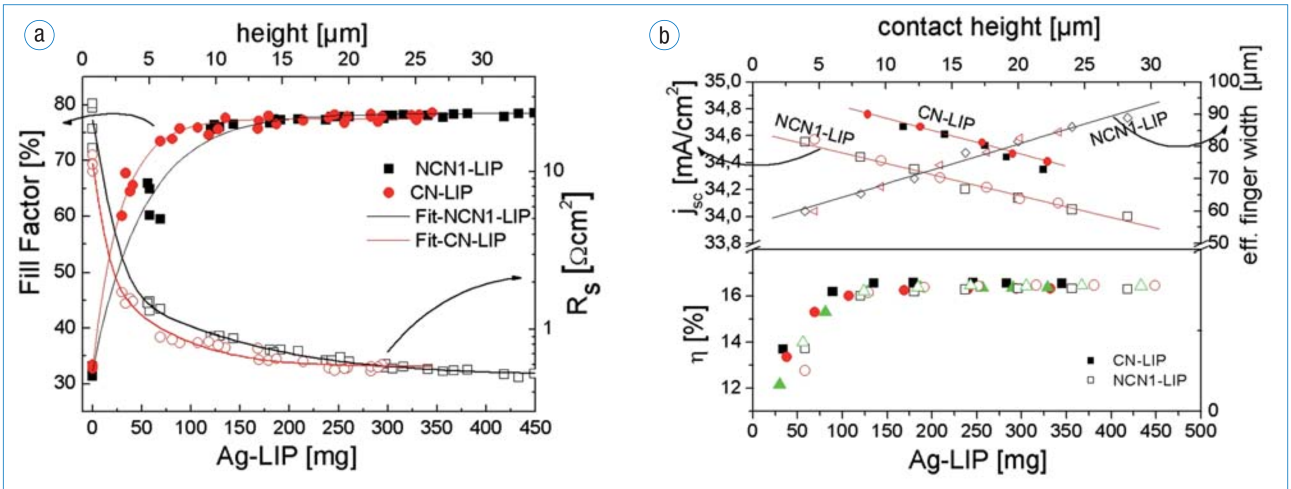


Figure 11. Fill factor, series resistance, current, effective finger width and efficiency as a function of the plated silver mass for two electrolytes (CN and NCN1).

electrical parameters were measured. To compare the inline contacts to high-efficiency contacts, we plated one group of cells in a manual setup comprising the cyanidic (CN) electrolyte as a reference.

As can be seen in Fig. 11 (left), the cells plated with the CN electrolyte need less deposition to reach very good values for series resistance and fill factor. The quality of the deposited layer is higher; nevertheless, the group of cells processed in the inline machine eventually reaches almost the same level. The CN-reference group shows only two minor advantages: the slightly lower consumption of silver, and the narrower effective finger width (Fig. 11, right). The second effect is due to the better reflective properties of the silver layer from a cyanidic bath, which will enable more direct and indirect reflection of light to the active cell area. Despite all of this, the value for the industrial process is still better than for a screen-printed finger. Naturally, the current shows an inversely proportional behaviour that has the highest impact on module scale.

The results obtained were used for another experiment, using the superior electrolyte in the inline machine. All cell results can be found in Table 1. We obtained excellent cell results on the same level as the CN reference process.

		VOC	JSC	FF	n
		[mV]	[mA/cm²]	[%]	[%]
NCN1-LIP	best cell	**620**	**33.6**	**80.0**	**16.7**
	Ave/15	621	33.6	78.7	16.4
CN-LIP	best cell	**622**	**34.1**	**79.4**	**16.8**
	Ave/15	621	34.3	77.9	16.5
NCN2-LIP	best cell	**621**	**34.2**	**79.4**	**16.8***
	Ave/5	621	34.5	78.7	16.8

* Independently confirmed by ISE CalLab.

Table 1. Cell results for the plating processes using different electrolytes on an industrial scale with multicrystalline solar cells. The CN-LIP group was manually plated as a reference.

Outlook

The two-step metallization process with silver as the conducting material has been very well evaluated and understood. It has been integrated into the process chain of Fraunhofer ISE's industrial pilot line in the PV-TEC laboratory. Our research on silver metallization will be extended to different textures, smaller line widths and new seeding systems and plating techniques.

However, a main focus in our research will be on new front-side metal stacks that enable the use of copper as the main conducting material. For example, a nickel layer may be grown electrochemically onto an aerosol-printed seed layer to form a diffusion barrier against copper. First solar cell samples with such stack systems prepared in our laboratories already show promising results.

Conclusion

Two-step metallization processes have been shown to have the potential to considerably improve the efficiency of crystalline silicon solar cells. Furthermore, novel metallization techniques may also lower the metallization costs, if less silver can be used or cheaper materials can be applied. The chemical basis must be chosen carefully, and the plating conditions need to be adjusted according to the requirements of different seed layers. However, the process has been shown to be suitable for application in industrial production. To maintain process speeds at higher levels at the same time, advanced plating techniques or setups can be used.

Acknowledgement

The authors gratefully acknowledge the contribution of **Mr. D. Erath** concerning the optimal conditions for screen-printing and grid design. We also thank **Mr. D. Schmid** for aerosol-printing of the wafers and **Mr. D. Puschnus** and **Ms. J. Pedroni** for sample preparation and experimental work in our group. We thank **Mr. C. Schetter** for his contributions in the field of LIP. Also, the great team of PV-TEC laboratory is acknowledged.

References

[1] Woehl, R. & Hoerteis, M. 2008, "Analysis of the optical properties of screen-printed and aerosol-printed and plated fingers of silicon solar cells", *Advances in Optoelectronics 2008*.

[2] Mason, N.B., Jordan, D. & Summer, J.G. 1991, "A high Efficiency Silicon Solar Cell Production Technology," *Proceedings of the 10th European Solar Energy Conference*, Lisbon, Portugal.

[3] Glunz, S. W. 2008, "Progress in advanced metallization technology at Fraunhofer ISE", *Proceedings of the 33rd IEEE Photovoltaic Specialists Conference*, San Diego, USA.

[4] Posthuma, N.E., John, J., Beaucarne, G. & Van Kerschaver, E. 2009, "Current and Future Metallization Challenges and Solutions for Crystalline Cell Manufacturing", *Photovoltaics International*, 3rd Edition, pp. 67-72.

[5] Hofmann, M., Erath, D., Bitnar, B., Gautero, L., Nekarda, J., Grohe, A., Biro, D., Rentsch, J. & Preu, R. 2008, "Industrial Type CZ Silicon Solar Cells With Screen-printed Fine Line Front Contacts and Passivated Rear Contacted by Laser Firing", *Proceedings of the 23rd European Photovoltaic Solar Energy Conference*, Valencia, Spain.

[6] Hörteis, M., Richter, P. L. & Glunz, S.W. 2008, "Improved Front Side Metallization by Aerosol Jet Printing of Hotmelt Inks", *Proceedings of the 23rd European Photovoltaic Solar Energy Conference*, Valencia, Spain.

[7] "Silberstreif aus der Düse", *Photon Magazine*, Germany.

[8] Hoornstra, J., Heurtault, B. & Carr, A. 2009, "Stencil Print Applications and Progress for Crystalline Silicon Solar Cells", *Proceedings of the 24th European Solar Energy Conference*, Hamburg, Germany.

[9] Alemán, M. & Bay, N. 2008, "Industrially Feasible Front-side Metallization Based on Ink-jet Masking and Nickel Plating", *Proceedings of the 23rd European Photovoltaic Solar Energy Conference*, Valencia, Spain.

[10] Nekarda, J. & Reinwand, D. 2009, "Industrial PVD Metallization for High Efficiency Crystalline Silicon Solar Cells", *Proceedings of the 34th IEEE Photovoltaic Specialists Conference*, Philadelphia, USA.

[11] Grohe, A. & Harmel, C. 2006, "Selective Laser Ablation of Anti-reflection Coatings for Novel Metallization Techniques", *Proceedings of the 4th World Conference on Photovoltaic Energy Conversion*, Waikoloa, Hawaii, USA.

[12] Mette, A. "New Concepts for Front Side Metallization of Industrial Silicon Solar Cells", Ph.D. thesis, Fakultät für Angewandte Wissenschaften, University of Freiburg, Germany.

[13] Hoerteis, M., Bartsch, J., Radtke, V., Filipovic, A. & Glunz, S.W. 2009, "Different Aspects of Seed Layer-printed and Light-induced Plated Front Side Contacts", *Proceedings of the 24th European Photovoltaic Solar Energy Conference*, Hamburg, Germany.

[14] Allardyce, G. & Cahalen, J. 2006, "The Commercial Application of Light Induced Electroplating for Improving The Efficiency of Crystalline Silicon Solar Cells", *Proceedings of the 22nd European Photovoltaic Solar Energy Conference*, Milan, Italy.

[15] Fioramonti, A. 2008, "Cell Efficiency Increase of 0.4% through Light-induced Plating", *Photovoltaics international*, 2nd Edition, pp. 60-63.

[16] Bartsch, J., Radtke, V., Schetter, C. & Glunz, S.W. (under review), "Electrochemical Methods to Analyse the Light-induced Plating process", *Journal of Applied Electrochemistry*.

[17] Bartsch, J., Radtke, V., Savio, C. & Glunz, S.W. 2009, "Progress in understanding the current paths and deposition mechanisms of light-induced plating and implications for the process", *Proceedings of the 24th European Photovoltaic Solar Energy Conference*, Hamburg, Germany.

About the Authors

Jonas Bartsch received a diploma degree in chemical engineering from the University of Karlsruhe in 2007. Since graduation, he has been working as a Ph.D. candidate at Fraunhofer ISE in the field of advanced silicon solar cell metallization with electrochemical techniques.

Christian Savio studied mineralogy at the University of Freiburg and prepared his diploma thesis at Fraunhofer ISE, investigating crystal growth mechanisms during the light-induced plating of silver on silicon solar cells.

Matthias Hörteis studied physics at the University of Augsburg and the Australian National University, Canberra and obtained his diploma in 2005. He started his Ph.D. in 2005 in the "Silicon Solar Cells – Development and Characterization" department at Fraunhofer ISE. The topic of his Ph.D. thesis is the development of functional materials for the metallization of crystalline silicon solar cells.

Dr. Stefan W. Glunz is the head of the "Silicon Solar Cells – Development and Characterization" department at Fraunhofer ISE. He received his Ph.D. degree in 1995 from the University of Freiburg. His research focusses on the design, fabrication and analysis of high-efficiency silicon solar cells. Among other scientific and technological achievements his group has set the actual world record for solar cells on multicrystalline silicon.

Enquiries

Fraunhofer Institute for Solar Energy Systems (ISE)
Heidenhofstr. 2
79110 Freiburg
Germany

Tel: +49 (0) 761 4588 5561
Fax: +49 (0) 761 4588 9000
Email: jonas.bartsch@ise.fraunhofer.de

Increasing the efficiency of multicrystalline silicon solar cells

Dr. Andreas Kux & **Dr. Jörg Müller**, Q-Cells SE, Bitterfeld-Wolfen, Germany

ABSTRACT

Standard solar cell technology nowadays offers a variety of measures – some linked, some not – to continuously improve conversion efficiency. The starting point for considering the different improvement steps is a kind of standard cell as produced on most current production lines. The main elements of this cell are diffused junction, aluminium back-surface field and screen-print metallization. This type of cell suffers losses from different sources like optics, recombination and resistance that can be considerably lowered to obtain higher cell efficiency. This paper will describe improvement steps on the standard type of multi-crystalline cell before addressing cell concepts that open further potential.

Introduction

Over the last couple of years photovoltaics has grown into a respectable sized industry. An enormous pull from the market has brought an average annual growth rate of more than 30% as the whole industry scaled up production across the value chain. This extraordinary growth fired by an enormous amount of equity money also allowed some big players in the industry to put huge efforts into R&D of crystalline cell technology.

Since the financial crisis also hit the solar industry, the solar cell market has been faced with new challenges. As with volumes, the prices for solar cells dropped dramatically. With further decreases anticipated, it all comes down to whether or not manufacturers can be competitive in terms of €/Wp. As Fig. 1 shows, there are different factors that can influence how best to reach that goal. Based on an internal Q-Cells analysis, cost reduction potential for multi-crystalline silicon is up between 40 and 50% from today's cost levels. Technology is a key driver to reach this cost reduction by 2015.

This article focuses on how to drive efficiencies of multicrystalline cells even further upwards. For a standard multicrystalline cell, improvements on the front and back surface will enhance the cell's overall efficiency output. A bundle of measures consistently linked to each other demonstrate how the front and back surface will be modified.

In the medium term, new cell concepts will play an increasing role in driving multicrystalline cell efficiencies beyond 18% in mass production at a very competitive cost basis. Further reduction of shading and a new approach to back contact cells can lead the way.

The multi-crystalline standard cell and its potential

Fig. 2 provides an overview of crystalline silicon solar cell efficiency for both multi- and monocrystalline cells. Standard multicrystalline silicon solar cells have evolved from having conversion efficiencies slightly above 14% around 2002 to today's scenario where efficiencies range typically from 15.0% to 16.6% depending on materials and processes. Over the last few years, the increase in efficiency was clearly visible but not extensive. Modern production techniques give access to improvements that allow for more distinct steps in raising cell efficiency into the region of 18% for multicrystalline material.

The starting point for considering the different improvement steps is a kind of standard cell as produced on most current production lines. While this

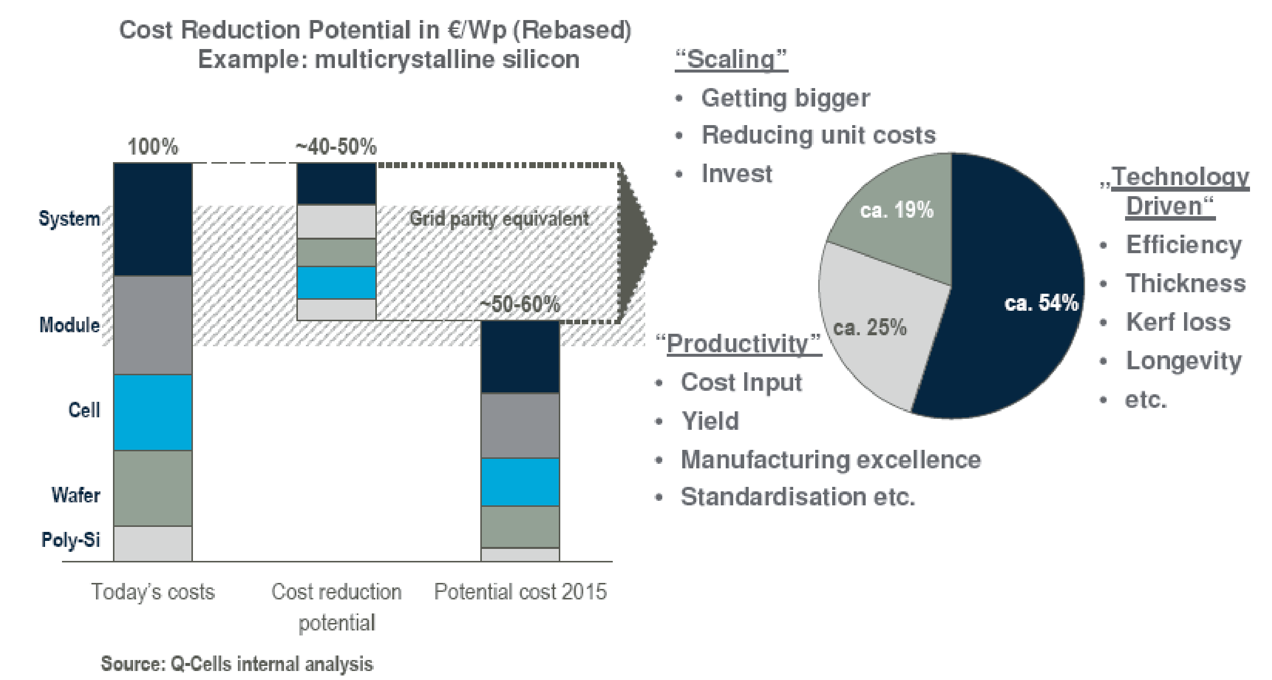


Figure 1. Cost reduction analysis illustrating the contribution of technology-driven factors to cost reduction potential.

Q-Cells Selects Camstar

Q-Cells Selects Camstar for New Malaysian Mega-factory and Upgrade of German Production Lines

Largest Global Solar Cell Manufacturer Selects Camstar's SolarSuite™ to Lower Cost per Watt and Drive Quality Output

CHARLOTTE, N.C. (October 20, 2009) – Camstar Systems, Inc. announced today that Q-Cells SE (QCE; ISIN DE0005558662), the world's largest solar cell manufacturer, has selected Camstar's SolarSuite™, configured for the Solar industry on the Camstar Enterprise Platform, to drive down cost per watt through improved process quality and cell efficiency. Q-Cells will deploy the solution in two new production lines in Bitterfeld-Thalheim, Germany, and in its new factory in Malaysia where production will exceed 300MW (peak) by the end of 2010.

Q-Cells selected SolarSuite over competing options for its strong "out-of-the-box" functionality that is designed specifically for and widely used by Camstar's global customers in the Solar and Semiconductor industries. In addition, in Q-Cells' environment of rapid process improvement and frequent tool upgrades, the unique flexibility of Camstar's platform enables rapid adaptation, global control and change enforcement – all critical to support Q-Cells' growth and quality goals.

"We are very pleased to be a strategic partner for Q-Cells as they create the most modern, fully automated solar cell production lines in the world," said Robert Rudder, Senior Vice President of Sales and Marketing for Camstar. "We have made significant investment in our enterprise platform as a seamless foundation for manufacturing execution, quality management, and manufacturing intelligence. That technology is delivering the ability not only to collect large volumes of data from automated tools, but to quickly analyze and immediately act upon that data for process improvement and increased equipment efficiency – driving real, measurable quality improvements faster."

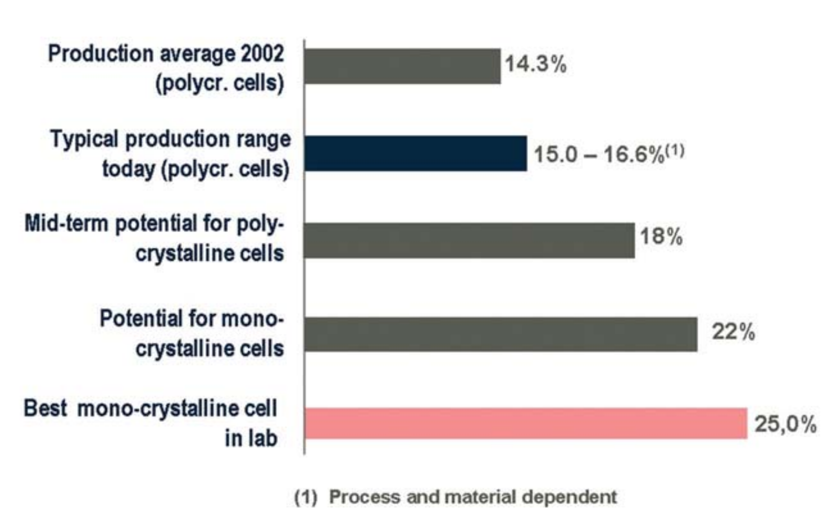


Figure 2. Overview of silicon cell efficiency potential.

cell type is still subject to losses from sources such as optics, recombination and resistance, these losses can be considerably lowered to obtain higher cell efficiency. The following section describes steps that could be taken on the standard type of cell to improve efficiency and also addresses cell concepts that could provide further improvements.

Development steps at the cell front surface

A first set of measures addresses the blue response of the cell. The standard cell suffers recombination in the blue part of the light spectrum that is absorbed near the surface. The main origin is in the doping profile of a typical 55Ω/sq emitter which uses surface doping well above 10^20 cm^{-3} leading to Auger-induced recombination. In order to lower this contribution to recombination, an emitter profile with lower surface doping concentration is desired. Fig. 3 shows internal quantum efficiencies with a standard and a low-doped emitter. The lower contribution of Auger recombination resulting in higher quantum efficiency in the blue spectral range is clearly visible in the left-hand side of the graph.

However, some boundary conditions and additional changes are needed to make a change in the emitter profile a real contribution to cell efficiency:

1. Good contact with the lower doped emitter needs to be achieved with metallization.
2. The distance of metallization fingers should be lowered using higher emitter sheet resistance of the emitter profile in order to limit resistive losses.
3. To avoid higher shading losses each finger needs to be printed in a more narrow fashion.
4. To avoid higher emitter saturation current the front surface needs better passivation since the emitter profile is less efficient in repelling holes from the surface to prevent recombination.

Consequently, concurrent advances in fine line print and surface passivation are required in conjunction with the emitter profile modification. The following section describes possible approaches to achieve these goals, addressing formation of the emitter itself as well as adaptation of metallization and passivation.

> "Higher doping beneath the metallization facilitates the creation of a contact to the emitter, while the area in between the fingers can be set to the profile desired for low recombination losses."

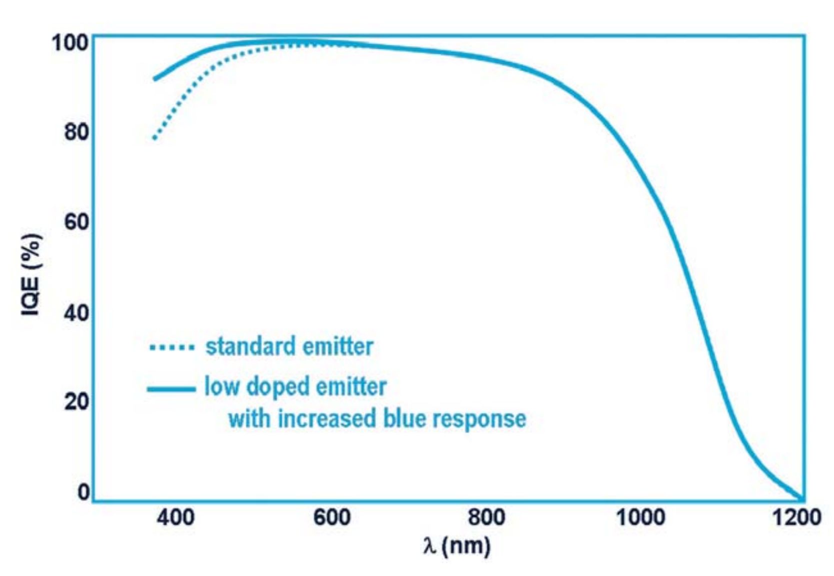


Figure 3. Internal quantum efficiency improvement of a multicrystalline cell in the blue spectral range showing optimized emitter profile.

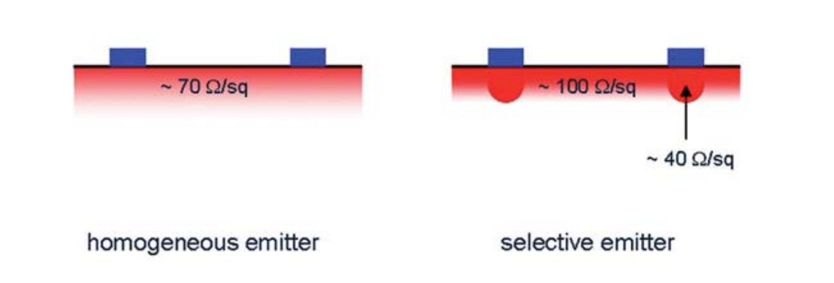
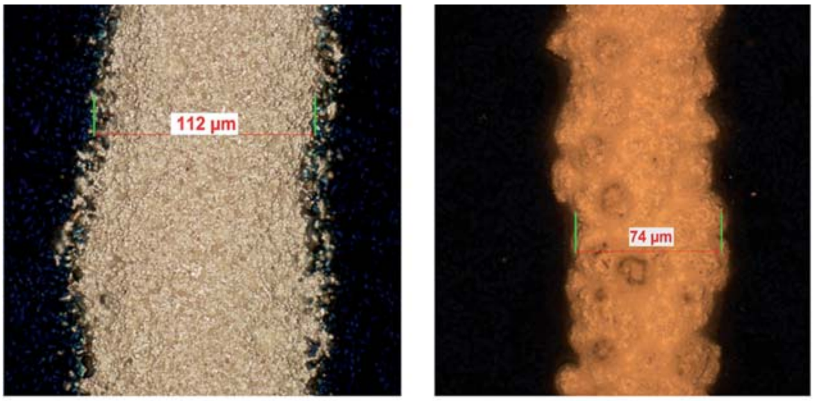


Figure 4. Schematic drawing of homogeneous emitter (left) and selective emitter (right).

Two fundamental approaches exist for creating the emitter profile, as shown in the schematic in Fig. 4. Staying ahead of the technology curve involves maintaining a homogeneous emitter structure (Fig. 4, left). This entails making sure that the silver paste can form good ohmic contact with the emitter despite this process becoming more and more difficult as a result of the lower surface doping concentration. Efforts in paste development are currently under way to achieve this goal. The plating type of metallization is also a help in this case, as the metallization seed layer can be optimized for contact resistance while



	w_f [µm]	V_{oc} [mV]	j_{sc} [mA cm^{-2}]	FF [%]	η [%]
standard	110 – 120	618	34.3	78.5	16.7%
seed & plate	70 – 80	621	34.9	78.3	17.0%

Figure 5. Print line width reduction by using conventional screen print (left) compared to seed and plate techniques (right).
A contribution to efficiency increase of about 0.3% can be achieved [3].

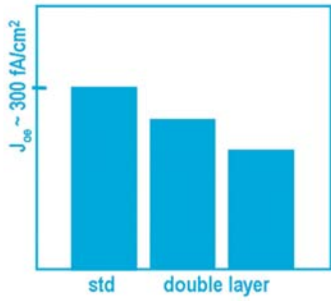


Figure 6. Schematic showing necessary evolution of surface passivation (with emitter optimization) at the cell's front surface.

plating provides the finger conductivity as an independent and decoupled step. Contact formation itself is less critical using the selective emitter approach (Fig. 4, right). In this case, two different doping concentrations are used: low doping in between the metallization fingers and high doping below the fingers. This higher doping beneath the metallization facilitates the creation of a contact to the emitter, while the area in between the fingers can be set to the profile desired for low recombination losses. However, this is usually at the expense of a more complex process, since alignment between the highly doped area and the metallization has to be maintained. As a result, historically this approach has only been seen on a few cells, but progress in equipment leads to constant re-assessment to find the best-suited approach for the industry. More detailed considerations on emitter profiles can be found in [1].

The high emitter resistivity between the fingers in both emitter approaches requires metallization using fine line printing. In order to keep losses caused by series resistance low, the emitter requires a denser grid of fingers and thus the individual finger needs to be printed narrower to avoid an increase of shading losses. This will lead to enhancements in screen printing and

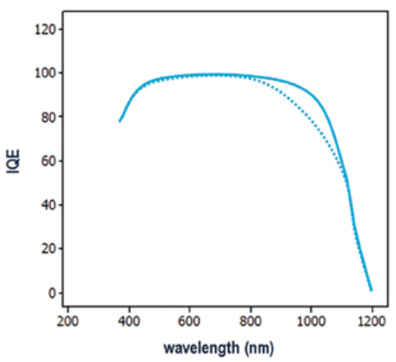


Figure 7. Internal quantum efficiency improvement of a multicrystalline cell in the infrared spectral range bringing optimization of the cell's rear side.

Material	Pros and Cons
SiO_2 – thermal	Proven material from semiconductor industry, high quality interface, limited growth rate.
SiO_2 – PECVD	Passivation properties under evaluation, attractive deposition rate.
SiN_x – CVD	Established in front optics and passivation
a-Si – CVD	Technically proven in PV, limited thermal stability.
Al_2O_3 – ALD	Dielectric with charges, good lab results, industrial feasibility questionable due to low dep rate.

Table 1. Materials candidates for rear-surface passivation of silicon solar cells.

use of metallization techniques allowing for significantly reduced lateral finger dimensions as well as high aspect ratio of the finger metallization to keep finger conductivity on a comparable level. One approach that showed high potential uses a two-step metallization process. A thin seed layer is printed followed by a light-induced silver-plating step [2]. Fig. 5 shows an example of reduced line width resulting from the seed and plate technique [3].

In addition, front-side passivation requires the reduction of the typical emitter saturation current density of 300fA/cm^2 to significantly lower values (Fig. 6). After optimization of the nitride itself, two-layer passivation consisting e.g. of a thin oxide under the more classical nitride layer will be considered as a candidate for achieving this goal. Double-layer dielectrics target the separation of the passivation layer from the antireflection layer. In this way, an independent optimization of the interface properties responsible for passivation and the refractive index of a thicker anti-reflective coating is possible.

In summary, the front surface is modified by an array of measures consistently linked to each other for suppressing recombination without suffering disadvantage from resistive and shading losses.

Development steps at the cell rear side

As with the front side, the rear side of the cell is also a candidate for lowering losses. The two major items addressed on the rear side are rear passivation and rear reflection.

The rear passivation of the standard cell has to date consisted of an Al back-surface field. Depending on the resistivity of the silicon and the BSF quality, this leads to a recombination velocity of around 600cm/s and a reflection of around 67%. Improvement of the passivation requires reduction of the contact area and covering major part of the rear surface by a passivating dielectric layer. For passivation itself this layer can be rather thin; a layer thickness less than 10nm can be sufficient. Combination with optical mirror properties needs higher thicknesses of around 200nm. The alternative to a single layer is a stack system to combine passivation and optical properties from two layers. Optical improvement can result from using an improved mirror as the rear surface, leading to rear reflection values up to 95% using optimized layers. The infrared part of the light spectrum is used more efficiently as it is reflected from the rear side, instead of being absorbed in the Al rear metallization as with a conventional cell (Fig. 7). In addition, this improved light trapping is a necessary step for cell thickness reduction while avoiding large losses in efficiency.

> "Improvement of the passivation requires reduction of the contact area and covering major part of the rear surface by a passivating dielectric layer."

There is a substantial number of candidates for use as rear passivation layers (Table 1), ranging from proven materials to promising candidates on the laboratory scale. Materials comprise thermally-grown silicon dioxide (well established in the semiconductor industry as a gate dielectric); silicon nitride (a standard material in the photovoltaic industry for front passivation); amorphous silicon (as used within the HIT cell concept); and some rather new candidates such as aluminium oxide [4,5]. Some issues arising from these different materials include, for example, limited growth rates or restrictions in process temperature budget. Several candidates are undergoing a more thorough investigation for possible application to the mass production of solar cells.

For the subsequent metallization step, again there are different approaches, such as adapting pastes for use on dielectrics, to more advanced schemes that attempt to replace pastes, which are costly, with PVD deposition of aluminium, for example. In both cases, contact with silicon has to be established by using laser-based techniques like laser-fired contacts (LFC) [6] or alternatively by patterning contact openings into the rear dielectric. LFC is an attractive approach for high throughput in production as it saves patterning effort – always critical from a cost perspective. On the other hand, patterning provides a higher degree of process freedom. It gives access to under-diffusion of contacts, which is another contributor to driving the cell in the direction of record-type PERL [7] cell structures.

With a rear passivation implemented, there will be a readjustment of the doping level of the p-type wafers used. The link that exists between doping level and surface recombination velocity for an aluminium back-surface field due to band bending is no longer valid in the same format with a dielectric interface. The doping level for optimum cell efficiency will shift to higher levels, i.e. lower resistivities of the wafer.

As with the front side, the cell rear benefits from reduced recombination, which allows the cell to attain a new optimum with respect to wafer doping. In addition, the rear mirror increases the optical path especially for infrared light and prepares for cell thickness reduction.

New cell concepts

New cell concepts need to incorporate higher efficiencies. Steps being taken in this direction are further reduction of shading along with exploiting possibilities originating from back-contact cells. Back-contact cells can be interconnected in a rather standard way on module level [8], but also offer new opportunities in connecting cells with less resistive losses [9]. Candidates for such developments are cell types like the MWT (metal wrap through) [10,11] and EWT (emitter wrap through) [12,13] cell.

In the case of the MWT, cell finger metallization is still on the front side while bus bar metallization is moved to the back side of the cell. The connectivity

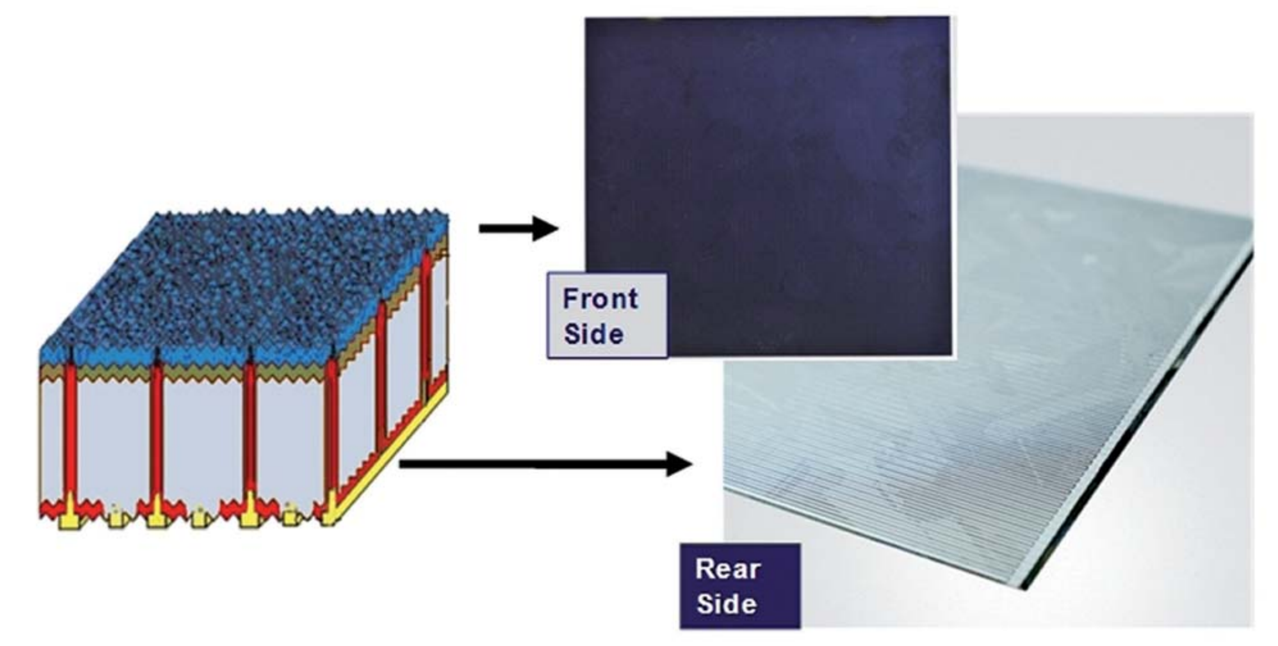


Figure 8. EWT (emitter wrap-through) schematic drawing and photograph of cells as produced within Q-Cells' R&D and research co-operations. The front side does not carry any metallization; emitter contacts to rear-side metal stripes are visible on the rear-side photo.

between front fingers and rear bus bars is via a few (< 1/cm^2) holes drilled with laser techniques and filled with metal paste.

The EWT concept as shown in Fig. 8 consequently moves all metallization to the back side with the emitter diffusion providing contact between the front and the rear side of the cell. Due to the lower conductivity of the emitter as compared to finger metallization, this requires a much higher hole density than does the MWT concept. The emitter extends from the cell front around many (> 20/cm^2) holes to its back-side contact and consequently, a large part of the rear cell surface is emitter. This leads to high efficiency in current collection and large immunity against the minority carrier lifetime variation of the wafer used for cell production. For this reason, the EWT cell type is well suited for application with multicrystalline silicon.

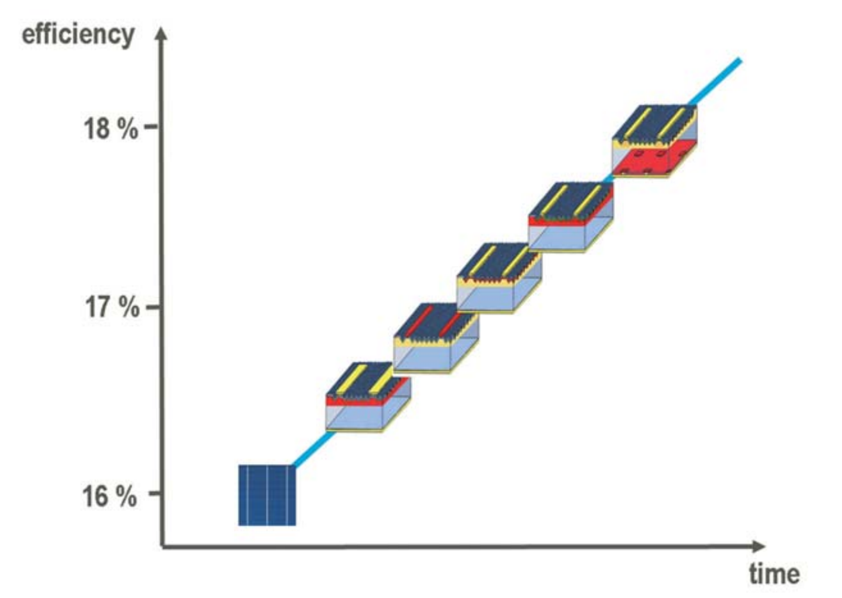


Figure 9. Overview of cell efficiency increase over time (steps not drawn to scale). Starting from the standard cell, changes refer to emitter, metallization and surface passivation before addressing the cell rear side. New concepts must also be taken into consideration towards the end of the process.

The EWT cell concept is still the subject of further investigations. A high conductivity of the diffusion area inside the holes connecting front and rear must be maintained in order to ensure high fill factors necessary for optimum cell efficiency [14].

Summary

We will see development of the classical screen-printed cell that addresses loss reduction in different parts of the cell. Major packages address cell front and rear sides before moving to new concepts. The contributing steps in this process are represented schematically in Fig. 9.

The front side will see a move to emitters, reducing Auger recombination along with the measures that are necessary as a direct consequence, i.e., an improved surface passivation and an adapted metal grid for contacting the emitter with low resistive losses. From a spectral point of view, this results in improved blue response.

The rear side will also move towards improved passivation and implement a mirror affecting mostly the infrared part of the spectrum. This will pave the way for reducing wafer thickness and silicon consumption as a significant contribution to cost reduction. These steps will enable multicrystalline cells to reach efficiency ranges of about 18% for efficient cell classes (Fig. 9). Improvements can be carried to a subsequent cell concept that also eliminates further losses like metallization shading.

With this high contribution of efficiency to the overall cost of energy generation, we expect a significant contribution to lowering the levelized cost of electricity (LCOE) of photovoltaics, and, depending on the regional boundary conditions, reaching the goal of grid parity in the near future.

Acknowledgement

The authors would like to thank colleagues in R&D and corporate departments of Q-Cells for discussion and assistance in preparation of this article.

References

[1] Peters, S. 2009, "Industrial diffusion of phosphorous n-type emitters for standard wafer based silicon solar cells", *Photovoltaics International*, 3rd Edition, pp. 60-66.

[2] Mette, A et al. 2006, Increasing the efficiency of screen-printed silicon solar cells by light-induced silver plating", *Proceedings of the IEEE 4th World Conference on Photovoltaic Energy Conversion*, p. 1056.

[3] Mette, A. & Glunz, S. 2008, "Potential of both-sides contacted solar cells", *Crystal Clear Workshop*, Utrecht, The Netherlands.

[4] Hoex, B. et al. 2006, *Appl. Phys. Lett.* 89, 042112.

[5] Benick, J. et al. 2008, *Appl. Phys. Lett.* 92, 253504.

[6] Schneiderlöchner, E., Preu, R., Lüdemann, R., Glunz, S.W. & Willeke, G. 2001, "Laser-fired contacs (LFC)", *Proc. 17th European Solar Energy Conference*, 1303, Munich, Germany.

[7] Zhao, J., Wang, A. & Green, M.A. 1990, "24% efficient PERL structure silicon solar cell concept", *Proc. 21st IEEE Photovoltaic Specialists Conference*, Orlando, FL, USA, p. 333.

[8] Szlufczik, J. 2009, *5th PV Industry Forum*, Munich, Germany.

[9] Gee, J. 2009, *5th PV Industry Forum*, Munich, Germany.

[10] van Kerschaver, E. et al. 1998, "A novel silicon solar cell structure with both external polarity contacts at the back surface," *Proc. 2nd World CPVSEV*, Vienna, Austria, p. 1479.

[11] Clement, F. et al. 2009, "Pilot-Line Processing of Screen-Printed Cz-Si MWT Solar Cells Exceeding 17% Efficiency", *34th IEEE PVSC*, Philadelphia, PA, USA.

[12] Gee, J. et al. 1993, "Emitter wrap-through solar cell", *Proc. 23rd IEEE PVSC*, Louisville, KY, USA, p. 265.

[13] Peters, C. et al. 2008, "Alba – Development of high-efficiency multi-crystalline Si EWT solar cells for industrial fabrication at Q-Cells", *23rd EUPVSC*, Valencia, Spain.

[14] Ulzhöfer, C. et al. 2008, "The origin of reduced fill factors of emitter-wrap-through-solar-cells", Phys. Stat. Sol. (RRL), 1-3.

About the Authors

Dr. Andreas Kux studied physics at the Technical University of Munich, going on to receive a Ph.D. in 1994 on light emission from porous silicon. He has 13 years' development experience in the semiconductor industry, mostly in the field of non-volatile memories within the R&D departments of Siemens Semiconductor, Infineon and Qimonda. He has worked since 2008 for the Technology Screening and Roadmap of Crystalline Silicon Technology at Q-Cells SE.

Dr. Jörg Müller received his diploma degree in physics from the Ludwig-Maximilians-University in Munich in 2000. He did his Ph.D. research in the field of rear contacted and bifacial sensitive solar cells at ISFH in Hamlin and obtained his Ph.D degree from Hannover University in 2005. He joined the technology devision at Q-Cells in 2004. Since 2007 he is leading the crystalline silicon cell and module development at Q-Cells SE.

Enquiries

Dr. Jörg Müller / Dr. Andreas Kux
Q-Cells SE
Sonnenallee 17-21
D-06766 Bitterfeld-Wolfen
Germany

Email: a.kux@q-cells.com

Further improvements in surface modification of MC silicon solar cells: comparison of different post-PSG cleans for inline emitters

Arno F. Stassen & **Martien Koppes**, ECN Solar Energy, Petten, The Netherlands; **Johan Hoogboom**, Mallinckrodt Baker B.V., Deventer, The Netherlands

ABSTRACT

Insufficient removal of phosphosilicate glass (PSG) after inline emitter formation for crystalline silicon solar cells reduces cell efficiency. With additional chemical steps, the surface can be modified to increase both short-circuit current and open-circuit voltage. In this paper we demonstrate that the efficiency can be increased by at least 0.4% absolute by using a simple surface modification process. The process is compatible with standard crystalline silicon production processes.

Introduction

For inline processing, the standard method of fabricating an emitter is by applying a phosphor-containing solution (either by spraying, sonic evaporation or by other methods), followed by a heating step. The phosphor present on the wafer dehydrates to form $(P_2O_5)_n$ which subsequently reacts with silicon and oxygen to form a phosphosilicate glass (PSG).

In order to obtain a high efficiency, this PSG layer has to be removed completely before applying a passivating anti-reflection coating (ARC), normally SiN_x:H. The standard method of removing PSG is by submerging the wafer in an aqueous hydrofluoric acid bath for one to two minutes.

Our paper previously published in *Photovoltaics International* [1] has shown that this process does not completely remove the PSG and that additional cleaning, or 'surface modification' will result in a higher efficiency.

"The presence of PSG-remains can be seen as either white spots or as a white glow over the wafers in SiN coating."

A thorough cleaning process can be divided into four steps: 1. removal of the PSG layer; 2. removal of particles such as dust from the surface; 3. removal of part of the dead layer; and 4. modifying the surface layer of the emitter. The standard PSG removal works poorly; the surface still contains large amounts of PSG remains and particles and the surface concentration of phosphor is often very high (over $3 \times 10^{21} cm^{-3}$) [2].

The presence of PSG-remains can be seen as either white spots or as a white glow over the wafers in SiN coating. This leads to more absorption, because the PSG is not fully transparent for visible light, and passivates poorly. The top layer of the emitter contains a very high amount of phosphor, the majority of which is not electrically active because the concentration is far above the solid solubility. By removing a small part of this so-called 'dead layer' (step 3), the absolute amount of non-active phosphor is reduced and therefore the number of recombination centres is reduced.

"Parameters of influence are crystal orientation, absolute surface area and surface morphology."

Finally, the passivation also depends on the resulting surface (step 4). Parameters of influence are crystal orientation, absolute surface area and surface morphology. For example, pinholes will reduce passivation quality.

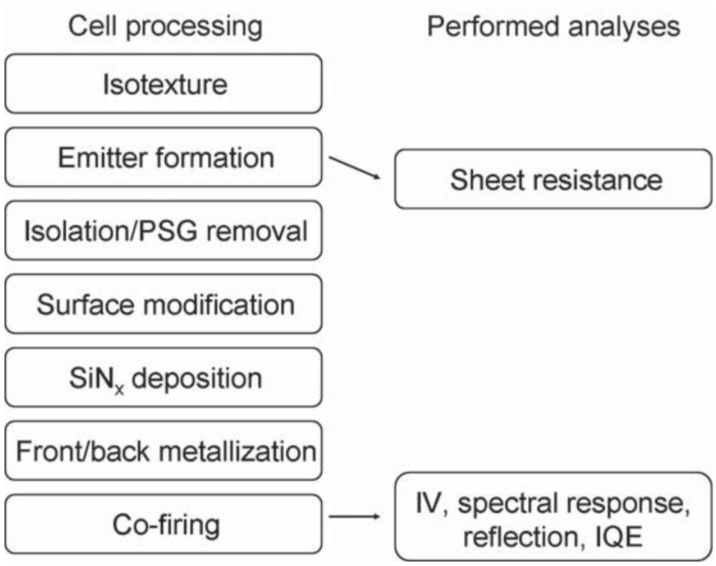


Figure 1. Process flow for fabricating solar cells and performed analyses. Groups 8 and 9 have isolation before surface modification, all other groups as final step.

At this moment, the ECN-Clean containing the J.T. Baker PV-160 surface modifier is the only commercial surface modification process used in the industry. We have looked at different processes for surface modification in order to improve on the existing system, and identified one process which results in improved cell performance for a small increase in cost. This process has been tested in different fabrication schemes.

Approach

All wafers are processed using an industrial firing-through process scheme (see Fig. 1). All tools are either identical to those used in the industry or scaled-down industrial tools.

The search for an improved method for surface modification has been divided in two parts. In the first part, six groups of 17 neighbouring wafers were used to test the effect of a wide range of different wet chemical surface modifications.

In group **1**, PSG is removed using only an aqueous HF solution without any additional chemical steps – a conventional PSG removal. The processing of group **2** is standard ECN-Clean using the PV-160 surface modifier. The modification performed on group **3** is an alternative processing sequence also using PV-160 as one of the active ingredients. This method is known to increase V_{oc}, J_{sc} and thereby efficiency compared to the standard ECN-Clean process, only for a much higher cost of ownership and has been previously published under the name "Pasha Clean" [2].

The surface modification steps performed on groups **4** and **5** are faster and cheaper versions of the processing used in group **3**. The processing time of group **4** is more than 15 minutes shorter than the processing time of group **3** and only a few minutes longer than the conventional ECN-Clean (group **2**). Group **6** is an alternative process not using the surface modifier as an active ingredient. The processing time is longer than that of the standard ECN-Clean, but only standard chemicals are used.

During each surface modification process, a very thin layer is removed from the top of the wafer. This is done in order to remove a part of the 'dead layer' (step 3) and to influence the surface (step 4). A result of this removal is an increase in sheet resistance R_{sheet}.

The wafers of each group were selected in such a way that each wafer has an almost identical 'neighbour' (sister wafer) in the five other groups. In this way, differences in material quality are excluded from the analyses. During all processing steps, except for the surface modification steps, the wafers were not processed per group but in order of position with the group (starting with all number 1s of each group, followed by all number 2s, and so on). By processing the wafer in this way, variation over time of the diffusion oven or the printing, for example, are excluded.

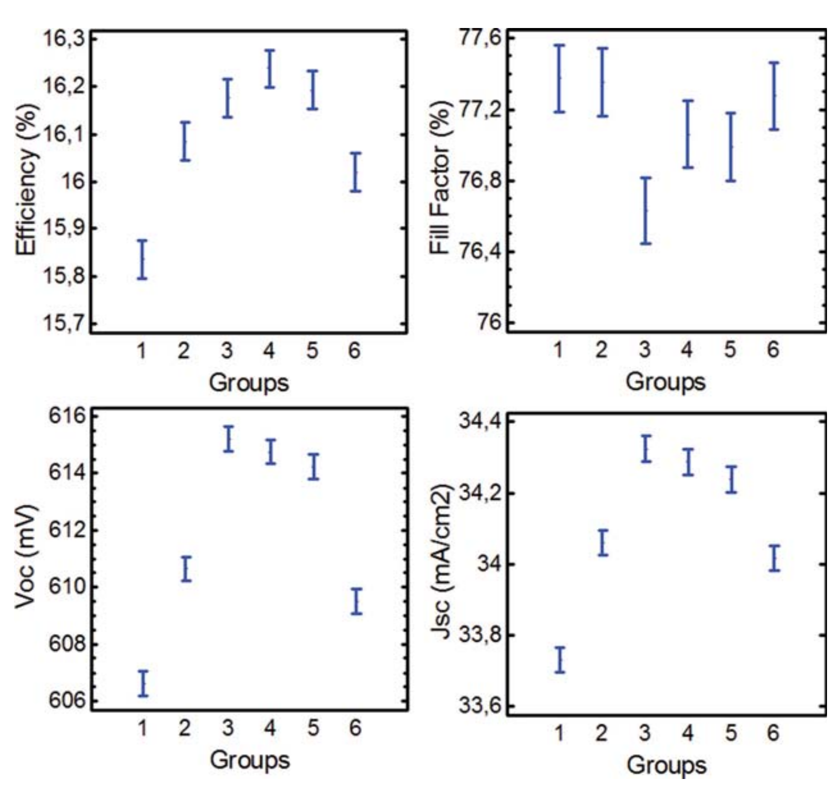


Figure 2. Means and 95.0% Tukey HSD Intervals of efficiency, current, voltage and fill factor of the six different mc-Si groups. **1**: only HF; **2**: ECN-Clean; **3**: Pasha Clean; **4**: very short variant on Pasha Clean; **5**: short variant Pasha Clean; **6**: alternative without PV-160 surface modifier.

	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (%)	ETA (%)	max ETA	$J_{sc} \times V_{oc}$
1	33.731	607	77.4	15.836	15.997	20.463
2	34.060	611	77.3	16.085	16.199	20.797
3	34.323	615	76.6	16.176	16.370	21.109
4	34.288	615	77.1	16.238	16.386	21.074
5	34.238	614	77.0	16.193	16.326	21.034
6	34.017	609	77.3	16.020	16.150	20.731

Table 1. Cell parameters from an average of 17 neighboring mc Si cells.

	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (%)	ETA (%)	max ETA	$J_{sc} \times V_{oc}$
7	33.703	607	77.7	15.901	16.015	20.460
8	33.992	609	78.1	16.163	16.214	20.698
9	34.156	613	77.9	16.300	16.348	20.928

7: only PSG removal with HF
8: WCJI with ECN-Clean
9: WCJI with surface modification **4**

Table 2. Cell parameters from an average of nine neighbouring mc Si cells.

Wafers were processed according to the process sequence given in Fig. 1. Before and after the cleaning steps, sheet resistance was measured using a Sherescan [3]. After processing, IV curves, spectral response and reflection were measured and internal quantum efficiency (IQE) was calculated. All multicrystalline silicon wafers had an area of 156 × 156mm^2 with an average thickness of 180µm.

The texture was the inline ECN-iso-texture, and the emitter was formed using a Despatch spraycoater and a Despatch IR heated belt furnace. SiN_x was used as ARC and deposited by an R&R SINA system. The wafers were screen printed using a Baccini printer. Firing was conducted in a Despatch IR firing belt furnace. All surface modification process steps are wet chemical steps in which only water-based chemistry is used.

After selecting the best industrial process, this chemical process (group **4**) was tested in combination with wet chemical junction isolation (WCJI) (group **9**) versus our standard process combining wet chemical edge isolation and ECN-Clean (group **8**) and a reference group with isolation by mechanical isolation and no surface modification (group 7). Each group consisted of nine wafers: each wafer with sister cells in the other two groups. The WCJI is performed before the PSG removal to prevent surface damage from vapours formed during the WCJI process.

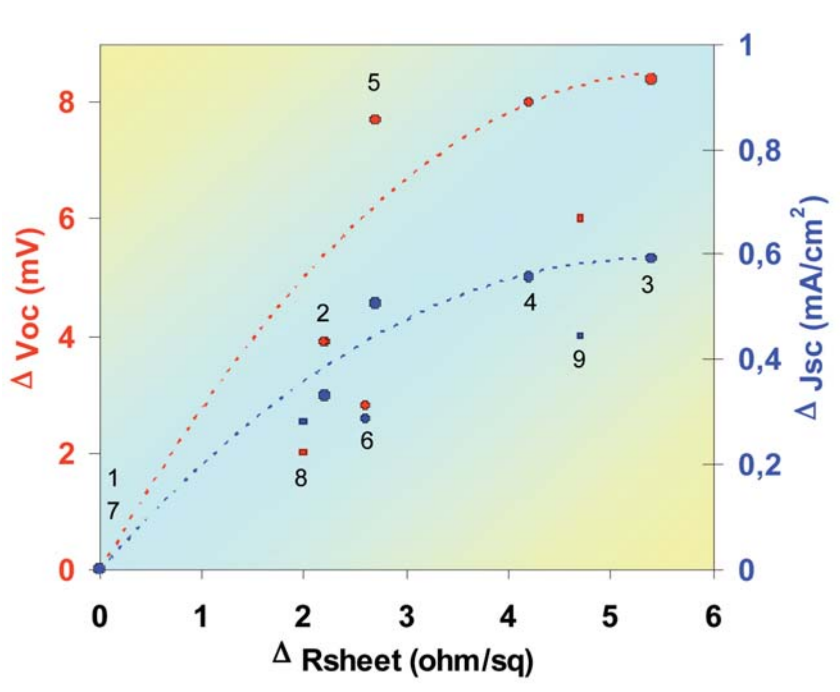


Figure 3. Increases in V_{oc} (red) and J_{sc} (blue) plotted versus the increase in R_{sheet}. The group number is plotted above or below the markers; the dotted lines are meant as guides for the eye. The circles correspond with Part 1 and the squares with Part 2.

The wafers selected for Part 1 and Part 2 are of a comparable material quality but there is no direct relation between the wafers selected for the two parts.

Results Part 1

The average cell results of groups **1** to **6** are shown in Table 1 and the statistical comparison in Fig. 2. The internal quantum efficiency and the increase in IQE compared to conventional PSG removal are shown in Fig. 4.

Results Part 2

The process used in group **4** has been tested in combination with wet chemical junction isolation **9** with as reference groups 7: PSG removal with HF and mechanical edge isolation, and group **8**: WCEI followed by the ECN-Clean process. The average cell results are shown in Table 2.

Discussion

In groups **1** to **6**, all groups with additional surface modification show a significant increase in efficiency, J_{sc} and V_{oc}

compared to conventional PSG removal. No significant reduction in fill factor was observed, except for group **3**, which underwent the most elaborate surface modification.

With respect to J_{sc} and V_{oc}, three levels can be distinguished. For group **1**, both J_{sc} and V_{oc} are significantly lower than for all other groups. Groups **2** and **6** show higher values than group **1**, but are still below the results observed in groups **3**, **4** and **5**.

As expected the use of ECN-Clean (group **2**) results in an absolute increase of 0.3% in efficiency. In group **3** even higher values for V_{oc} and J_{sc} are reached.

The novel surface modification steps of groups **4** and **5** shows that a J_{sc} and V_{oc} can be reached comparable to group **3** without a significant loss in fill factor. The efficiency gain of group **4** compared to group **1** (conventional PSG removal) is 0.4%.

Group **6** shows that it is possible to increase the efficiency by 0.2% absolute using only standard chemicals. However, this increase is significantly lower than using processing based on the PV-160 surface modifier. The main difference between group **6**'s results and the other groups is a lower gain in V_{oc}.

A direct relation exists between the increase in sheet resistance and resulting cell parameters changes for groups **2**, **3**, **4** and **5** (see Fig. 3). A higher increase in Rsheet not only results in higher values for J_{sc} and V_{oc} but also in a (except for group **3**) non-significant decrease in fill factor (see Table 1). The reason that group **4** has a higher efficiency than groups **3** and **5** (which have a higher product of $J_{sc} \times V_{oc}$) is that this reduction in fill factor is smaller.

The values of V_{oc} and J_{sc} of group **6** do not follow the trend observed in groups **2** to **5**. Although the increase in R_{sheet} is comparable to group **5**, the increases in J_{sc} and V_{oc} are much lower. This can be an indication that not only step 3 (removal of part of the dead layer), but also step 4 (modified surface) have a strong influence on the resulting I_{sc} and V_{oc}. The V_{oc} and J_{sc} increase due to the rise in R_{sheet} but are decreased simultaneously due to a less suitable surface for passivation.

The same trend is also seen in the internal quantum efficiency (see Fig. 4). Because both material and further processing are identical for all groups, except for the cleaning of the surface of the solar cell, the IQE is identical for both the bulk and the backside of the wafer (>600nm). The differences between 330 and 600nm coincide exactly with the voltage of the different solar cells (values given in Fig. 4b).

"The V_{oc} and J_{sc} increase due to the rise in R_{sheet} but are decreased simultaneously due to a less suitable surface for passivation."

The second part, testing the surface modification with the shortest processing time and the highest gain in efficiency in combination with wet chemical edge isolation, has been performed with three groups of nine neighbouring wafers each.

The comparison between groups **1** and **7** indicates that processing differences can be neglected. Both J_{sc} and V_{oc} in the two groups are almost identical. Only the fill factor shows a difference, due to a further optimization of the processing. This increase in fill factor is even more pronounced in groups **8** and **9**. Where a small drop would be expected, a small (statistically insignificant) increase is observed (see Table 2).

The combination of WCJI and ECN-Clean results in an increase of approximately 0.25% absolute compared to no surface modification. The gain is in J_{sc}, V_{oc} and in fill factor.

The positive effects of the processing of group **4** versus those of a comparable group with the ECN-Clean as surface modification appear to be independent of the isolation method. Increases of 4mV and ~0.2mA/cm² are seen between both groups **2** and **4** and between groups **8** and **9**. Also, the reduction in fill factor of 0.2% is identical in both comparisons.

The relation between ΔR_{sheet} and ΔJ_{sc}, and ΔV_{oc} of group **9** is not in complete agreement with the relation found between groups **1** to **5** (see Fig. 3). In both groups, the J_{sc} and V_{oc} appear to follow a comparable trend versus the increase in R_{sheet}, but the absolute values are lower than in groups **2** to **5**. One explanation could be that, even though the PSG should act as an etching barrier, the emitter is slightly damaged during the WCJI without increasing the R_{sheet} observed. This damage results in a surface which is less ideal for surface passivation (step 4). If for group **9** comparable increases had been found as in groups **2** to **5**, average efficiencies of 16.5% would have been possible.

Conclusions

It is possible to increase the efficiency of solar cells produced with inline diffusion methods. This is done by using wet chemical steps after conventional PSG removal and before applying the anti-reflection coating (normally silicon nitride). Next to removal of PSG remains, particles and partial removal of the dead layer, surface morphology after the surface modification steps most likely influences the resulting cell performance.

The results from this paper show that an absolute increase of at least 0.4% in efficiency is possible by using a process suitable for industry.

Trends are observed in the increases in V_{oc} and J_{sc}. Groups with comparable processing (all containing J.T. Baker's

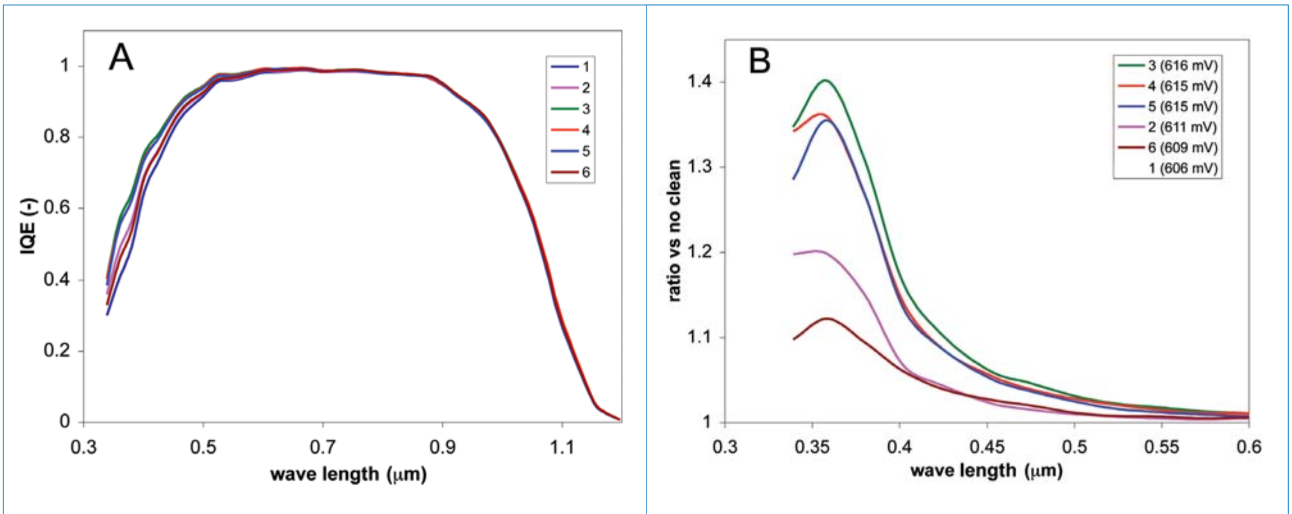


Figure 4. A: Internal quantum efficiency of a set of neighbouring cells with different surface modifications; B: the relative increase in blue response compared to no clean (included are the voltages of the individual cells).

PV-160 and no WCJI) show increases in V_{oc} and J_{sc} related to increasing ΔR_{sheet}. In groups with alternative processing (all containing PV-160 but with WCJI) a comparable trend is observed; only the actual increases in J_{sc} and V_{oc} are smaller.

The use of surface modification **4** instead of the ECN-Clean results in an increase in efficiency of 0.15% absolute. This increase is independent of the isolation method. In both tests, gains were seen of 4mV in V_{oc} and 0.2mA/cm^2 in Jsc and a loss of 0.2% in fill factor, resulting in this 0.15% increase in efficiency.

Acknowledgements

This work is financially supported by SenterNovem EOS KT program (project number IS074007).

References

[1] Hoogboom et al. 2009, "Surface modification for efficiency improvement of inline solar cell manufacture", *Photovoltaics International*, 2nd Edition, 2009.

[2] Cesar, I. et al., *Proc. 23nd EUPVSEC*, Valencia, Spain, 2008.

[3] Information available at http://www.sunlab.nl/sherescan/.

About the Authors

Arno Stassen has worked as a research scientist in ECN's Silicon PV Technology group since 2006, addressing chemical etching, oxidation and cleaning of silicon wafers. As project leader, he is responsible for the ECN pilot line process. 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 at the Technical University of Vienna, Leiden University, Technical University of Delft and ETH Zurich.

Martien Koppes has worked as a chemical specialist in ECN's Silicon PV Technology group since 1991. Koppes has been strongly involved in the development of multiple wet chemical processes such as the ECN-isotexture, the ECN T2 low reflection texture, the ECN-Clean, the Pasha Clean and wet chemical processes dedicated for n-type solar cells.

Johan Hoogboom obtained his Ph.D. in 2004 on physical-organic chemistry and solid-state physics from the Radboud University in Nijmegen, The Netherlands, focusing on self-assembled alignment layers for LCDs. After that, he moved to MIT as a postdoctoral fellow, working on polymer-based explosives sensors in a joint project with the US Army. In 2006, he moved back to the Radboud University as an assistant professor in organic electronics, coordinating material research into organic solar cells, LEDs, FETs, TFTs and nanowires. In early 2008, he joined Mallinckrodt Baker B.V. and is now the global R&D coordinator for silicon photovoltaics.

Enquiries

ECN Solar Energy
P.O. Box 1, 1755 ZG Petten
The Netherlands

Tel: +31 224 56 49 85
Fax: +31 224 56 8214
Website: www.ecn.nl

Mallinckrodt Baker B.V.
P.O. Box 1, 7400 AA, Deventer
The Netherlands

Email: stassen@ecn.nl

Thin wafer handling methods

Christian Fischmann, **Tim Giesen** & **Steve Gao**, Fraunhofer IPA, Stuttgart, Germany

ABSTRACT

Despite the fall in silicon prices, wafer thickness continues to be reduced. The handling of thin wafers between 120 and 160µm is under research at the Fraunhofer IPA, where gripper-dependent and independent variables were determined as parameters for the handling process. Diverse grippers are tested on an automated test platform. Among these are grippers that are specifically designed for wafer handling, as well as others that are not but are used for wafer manipulation. The test platform includes several different test and handling equipments and utilizes critical parameters that might be required for achieving a high production rate via shortest cycle times to investigate the impact on thin wafers. The first results of the position accuracy measurement in relation to the physical movement parameters and other industrial key figures in ongoing handling research are presented within this paper.

Introduction

Without a high level of automation, neither the target of high throughput nor the demanded high quality and low breakage rate of the thin wafers can be assured. Therefore, the researchers at Fraunhofer IPA aim at developing, evaluating and demonstrating methods for the automated handling and transport of thin wafers.

With the current wafer thickness in mass manufacturing, the highest breakage rates mainly result from:

- Separation of thin wafers (the wet separation during the wafering, and the pre-separation in the cell manufacturing and the module assembly)
- Pick-and-place operations which occur before, during and after manufacturing
- Transport operations, especially from alignment functionalities
- Handling in/out of carriers, transport boxes, magazines and stackers.

In short, every production step involves the wafer being on the surface or at the corners, which can stress the sensitive and porous photovoltaic material.

To give an example from actual Fraunhofer IPA tests, wafers with a thickness of 150µm become heavily stressed and bowed during the pick-and-place operations even with the newest gripper generations. Fig. 1 shows such a pick action analyzed with a high-speed camera: with a handling cycle time of 1.5 seconds per wafer, the actual state-of-the-art wafer gets bended about 10mm on the corners before cracking.

Depending on the production principle (batch or inline processing), a multiplicity of pick-and-place operations with a very high throughput under critical physical parameters is necessary. Several grippers like, for example, the Bernoulli grippers, have been developed to overcome these challenges, and some of these have already been applied in the industry. By means of a handling prototype, tests can be carried out in the automation lab of the Fraunhofer IPA to investigate the physical limitations of the grippers. The main objective of the analysis and the evaluation is to optimize the handling of thin wafers, effectively maximizing the throughput without neglecting the reliability.

"The typical handling processes in a thin wafer production line can be modelled with a travelled horizontal distance up to 900mm."

Test platform equipment

For the experimental analysis of the gripper behaviour and the evaluation of gripper qualities, a test platform was set up at Fraunhofer IPA. The goal is to demonstrate industrial state-of-the-art conditions and to determine the future needs of automation for the photovoltaic industry. Wafer handling on the laboratory scale exemplifies an industrial wafer handling application.

The main task of this wafer handling prototype is to carry out pick-and-place operations for mono- and polycrystalline wafers. The typical handling processes in a thin wafer production line can be modelled with a travelled horizontal distance up to 900mm. The required vertical travel can be set up to 50mm. Since the industrial state-of-the-art handling rate of wafers currently levels off at approx. 1.5 wafers per second, the laboratory wafer handling should be able to operate at this rate and even at shorter cycle times.

Two linear solenoid drives manipulate the gripper in the researched workspace. According to the assembled payload, an acceleration and deceleration up to $40m/s^2$ and a velocity up to 3.4m/s can be operated. The accurate linear positioning is supported by a ball monorail guidance system (Fig. 2). A feeder module prototype by AMB Automation separates dry wafers from a staple and provides the top wafer with a certain sensor-controlled altitude.

The metrology sub-system contains several sensors and valves such as a vacuum ejector, a solenoid valve, pressure sensors, an accelerometer and a thermal mass flow meter, among others. A high-speed camera allows the detailed observation of pick-and-place processes (Figs. 1 & 7). Wafer deformations and the critical behaviour of the handled object can then be evaluated separately. Furthermore, a position accuracy study is carried out by a

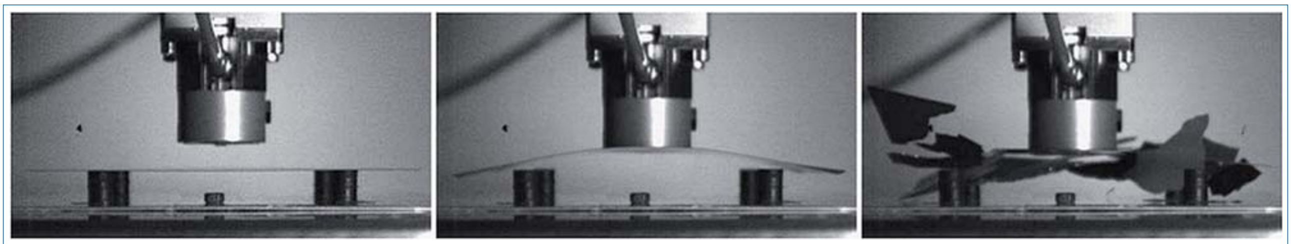


Figure 1. Wafer-gripping sequence with critical parameters.


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

visual displacement measurement. Gripper-dependent placement deviations can be measured accurately by as little as 20µm within an area of 1mm². An upcoming extension of the demonstration line will be a micro-crack detection instrument. The quality validation will be executed by Manz's industrial state-of-the-art system which is implemented into the control system of the test platform.

The steering and controlling of all single components was integrated via Ethernet and Profibus into one control system. The parameters setting, a log-file generation, diverse handling process adjustments and the start/stop of handling operations are executed via an adequate graphical user interface.

A further extension of the test platform will gradually turn the laboratory handling process into an industrial application. In the near future, pick-and place processes from/on conveyor belts will be analyzed. Moreover, other equipments will broaden the range of the wafer handling module. The flipping and the alignment of wafers as well as a carrier loading port will be included in the evaluation of thin wafer handling.

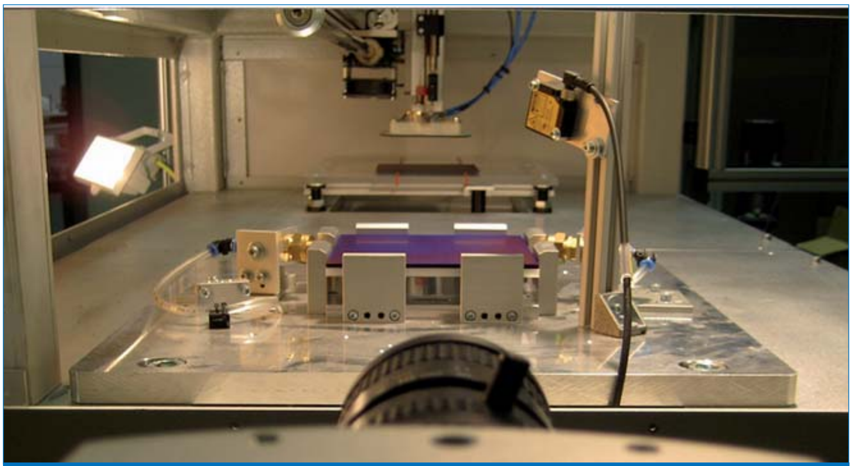


Figure 2. Two-axis handling module with gripper.

Gripper No.	Function Principle	Size (incl. adapter) [mm]	Weight incl. Adapter [g]	Direct Wafer Contact Area/Area Geometry	Features
1	Bernoulli	Ø 40 x 18 (Ø 40 x 37.5)	126	3 x 0.24cm²/punctual	Light and robust
2	Bernoulli	Ø 147 x 20 (Ø 148 x 36)	292	41.5cm²/ring-shaped	Contact area not planar
3	Bernoulli	Ø 148 x 20 (Ø 148 x 36)	301	64.5cm²/ring-shaped	Contact area not planar
4	N/A	146 x 146 x 79 (146 x 146 x 84)	485	160cm²/rectangular	Exhausting of sucked-in air Blow-off function Attenuators
5	Vacuum	173 x 153 x 74 (173 x 153 x 80)	494	3 x 0.85cm²/punctual	Designed for delta kinematic robots Blow-off function
6	Vacuum	150 x 150 x 14 (150 x 150 x 33)	555	220cm²/rectangular	Soft contact area Blow-off function

Table 1. Tested grippers from different manufacturers and their specifications.

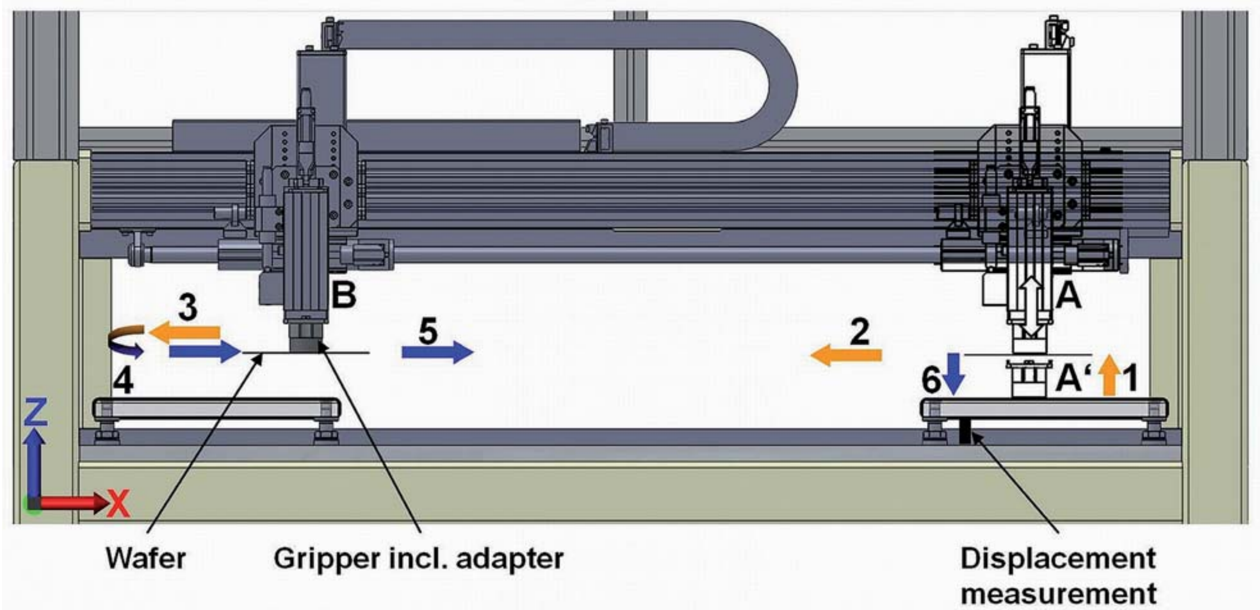


Figure 3. Exemplary procedure of a test cycle in the wafer handling module. 1. Pick-up and vertical travel; 2. Horizontal travel; 3. Stop after certain travel distance; 4. Short waiting time; 5. Horizontal return; 6. Vertical return and placement incl. waiting time.

The gripper system within the test platform has a significant influence on the thin wafers. Depending on the gripper geometry and the force-generating principle, several different gripper test cycles are performed until the optimal parameter settings are determined. In handling different thin wafers and in varying the gripper-dependent parameters of the overall system the suitability of the pairs of wafer and gripper are evaluated. Focusing strictly on the position accuracy and the intactness of the handled object allows for the optimization of economical and productive key figures. For example, the minimization of the air consumption as well as the cycle time are in turn restricted by the minimization of the breakage rate.

There are several different state-of-the-art grippers available for photovoltaic and semiconductor applications, such as those listed in Table 1, as well as tested prototypes of international partners. Further gripper developments are waiting to be tested and evaluated for market entry, reengineering and product benchmarking.

Thin silicon wafer handling means the transportation of wafers from one certain position to a required position and orientation with the least rate of damage caused and the shortest cycle times. In short, the optimal handling of wafers must be able to realize the highest rate of wafer production. In order to achieve this, many new grippers have been designed and developed in due consideration of the new requirements and challenges.

Grippers can be classified sensibly into groups by distinguishing the models on the basis of their working principles (see Table 1). The lifting force generation can be very different, even among grippers within one group.

A Bernoulli gripper gets its name from the Bernoulli law which explains the correlation between the velocity and the pressure of a fluid. An increase in velocity means a decrease in pressure. Using compressed air and an adequate gripper geometry, the object can be lifted due to the pressure reduction between the fluid stream and the object at ambient pressure. One advantage of the Bernoulli grippers for thin wafer handling is the fact that there is minimal tactile handling. According to the generated strength of the Bernoulli effect, the wafer needs to touch the gripper slightly to overcome inertia forces with static friction, especially in high-speed applications.

> "Depending on the gripper geometry and the force-generating principle, several different gripper test cycles are performed until the optimal parameter settings are determined."

Vacuum grippers operate by evacuating the ambient pressure between the handling object and a suction cup. In order to generate a vacuum and therefore a lifting force it is necessary to touch the object because without it the suction cup would not be sealed and ambient air would disturb the evacuation. The size and the amount of suction cups vary up to wafer area-covering models. A blow-off function of a gripper-independent ejector enables a faster placement. There are many different vacuum grippers available that work with enormous tactile handling for wafer or cell movement.

A recent development is [2] which uses an ultrasonic sonotrode to avoid the wafer contacting the gripper surface. Ultrasonic grippers generate lifting forces by applying a vacuum. Furthermore, they use ultrasonic waves in combination with ambient air and the sonic reflecting handling object as a spacer. A clearance of a few micrometers remains between the object and the gripper. Lateral forces which are generated by a gripper manipulation are counteracted by self-centering interactions of the vacuum and compressed air. In [2], a high accuracy is achievable with accelerations up to $3.6 m/s^2$.

The electrostatic gripping principle uses electrostatic induction as a holding force. An electric field is generated by isolated electrodes, and can be used as a chuck for fixing wafers, [3].

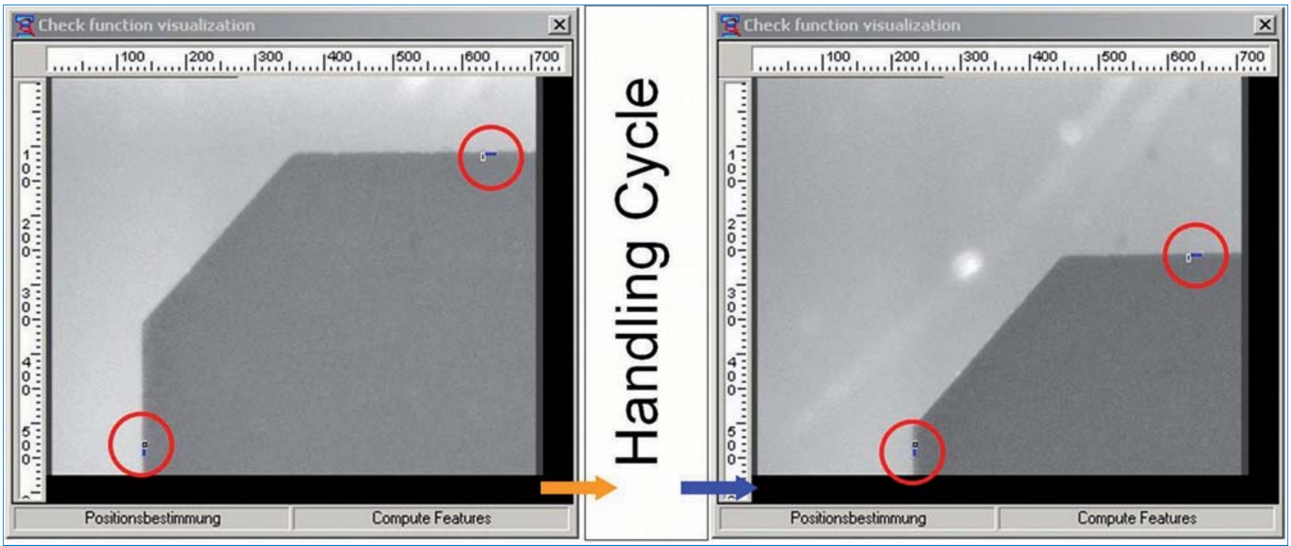


Figure 4. Position of the wafer before the test run is executed (left) and position of the wafer after the test run (right).

Handling methods and testing

The grippers shown in Table 1 were tested in a first-handling method evaluation. These grippers were primarily analyzed in terms of position accuracy and air consumption, and operated with the same cycle procedure as shown in Fig. 3.

Firstly, the program places the gripper into the specific start position A. Within the first step the gripper is moved in z-direction down to position A'. The next program command activates the pressure or vacuum valve. For the generation of gripping forces the gripper needs to wait a certain period of time, t_{pick}, at A'. A certain amount of time is needed for the pick-up process to ensure the full generation of the required gripping forces. In the following step the gripper moves in positive z-direction back to A for horizontal travelling. After a travel distance of approximately 900mm, point B is reached within the next program command. At B, the gripper waits for 100ms and then moves back to position A, before approaching A' again, at which point the active valve is deactivated. Due to the relief of pressure, a waiting time t_{place} is necessary. If the gripper allows a blow-off function, this function will be activated at that very moment. After the placement the gripper travels back to the initial position A. The gripper travels a cumulated stroke of 200mm in vertical and 1800mm in horizontal direction. The displacement of wafers, which might occur after handling, is optically measured by laboratory software and evaluated by a pre-post position comparison, shown in Fig. 4.

The accuracy of the handling system was analyzed to investigate the influence of the gripper manipulating machine. Therefore, an adapter was designed and a piece of wafer was attached to the adapter. The adapter which was assembled on the z-axis should simulate the wafer during the handling cycle. In this case the adapter is securely assembled on the machine, so that the wafer cannot slip during the transportation. The slip-off of the wafer may occur during the regular wafer transportation when the gripper carries the wafer. Instead of capturing the position of the handled wafer, the corner of the fixed wafer on the adapter was taken for the displacement measurements.

> "Oscillation of the wafer can be absorbed by a large contact area during pick-up and transportation. These oscillations may be one cause of wafer breakage."

By evaluating the pre-post comparison of the adapter positioning the deviation and thus the real accuracy of the whole system, including the measuring system and the biaxial wafer handling system, is reflected. The experiment shows that the average accuracy of the system is about 10µm for x- and y-direction. This experiment confirms the expectation that the resulting position inaccuracy of a handled wafer is mainly caused by the used gripper. A detailed analysis and evaluation of various wafer grippers will show the differences in the placement accuracy.

Results of handling tests

The grippers in Table 1 were tested and evaluated for different pressures, velocities, accelerations and distances between the gripper and the wafer during the pick-and-place operations. Due to the geometric design of the gripper, the material of the contact area and the gripping principle, the results were different. In general, the results of the experiment show that the position accuracy decreases if the acceleration or the velocity is increased. Fig. 5 shows (partial) results of the position accuracy investigation. Grippers 1 and 6 do not appear since the set suction forces were

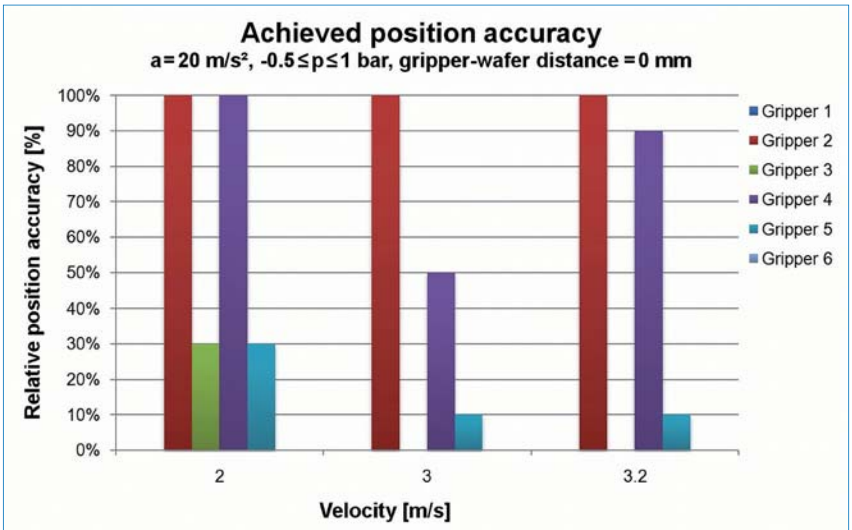


Figure 5. Dependency of restricted position accuracy and physical parameters.

insufficient in relation to the restricted position accuracy.

The results show the significant influence of the operating pressure whereas gripper 4 does not follow the general conclusion. As a result, a short cycle time is associated with an inexact gripping. The gripper tests were performed with a cycle time between 1.5 seconds to 2 seconds. The long cycle times are based on the long waiting periods during the pick-up (t_{pick} = 200ms) and the placement (t_{place} = 200ms). Short waiting times lead to slippages at the pick-up process as well as to an unregulated vacuum effect at the placement. Therefore, a short t_{pick} or t_{place} has a big influence on the position accuracy. A long cycle time can be reduced either by lowering the pressure or by using the blow-off function for the placement. If a blow-off function is applied the waiting period t_{place} can theoretically be set to 0ms.

Another point of interest is the operating pressure which is relevant not only for commercial reasons (Fig. 6). A high operating pressure is associated with high air consumption. The experiments show that in general a high operation pressure by no means results in a better position accuracy. Furthermore, a high operation pressure may lead to a fast wafer breakage with certain grippers because the wafer is highly stressed by the strong suction power. An operation pressure above 2 bar may be very harmful to the wafer if grippers 2 and 3 are applied. At 2 bar, the operation is already very loud and the position accuracies are above 400µm. A high wafer breakage rate was noted up from 3 bar. If a low operation pressure is sufficient a shorter t_{place} time is possible which again shortens the cycle time of the wafer handling.

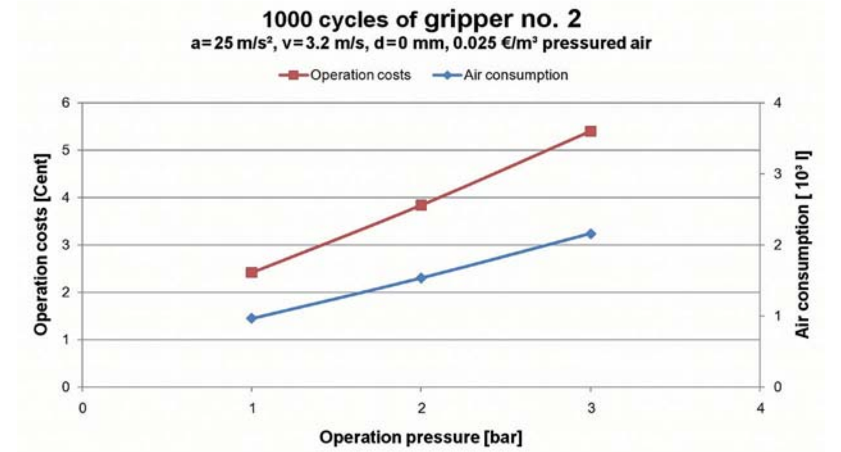


Figure 6. Relation between operation pressure, operation costs [4] and air consumption.

For vacuum grippers, a direct contact between the gripper and the wafer is necessary; otherwise the vacuum cannot be generated. Bernoulli grippers allow a variation of the gripper-wafer distance between 0mm and 3mm. However, due to a close positioning of the gripper a compressive load caused by direct contact may stress the wafer before the pick-up and the placement is performed. In addition to the high acceleration and the velocity, the risk of provoking micro-cracks or wafer breakages increases. If a certain distance between the gripper and the wafer is assured, only the suction force will affect the wafer. If the gripper-wafer distance is too large, the wafer falls down during the placement operation. Air turbulences and remaining flows of the degrading pressure can affect the position accuracy negatively if the wafer is placed by free fall. Based on that knowledge, the tested Bernoulli grippers should be operated with a gripper-wafer distance between 0.5mm and 1.5mm during the pick-up and the placement procedure.

Figure 7. Moments of a pick-up procedure with a Bernoulli gripper. Where do micro-cracks occur?

A comparison of the gripper tests with respect to the gripper size shows that those with a large gripping area can be operated with lower pressure. While gripping is optimal at 3 bar for gripper 1, grippers 2, 3 and 4 can be operated at 1 bar or even lower. In addition, oscillation of the wafer can be absorbed by a large contact area during pick-up and transportation. These oscillations may be one cause of wafer breakage. Thus, the material of the contact area also has an influence on the handling of wafers. If the contact material is hard and smooth then the static friction is lower and the suction force can be quickly generated and reduced. If the material of the contact area is soft and rough, like foam, the static friction is high on one side and the handling is very gentle at the pick-up procedure. Suction force, however, can only be generated slowly because the vacuum generation needs to overcome the material structure.

Besides the advantages, there is also a disadvantage to the large-area gripper. During the placement procedure, when the gripper releases the wafer and quickly travels away vertically, the large area of the gripper causes a strong unregulated side effect. Causing a kind of vacuum, the placed wafer becomes uncontrollably sucked by the gripper and moves slightly away from the planned end position.

Summary and outlook

The present tests at Fraunhofer IPA show that even with the newest gripper generations, the wafers with state-of-the-art thickness become heavily stressed and bowed during pick-and-place operations. By means of a handling prototype, tests can be carried out in the automation lab of the Fraunhofer IPA to investigate the physical limitations of the grippers. The typical handling processes in a thin wafer production line can be modelled and further researched with a diversity of measuring instruments. Further extension of the automation handling platform will gradually turn the laboratory handling process into an industrial application. Handling tests with some state-of-the-art grippers as well as with prototype grippers have been performed, with results suggesting that a sensible use and regulation of the operating pressure can affect the handling cycle time positively. Testing continues to be carried out on textured 120µm wafers and evaluation results are expected soon.

Acknowledgements

This work is co-funded by the **European Commission** within the 6th Framework Programme. Thanks to all partners of the **HighSol-project consortium** for their contributed work and input.

Further information can be found on www.highsol.eu.

References

[1] Reddig, K. 2009, "Overview of automation in the photovoltaic industry", *Photovoltaics International*, 4th Edition, pp. 18-29.

[2] Schilp, M. 2007, "Auslegung und Gestaltung von Werkzeugen zum berührungslosen Greifen kleiner Bauteile in der Mikromontage", Diss. TU München.

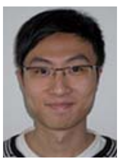
[3] ProTec Carrier Systems GmbH, information available online at http://protec-carrier-systems.com/cms/upload/Download/Broschre_Racket.pdf.

[4] Festo AG & Co. KG: "Energieeffizienz in pneumatischen Anlagen", information available online at http://p31726.typo3server.info/fileadmin/redakteure/energie_arena/pdf-Dateien/Antriebe_Juergen_Billep_Pneumatische_Anlagen.pdf.

About the Authors

Christian Fischmann is a project manager at Fraunhofer IPA. He joined the IPA in 2005 after having finished his studies in mechanical engineering at the University of Applied Sciences Konstanz. He focuses on the development and the evaluation of logistics concepts and also has experience in equipment automation in both the semiconductor and photovoltaic industry.

Tim Giesen received his diploma degree in industrial engineering from the University of Applied Sciences Kaiserslautern in 2008. After graduation he joined Fraunhofer IPA in the department of ultraclean technology and micro-manufacturing. He works in the field of production engineering, material flow automation and product development mainly in the photovoltaic industry.



Steve Gao completed his diploma thesis at Fraunhofer IPA where he worked on the analysis and the evaluation of handling issues for photovoltaic wafers. While studying mechanical engineering at the University of Stuttgart, he focused on industrial management and control technology.

Enquiries

Tim Giesen
Fraunhofer IPA
Nobelstrasse 12, 70569 Stuttgart
Germany

Email: giesen@ipa.fraunhofer.de

Dielectric coatings: agents for passivation and anti-reflection

R. Jayakrishnan, Department of Physics, Christian College Chengannur, Kerala, India; **Prakash Suratkar**, Tata BP Solar India Ltd, Bangalore, India

ABSTRACT

The key to delivering highly efficient solar cells is to absorb as much light as possible from the solar spectrum and convert it effectively into electrical energy. Anti-reflective coatings have served as agents for reducing reflective losses and improving bulk and surface passivation thus enhancing both of the parameters – short circuit current and open circuit voltage of a solar cell. Simulation studies show that an SiN/MgF dual-layer anti-reflective coating is best for a bare cell. This paper takes a closer look at how this coating can reduce the reflectance for a broad range of wavelengths and thus enhance the quantum efficiency of the cell in the blue and red region of the solar spectrum.

Introduction

Bare silicon surface reflects more than 30% of incident sunlight for wavelengths corresponding to energy greater than the band gap of silicon [1]. Minimizing reflection losses is crucial in order to produce high efficiency silicon solar cells. Single-crystal silicon (sc-Si) cells commonly use anisotropic etches to form a textured surface to reduce surface reflectance. These anisotropic etches are less effective with mc-Si-substrates because the grains have random crystal orientations [2]. Several methods have been investigated to texture mc-Si to reduce reflectance losses, including: isotropic chemical etches with masks [3]; scribing the surface with a laser [3]; mechanically texturing the surface with a dicing wheel or saw [4]; and chemically texturing the surface with anodic HF porous-silicon etchants [5].

"Single-crystal silicon (sc-Si) cells commonly use anisotropic etches to form a textured surface to reduce surface reflectance."

Mitsubishi Electric achieved an 18.9% conversion efficiency rate by introducing: 1) A 26% improved efficiency in utilizing infrared rays with a newly developed rear surface reflection structure, and 2) A low-reflective honeycomb-textured front surface to absorb more sunlight at the front surface [6]. Future highly efficient cell technologies are evolving towards methodologies of utilizing the full solar spectrum. A common thread in all these systems is the tradeoff between efficient light absorption and charge collection. Cells engineered to absorb as much light as possible exhibit decreased efficiency, because increased path lengths strongly increase energy losses by recombination of oppositely charged electrical carriers. Photovoltaics engineered to exhibit less recombination absorb little light.

An antireflection (AR) coating is a type of coating applied to the surface of a material to reduce light reflection and to increase light transmission. An AR coating plays a significant role in reducing these reflective losses in crystalline silicon substrates even after surface texturization using acidic or alkaline solutions. The coating can improve solar collection efficiency and, therefore, the overall light-to-electricity conversion efficiency. As solar radiation is broadband, the AR coating needs to be effective over the entire solar spectrum from ultraviolet and visible to IR wavelengths. A single layer of quarter-wave AR coating can give zero reflection at a specific wavelength [7]. However, it is effective only for a small wavelength range. A double-layer AR coating has also been proposed to extend the wavelength range between 450–700nm [8]. Double-layer anti-reflective coatings work on the principle of creating two reflectance minima fairly close together and keeping the interconnecting maximum as low as possible. An alternative approach to increase the bandwidth is to create an artificially modified surface structure. For example, a periodic sub-wavelength surface structure was shown to suppress reflection in the visible and near-IR wavelength regime [9]. It has been reported that a random silicon nano-tip structure can give a total reflectance of less than 1% for the wavelength regime of 200–2500nm [10].

Anti-reflection properties are dependent on the composition and thickness of the encapsulation material. Some of these ARCs serve as good agents for bulk/surface passivation, which lead to improvement in open circuit voltage (V_{oc}) of the solar cells. In this paper we review some of the best electrical results reported based on the design of an ARC and its passivation properties. The most efficient ARC in practice is the zinc sulphide/magnesium fluoride (ZnS: MgF_2) double layer, with an effective reflectance of 3.3 % [11]. A very high V_{oc} of 649mV was reported for a solar cell passivated with SiN at the front and rear surface (all-SiN cells) by Hubner et al. [12]. Duerinckx et al. has reported a V_{oc} of **621mV** and a very impressive efficiency of **17.1%** for a variety of multicrystalline substrates with resistivity in the range 0.5-1Ωcm and a cell area of 12.5cm by 12.5cm [13]. These cells were given an isotropic acidic texturing and a double-layer anti-reflection coating of SiN and MgF_2.

Anti-reflective coatings

Single-layer ARC is far from being the most efficient system because it allows a reduction in reflectance only in a narrow wavelength domain of the solar spectrum. As a result of this, the effective reflectance still represents about 11% of the incident photon flux [14]. At normal incidence, a quarter wavelength-thick single ARC layer effectively reduces the reflection to a minimum. The optimal single-layer thickness for minimum reflection at wavelength λ is defined by the equation:

$$d_{SL} = \lambda/(4n_{SL}) \qquad (1)$$

where n_{SL} is the refractive index of the single layer AR coating (SLARC). The zero reflection condition requires that the refractive index of the single layer be the geometric mean of the refractive indices of the adjacent layers and the light be at normal incidence. For a λ/4 thick coating on Si, the reflectance is given by the general equation:

$$R = ((n_0 n_{Si} - n^2_{SL})/(n_0 n_{Si} + n^2_{SL}))^2 \qquad (2)$$

Therefore, the reflectance is zero, if

$$n^2_{SL} = n_0 n_{Si} \qquad (3)$$

For the air/SLARC/Si system (considering n_0=1 for air and n_{Si}=3.87

Fab & Facilities
Materials
Cell Processing
Thin Film
PV Modules
Power Generation
Market Watch

at 640nm, for Si), the ideal values of n_{SL} and d_{SL} are 1.97 and 81nm respectively. Considering the glass/SLARC/Si system with encapsulating glass refractive index of n_g =1.55, the optimum values change to 2.45 and 65nm respectively.

Studies on double layer ARCs (DLARC) have been reported. The most stable configuration with respect to variations in film thicknesses have been found to be designs with a high refractive index (n) on the substrate and a low n towards the ambient [14]. Explanations of minima and maxima in double layers are more complex than for single layers. Two-quarter wavelength coatings of optimized indices can effectively reduce the reflectance at two wavelengths. The required refractive indices for the top and bottom layers of the dual layer ARC coating are given by the equations:

$$R_1 = ((n_0n_2 - n_1^2)/(n_0n_2 + n_1^2))^2 \text{ and}$$
$$R_2 = ((n_1n_{Si} - n_2^2)/(n_1n_{Si} + n_2^2))^2 \qquad (4)$$

Where R_1 is the reflectance of the top layer, R_2 is reflectance of the bottom layer adjacent to Si and n_1 and n_2 are the refractive indices of the top and bottom layers respectively. For zero reflectance at normal incidence, these equations reduce to:

$$n_1^2 = n_0n_2 \text{ and } n_2^2 = n_1n_{Si} \qquad (5)$$

The optimal thickness for each layer in terms of their refractive indices can be obtained using relation 1. For the air/Layer1/Layer2/Si component system, the ideal values for n_1 and d_1 are 1.57 and 102nm whereas the bottom layer parameters are 2.46 and 65nm respectively. For the glass/Layer1/Layer2/Si system, the optimum values change to 1.96/81nm for the top layer and 2.76/58nm for the bottom layer respectively. Among the various possible combinations of DLARC, combinations such as SiO_2/TiO_2, MgF_2/ZnS, MgF_2/TiO_2, SiO_2/SiN_x, and MgF_2/CeO_2 have already been reported [15, 16]. Both magnesium fluoride/zinc sulphide (MgF_2/ZnS) double layers deposited by electron beam sputtering [17] and titanium oxide (TiO_2) double layers deposited by Atmospheric Pressure Chemical Vapour Deposition [18] show very low reflectance over a broad wavelength range. However, both techniques require a separately thermally grown silicon oxide (SiO_2) layer for surface passivation.

Takato et al. demonstrated use of textured antireflection coatings for mc-Si solar cells. They showed an improvement of current and long-wavelength spectral response compared to a planar SLAR c-Si cell, which they attributed to optical confinement in the textured ZnO coating [14]. The textured-dielectric coating works optically with the module encapsulation to promote optical confinement of rays inside the module encapsulation structure, which reduces the net reflectance of the photovoltaic module. The advantage of the approach was that deposition of a textured dielectric film may be less costly and less intrusive on the cell manufacturing process than texturing multicrystalline-silicon substrates. Suitable materials for the textured dielectric coating include ZnO, TiO_2, and SnO_2; these materials have large refractive indices (~2) and have been deposited with textured surfaces and with low-cost technologies [19].

Porous silicon (PS) has been extensively investigated over the past 10 years for solar cell applications due to several advantages, including light trapping, antireflection properties, variable refractive index and solar light conversion from ultraviolet to red wavelengths [20,21]. The PS morphology depends critically on the metal type and thickness, silicon doping type and level and etching solution concentration. The resulting nano-scale texturing markedly reduces the reflectivity of the multi-crystalline silicon surface to below 6% in the spectral range 350-1000nm [22, 23].

Another method of increasing solar energy conversion is through surface plasmons, i.e., collective surface oscillations of conducting electrons in metal nanostructures that tend to trap optical waves near their surface. They enhance optical absorption, allowing for development of solar cells that circumvent the tradeoff between optical thickness and carrier transport [24,25]. Yet, because strong recombination can occur at metal surfaces in contact with the active layer of a solar cell, attempts at this approach have not been very successful, except for some cases where they were used deliberately as recombination sites. These issues have recently been circumvented by employing buffer layers between the plasmonically active material and the active layer of the solar cell [26,27]. A hybrid approach has been employed, where plasmonic effects potentially enable third generation solar-energy conversion [28].

Anti-reflective and passivation properties of multi-layer stacks

Historically, silicon dioxide films, thermally grown into the silicon surface at high temperatures, have been the preferred means used for surface passivation. Indeed, the use of silicon oxide for passivating non-diffused surfaces resulted in the first solar cells with efficiencies >21% [29,30]. The surface passivation properties of SiO_2 are excellent, but it does not passivate the bulk defects in multicrystalline silicon. Furthermore, oxidation requires high temperatures creating additional defects within multicrystalline silicon and reducing equipment throughput.

Stacks of amorphous silicon and silicon oxide – both deposited applying a PECVD system – were successfully used to passivate crystalline silicon solar cells' rear surfaces and led to a maximum cell efficiency of 21.7% on p-type (boron-doped) float zone silicon substrates with a thickness of 250μm [31].

It has been observed that the refractive index of TiO_2 can be increased from 1.9, directly after an APCVD process, to a more optimal valve for encapsulation of 2.3 if a thermal treatment at temperatures above 700°C is applied. However, TiO_2 has no surface or bulk passivation properties. Solar cells fabricated using the firing through PECVD SiN_x delivers cells which are 2.5% more efficient that the firing through APCVD TiO_2 ARC processed cells [32].

"As solar radiation is broadband, the AR coating needs to be effective over the entire solar spectrum from ultraviolet and visible to IR wavelengths."

Lauinger et al. [33,34] have shown that the quality of the surface passivation obtained for 1.5Ωcm p-type silicon is strongly affected by the deposition parameters used, as well as by the mode of PECVD deposition. They concluded that films fabricated using either remote or high frequency direct PECVD result in a lower surface recombination velocity than films prepared using low-frequency direct PECVD. Lauinger et al. also showed there is a clear correlation between the refractive index of the SiN films and their ability to passivate the silicon surface. They demonstrated that the surface passivation is maximized when SiN films with a refractive index greater than 2.3 were used, that is silicon-rich SiN films [34]. These films bring about several issues which limit their applicability to solar cells in production lines: (i) the etch rates of the films are extremely low, hindering the local opening of the SiN by means of photolithography and chemical etching; (ii) the films show a considerable absorption in the UV range of the sun spectrum, leading to a reduction of the short-circuit current; and (iii) the films are very poor insulators and cannot be used at point-contacted rears of solar cells. PECVD SiN contains between 15 to 20 at.% hydrogen [35,36] due to the high hydrogen content in the precursor gases. During the high temperature process of contact firing, the hydrogen will be released from the silicon nitride and diffuse into the silicon and passivate recombination sites in the bulk [37].

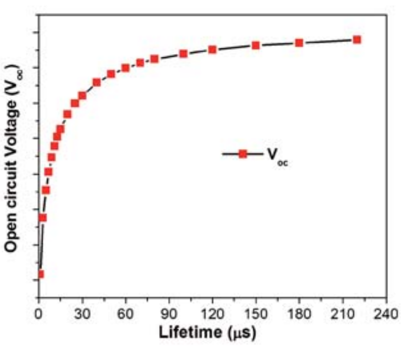


Figure 1. Effect of bulk lifetime on the open circuit voltage.

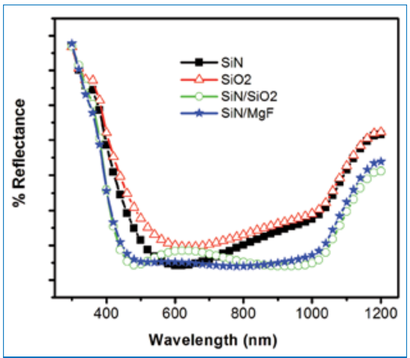


Figure 2. Relative reflectance plots based on PC1D simulation.

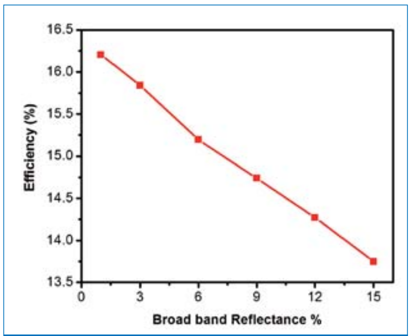


Figure 3. Cell efficiency as a function of reflectance of the single layer SiN AR coating.

Simulation studies

Gettering and hydrogen passivation improve the minority carrier lifetime in μc-silicon wafers. Bulk passivation can lead to increase in minority carrier lifetime (τ) and in effect lead to increase in open circuit voltage (V_{oc}) of the solar cell. Fig. 1 shows the effect of bulk lifetime τ on the V_{oc} based on PC1D simulation. For typical industrial phosphorus diffusions with sheet resistances in the vicinity of 50Ω/sq, there is minimal difference in the passivation quality obtained with PECVD SiN compared to any of the oxides or the oxide/nitride stacks. Conventional forming gas anneals of the finished cells are known to improve carrier lifetime up to 90μs.

From the perspective of optimizing the reflective properties of the ARC coatings we present the results of the simulation studies done on different dielectric combinations. As seen in Fig. 2, single-layer AR coatings are out-performed by the multilayer AR coating in terms of the broad range of wavelengths for which the coatings are effective. The simulation clearly shows the advantage in lowering the reflectivity while using the SiN single layer compared to the SiO_2 single layer. The average weighted reflectance is lower for single-layer SiN compared to any single- or double-layer ARC; however it is limted by the bandwidth of the AR coating. The SiN/MgF combination appears to be the best in terms of flatness of the response achieved from the overlapping of the minima of the individual layers. The simulation is done assuming there are no absorption losses in the layers. The simulation also shows that a ~2mV gain in V_{oc} can be delivered (provided all other cell parameters are unaltered) by the SiN/MgF stack compared to the single layer of SiN. Typically for the 12.5 x 12.5cm^2 Si solar cell, a 1mV gain in V_{oc} can deliver ~0.024% absolute increase in efficiency so that the 2mV gain can deliver a ~0.048% absolute increase in efficiency. The SiN/SiO_2 stack appears to be the best industrially feasible approach of improving the cell response both at the red and blue end of the spectrum.

Another study we carried out was to quantify the gain attainable by improving the reflective properties based on PC1D simulation. We started with the assumption of a single-layer broad band SiN AR coating with average reflectance of 15% at the quarter-wave thickness for a 12.5 x 12.5cm^2 c-Si solar cell. Fixing all other cell parameters for the simulation and varying only the reflectance from 15% to 1%, the variation in electrical performance of the cells was studied. The cell efficiency as a function of the reflectance is plotted in Fig. 3. Increase in short circuit current I_{sc} with decrease in reflectance was the most evident contributor to improved cell efficiency. Our calculations show that for the 12.5 x 12.5cm^2 cell, and for a decrease in broadband reflectance from 15% to 1%, the short circuit current I_{sc} increases by ~0.85A. For the 12.5 x 12.5cm^2 Si solar cell, a 1mA increase in I_{sc} can deliver a ~0.0028% absolute increase in efficiency so that the 850mA increase in Isc can deliver a ~2.38% absolute increase in efficiency.

Conclusions

Most of the commercially available cell technologies today use single-layer or dual coating with weighted average reflectance of ~8%. AR coating technologies that can reduce average reflectance below 3% are much sought after. The limitation on actual production lines that are unable to tap these potential technologies is in the inability of the screen-printed contacts to fire through the AR coatings of dielectric multi-layers and form proper front contacts. With the evolution of back contact cells and alternate paste, the possibility of implementing such multilayer stacks is being pursued widely. From an industry perspective, the most widely used AR coating today is the single- or dual-layer SiN based on the compromise between throughput, equipment availability and volume demands. The coming age presents a challenge to production lines on their ability to adapt to these new designs and find alternatives to complement minor snags put forth by such technological changes.

References

[1] Kumar Dhungel, S., Yoo, J., Kim, K., Jung, S., Ghosh, S. & Yi, J. 2006, "Double-Layer Antireflection Coating of MgF_2/SiN_x for Crystalline Silicon Solar Cells", *Journal of the Korean Physical Society*, Vol. 49, No. 3, pp. 885-889.

[2] Macdonald, D.H., Cuevas, A., Kerr, M.J., Samundsett, C., Ruby, D., Winderbaum, S. & Leo, A. 2004, "Texturing industrial multicrystalline silicon solar cells", *Solar Energy*, Vol. 76, Issues 1-3, pp. 277-283.

[3] Narayanan, S., Zolper, J., Yun, F., Wenham, S.R., Sproul, A.B., Chong, C.M. & Green, M.A. 1990, "18% Efficiency Polycrystalline Silicon Solar Cells", *21st IEEE PVSC*, pp. 678-680, DOI: 10.1109/PVSC.1990.111706.

[4] Nakaya, H., Nishida, M., Takeda, Y., Moriuchi, S., Tonegawa, T., Machida, T. & Nunoi, T. 1993, "Polycrystalline silicon solar cells with v-grooved surface", *Techn. Digest of the 7th Intern. Photovoltaic Science and Engineering Conf.*, pp. 91-92.

[5] Tsuo, Y.S., Xiao, Y., Heben, M.J., Wu, X., Pern, F.J. & Deb, S.K. 1993, "Potential applications of porous silicon in photovoltaics", *Proc. 23rd IEEE Photovoltaic Specialist Conf.*, Louisville, KY, USA, pp. 287-293.

[6] Shimomura, S. 2009, available online at https://www.mitsubishielectricsolar.com/news/download_file.php?file=1243468174Mitsubishi%20Electric%20Breaks%20Own%20Record%20With%20World.pdf

[7] Fowles, G.R. 1975, *Introduction to Modern Optics*, Dover Publications, pp. 99–100.

[8] Aroutiounuian, V.M., Martirosyan, Kh. & Soukiassian, P. 2006, "Almost zero reflectance of a silicon oxynitride/porous silicon double layer antireflection coating for silicon photovoltaic cells", *J. Phys. D: Appl. Phys*. Vol. 39, pp. 1623-1625, Mar. 2006.

[9] Kanamori, Y., Sasaki, M. & Hane, K. 1999, "Broadband antireflection

gratings fabricated upon silicon substrates", *Opt. Lett.*, Vol. 24, pp.1422-1424.

[10] Huang, Y., Chattopadhyay, S., Jen, Y., Peng, C., Liu, T., Hsu, Y., Pan, C., Lo, H., Hsu, C., Chang, Y., Lee, C., Chen, K. & Chen, L. 2007, "Improved broadband and quasi-omnidirectional anti-reflection properties with biomimetic silicon nanostructures", *Nat. Nanotechnol.* Vol. 2, pp. 770-774.

[11] Strehlke, S., Bastide, S., Guillet, J. & Lévy-Clément, C. 2000, "Design of porous silicon antireflection coatings for silicon solar cells", *Mat. Sci. Eng. B*, Vol. 69, pp. 81-86.

[12] Hübner, A., Aberle, A.G. & Hezel, R. 1997, "20% Efficient Bifacial Silicon Solar Cells", *14th European Photovoltaic Solar Energy Conference*, Barcelona, Spain, pp. 92-95.

[13] Duerinckx, F. & Szlufcik, J. 2002, "Defect passivation of industrial multicrystalline solar cells based on PECVD silicon nitride", *Sol. Energy. Mater. Sol. Cells*, Vol. 72, pp. 231-246.

[14] Bouhafs, D., Moussi, A., Chikouche, A. & Ruiz, J.M. 1998, "Design and simulation of antireflection coating systems for optoelectronic devices: Application to silicon solar cells", *Sol. Energy Mater. Sol. Cells*, Vol. 52, pp. 79-93.

[15] Richards, B.S., Rowlands, S.F., Honsberg, C.B. & Cotter, J.E. 2003, "TiO2 DLAR coatings for planar silicon solar cells", *Prog. Photovolt. Res. Appl.* Vol. 11, pp. 27-32.

[16] Morales-Acevedo, A., Luna-Arredondo, E. & Santana, G. 2002, "Double anti-reflection layers for silicon solar cells obtained by spin-on", *Proceedings of the 29th IEEE PVSC*, New Orleans, LA, USA, pp. 293-295.

[17] Cid, M., Stem, N., Brunetti, C., Beloto, A.F. & Ramos, C.A.S. 1998, "Improvements in anti-reflection coatings for high efficiency silicon solar cells", *Surface and Coatings Technology*, Vol. 106, pp. 117–120.

[18] Richards, B.S. 2003, "Single-material TiO_2 double-layer antireflection coatings", *Sol. Energy Mater. Sol. Cells*, Vol. 79, pp. 369-390.

[19] Takato, H., Yamanaka, M., Hayashi, Y., Shimokawa, R., Hide, R., Gohda, S., Nagamine, F. & Tsuboi, H. 1992, "Effects of Optical Confinement in Textured Antireflection Coating using ZnO Films for Solar Cells", *Japn. J. Appl. Phys.*, Vol. 31, pp. L1665-L1667.

[20] Yu Yerokhov, V. & Melnyk, I.I. 1999, "Porous silicon in solar cell structures: a review of achievements and modern directions of further use", *Renew. Sustain. Energy Rev.* Vol. 3, p. 291.

[21] Bilyalov, R.R., Lüdemann, R., Wettling, W., Stalmans, L., Poortmans, J., Nijs, J., Schirone, L., Sotgiu, G., Strehlke, S. & Lévy-Clément, C. 2000, "Multicrystalline silicon solar cells with porous silicon emitter", *Sol. Energy Mater. Sol. Cells*, Vol. 60, pp. 391-420.

[22] Koynov, S., Brandt, M.S. & Stutzmann, M. 2007, "Black multi-crystalline silicon solar cells", *Phys. stat. sol.* (RRL) 1, R53-R55.

[23] Koynov, S., Brandt, M.S. & Stutzmann, M. 2006, "Black nonreflecting silicon surfaces for solar cells", *Appl. Phys. Lett.*, Vol. 88, pp. 203107.

[24] Jiang, J., Bosnick, K., Maillard, M. & Brus, L. 2003, "Single molecule Raman spectroscopy at the junctions of large Ag nanocrystals", *J. Phys. Chem. B*, Vol. 107, no. 37, pp. 9964-9972.

[25] Rand, B., Peumans, P. & Forrest, S. 2004, "Long-range absorption enhancement in organic tandem thin-film solar cells containing silver nanoclusters", *J. Appl. Phys.* Vol. 96, no. 12, pp. 7519-7526.

[26] Morfa, A., et.al. 2008, "Plasmon-enhanced solar energy conversion in organic bulk heterojunction photovoltaics", *Appl. Phys. Lett.* Vol. 92, no. 1, pp. 013504.

[27] Reilly, T., van de Lagemaat, J., Tenent, R., Morfa, A. & Rowlen, K. 2008, "Surface-plasmon enhanced transparent electrodes in organic photovoltaics", *Appl. Phys. Lett.* Vol. 92, no. 24, pp. 243304.

[28] Johnson, J., Reilly, T., Kanarr, A. & van de Lagemaat, J. 2009, "The ultrafast photophysics of pentacene coupled to surface plasmon active nanohole films", *J. Phys. Chem. C*, Vol. 113, no. 16, pp. 6871-6877.

[29] King, R.R., Sinton, R.A. & Swanson, R.M. 1989, "Doped surfaces in one sun, pointcontact solar cells", *Appl. Phys. Lett.*, Vol. 54 (15), pp. 1460-1462.

[30] Blakers, A.W., et. al. 1989, "22.8% Efficient Silicon Solar Cells" *Appl. Phys. Lett.*, Vol. 55 (13), pp. 1363-1365.

[31] Hofmann, M., et.al. 2009, "PECVD a-Si layers for industrial high efficiency solar cell processing", *Photovoltaics International*, 4th edition, p. 68, 2009.

[32] Szlufcik, J., et. al. 2000, "Advanced Concepts of Industrial technologies of Crystalline Silicon Solar Cells", *Opto-Electronics Review 8(4)*, pp.299-306.

[33] Lauinger, T., Moschner, J.D., Aberle, A.G. & Hezel, R. 1998, "Optimization and characterization of remote plasma-enhanced chamical vapor deposition silicon nitride for the passivation of p-type crystalline silicon surfaces", *J. Vac. Sci. Technol. A*, Vol. 16 (2), pp. 530-543.

[34] Lauinger, T., Aberle, A.G. & Hezel, R. 1997, "Comparison of Direct and Remote PECVD Silicon Nitride Films for Low Temperature Surface Passivation of P-type Crystalline Silicon", *14th EU PVSEC*, Barcelona, Spain, pp. 853-856.

[35] Mittelstadt, L., Metz, A., Hezel, R. 2002, "Hydrogen passivation of defects in EFG ribbon silicon", *Sol. Energy Mater. Sol. Cells*, Vol. 72, pp. 255–261.

[36] Hughey, M.P. & Cook, R.F. 2004, "Massive stress changes in plasma-enhanced chemical vapor deposited silicon nitride films on thermal cycling", *Thin Solid Filmss*, Vol. 460, pp. 7–16.

[37] Sopori, B.L., et. al. 1996, "Hydrogen in silicon: A discussion of Diffusion and passivation mechanisms", *Sol. Energy Mater. Sol. Cells*, Vols. 41/42, pp. 159-169.

About the Authors

R. Jayakrishnan completed his Ph.D. in thin-film solar cells at Cochin University of Science and Technology and has over six years of academic and industrial experience. He worked with Hind High Vacuum and Tata-BP Solar prior to joining Christian College, Chengannur where presently he is a lecturer in physics.

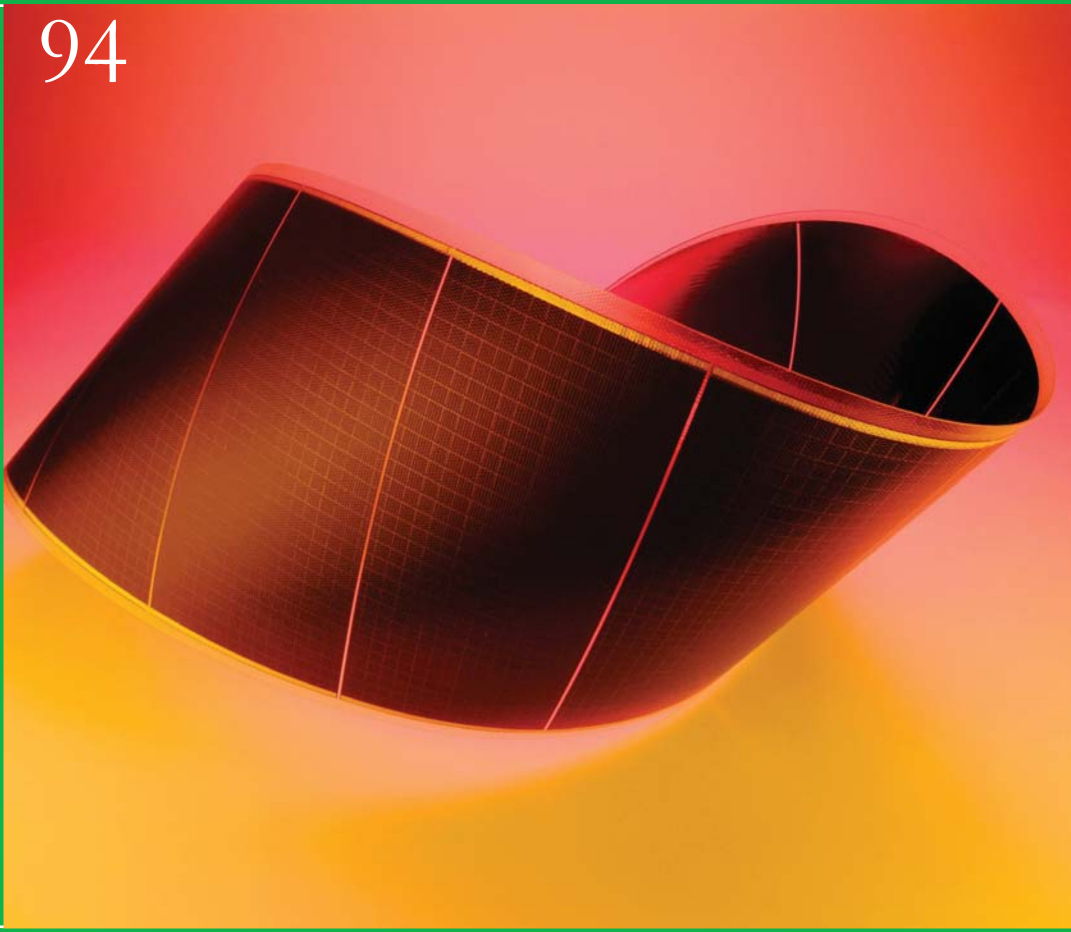
Prakash Suratkar completed his post-graduate studies at the University of Mumbai and has 23 years of experience in research and development of Si and GaAs semiconductor devices. He worked with Infineon Technologies and Lucent Technologies-Bell lab prior to working with Tata-BP Solar where presently he serves as the General Manager of Technology.

Enquiries

R. Jayakrishnan
Department of Physics
Christian College Chengannur
Kerala
India-689122
Email: rjayakrishnan2002@yahoo.co.in

Prakash Suratkar
Tata BP Solar India Ltd.
Bangalore
India-560100

Thin Film



News

First Solar maxed out

Source: First Solar

First Solar thin-film module installation.

Demand for First Solar's CdTe thin-film modules nearly exceeded supply in the third quarter as major projects were completed and the company's German rebate program came into full effect. First Solar expects demand to exceed supply for installations in the fourth quarter and expects to enter 2010 with low inventories. First Solar produced 292MW during the third quarter, 1% over the prior quarter as all lines including those in Malaysia were fully ramped, shipping its entire production during the 12-week period.

Production improvements continued as First Solar's current 22 lines' annual run rate was 53MW, up 2.5% over the second quarter due to improved throughput and conversion efficiency improvements. The thin-film leader noted that average conversion efficiencies had reached 11% in the quarter, up 0.1% compared with the previous quarter.

Cost per watt produced also declined slightly to US$0.85, down US$0.02 or 2.3% sequentially, due to lower material cost as well as the impact from higher throughput and conversion efficiencies seen in the quarter. With the completion of ramps in Malaysia and the reconfiguration of the Ohio line, First Solar guided full-year capital expenditure at between US$260 million and US$275 million. Capital expenditure for the fourth quarter was said to be in the range of US$50 million to US$65 million.

Business News Focus

AT&M, Odersun plan joint venture in Beijing

Advanced Technology & Materials (AT&M) and Odersun AG are planning to form a joint venture in Beijing, China, for the production and sales of solar cells and modules from Odersun's CIS thin-film technology. The construction of the facilities in Beijing is anticipated to begin in 2010. The two companies began working together in 2004 when AT&M was an investor in Odersun and a partner in many of their joint research projects. They look at this new JV as a way to take advantage of the growing PV industry in China.

G24i ships dye-sensitized solar cell modules to Mascotte for consumer electronics bags

G24 Innovations has sent what it calls the first commercial shipment of flexible dye-sensitized solar modules to Mascotte Industrial Associates, a Hong Kong-based consumer electronics bag manufacturer. The G24i DSSC units, which are produced on the company's roll-to-roll production line in Wales, will be integrated into a range of products, including backpacks and camera bags.

The G24i module is based on a technology invented by Michael Grätzel, director of the Laboratory of Photonics and Interfaces at the Swiss Federal Institute of Technology in Lausanne. The company first acquired a license to manufacture the technology in 2006, with unlimited worldwide distribution rights.

G24i says that this announcement is the first of a number of commercial partnerships under active development. As it builds its manufacturing to mass production levels, the company is focused on expanding the DSSC product portfolio through R&D and partnerships with other consumer product manufacturers, including the forthcoming "Power Up Your Products" program allowing developers to use DSSC in their products and applications.

Major executive shuffling at Applied Materials as solar segments combined

Applied Materials has made important changes to its organization and senior executive positions as Tom St. Dennis, senior vice president and general manager of Applied's Silicon Systems Group and its main source of revenue, has resigned from the company. The main beneficiary within Applied's corporate ranks would seem to be Randhir Thakur as he will take over the running of the Silicon Systems Group. Thakur had only recently been tasked with running Applied's SunFab thin-film operations and was the senior vice president and general manager of the Display and SunFab Solar Group.

A key change in the organizational structure of the company will see the merging of crystalline silicon and thin-film sections into its existing Energy and Environmental Solutions (EES) division. Thin-film, which was the primary focus of the SunFab operations, was previously aligned with the LCD flat panel arm, where much of the technology for thin-film originated. Mark Pinto (pictured) has been given the role of running the EES division as senior vice president and general manager but will also continue as CTO at Applied.

Source: Applied Materials

Applied Materials' senior vice president and general manager, Mark Pinto.

Source: Signet Solar

230 kW installation, Signet Solar's factory in Mochau, Germany.

eIQ, Signet Solar to offer bundling agreement for solar energy installations

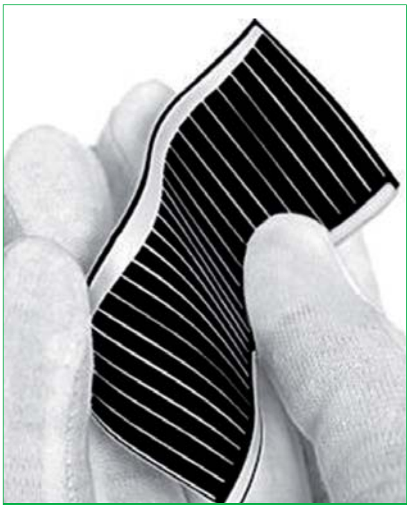
eIQ Energy and Signet Solar have agreed to a bundling agreement to help its customers streamline the building of a solar energy installation. The agreement calls for the use of Signet's thin-film solar modules and eIQ's parallel solar technology to be marketed by both companies. One SKU number for both products will make ordering more convenient for all customers.

"These are products that go hand-in-hand," commented Dr. Keshav Prasad, Signet Solar's vice president of business development. "We want to provide value up and down the solar energy chain, and for our customers, this takes the guesswork out of working with different parts – we've done the background work." The parallel solar method potentially provides a 5-10% decrease in balance-of-system costs by lowering the need for junction boxes, custom cabling and other hardware. Orders for the bundle are being taken now for delivery in Q1 of 2010.

Research and Development
News Focus

Fraunhofer ISE verifies 13.4% conversion efficiencies for Solarion's plastic CIGS cells

The Fraunhofer Institute for Solar Energy Systems has independently verified record conversion efficiencies of 13.4% for Solarion's copper-indium-gallium-(di) selenide photovoltaic cells on a plastic substrate. The 20cm-wide CIGS cells, which do not have an antireflective coating, were processed on the company's roll-to-roll pilot production line.

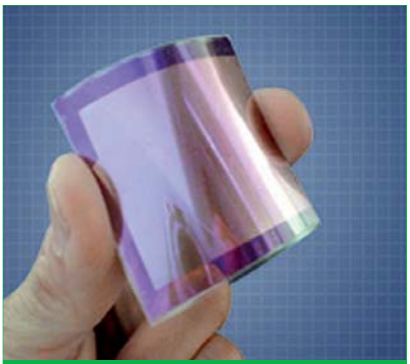

Solarion's plastic CIGS cell.

The Leipzig, Germany-based firm did not specify whether the results achieved by Fraunhofer ISE were for full-area or active-area efficiencies. Ascent Solar, another thin-film PV company developing CIGS-on-plastic cells, has seen NREL-verified efficiencies of 10.4% on modules from its production line.

Solarion says that its patented ion beam process for producing the CIGS absorber allows for a reduced process temperature and thus enables the use of a flexible polymer substrate. Solarion, which was founded in 2000, will enter into volume production in 2010. The first product will be a frameless module using its CIGS cells in a glass-glass encapsulation approach.

Ampulse secures US$8 million funding for development of new Film-Silicon technology

Ampulse Corporation disclosed its US$8 million Series A funding co-led by Globespan Capital Partners and El Dorado Ventures, who are joined now by existing investors Battelle Ventures and its affiliate fund, Innovation Valley Partners. As a direct result of the funding, Daniel Leff of Globespan and Jeff Hinck of El Dorado Ventures have been appointed to Ampulse's board of directors.


Ampulse Film-Silicon technology.

Ampulse is developing what they term as film-silicon technology which is a thin-film PV technology that optimizes crystalline silicon energy conversion efficiency while lowering manufacturing costs for existing silicon based technologies. The company's film-silicon product uses hot-wire chemical vapour deposition techniques to place a thin layer of crystalline silicon onto a flexible metallic substrate. Ampulse aims to offer lower cost, high-throughput fabrication of high efficiency flexible cells utilizing the industry's traditional PV equipment; offer double the gain in module efficiency; a 75% reduction of cost; a 60-time reduction in layer thickness; a 60-time reduction in deposition process time; and the elimination of the need to insert multiple junctions at slow deposition rates.

Ascent Solar tops 14% CIGS cell efficiency, averages 10.5%-plus on modules; signs deal with FTL

The U.S. National Renewable Energy Laboratory has validated conversion efficiencies of 14.1% for flexible copper-indium-gallium-(di)selenide (CIGS) solar-cell materials produced on Ascent Solar's 1.5MW commercial pilot line in Littleton, CO. The company's internal testing shows active-area peak efficiencies for its full-size monolithically integrated CIGS-on-polyimide modules reaching 11.7%, with median efficiencies on the line averaging between 10.5 and 11%-plus, according to president/CEO Farhad Moghadam.

Earlier this year, NREL measured peak module efficiencies of up to 10.4% after the company had stated 10% module efficiencies as its goal for 2010, when it plans to ramp up its 30MW volume production line. Ascent now believes it can hit a 12% median mark.

In other news, Ascent said that it will be providing modules to FTL Solar for that company's R&D contract with the New York State Energy Research and Development Authority (NYSERDA). The parties will work on the development of FTL's lightweight, flexible tensile structures integrated with Ascent's CIGS panels.

The development work will be carried out under a US$22,500 collaborative agreement between FTL Solar and the Center for Advanced Microelectronic Manufacturing (CAMM) in Endicott, and the Center for Autonomous Solar at Binghamton University.

Ascent Solar Flexible CIGS cell.

Sunovia claims dramatic increase in CdTe thin-film performance

Although yet to be independently verified, Sunovia Energy Technologies and partner EPIR Technologies have claimed a dramatic increase in the performance of cadmium telluride (CdTe) based solar cells. According to the company it has shattered the previous world record for open circuit voltage (V_{oc}) readings by 45%. Sunovia said that an open circuit voltages of 1.34 V and 1.75 V were achieved with a single-junction and two-junction configurations, respectively.

The 1.34 V value for the single-junction cell was more than 95% of the theoretical upper limit for the II-VI alloy used. Sunovia said that the highest reported V_{oc} for a CdTe solar cell was 0.91 V, representing about 76% of the theoretical maximum for CdTe. The partners claimed that its two-junction II-VI cell would reach production efficiencies over 35%.

"These are by far the highest V_{oc} measurements ever exhibited by a CdTe-based solar cell. There is no data in the literature that comes close to what we have achieved, and we believe that our two-junction device also represents the first ever high efficiency monolithic, two-junction solar cell using CdTe or any other II-VI material," noted Dr. Michael Carmody, Senior Director for Development of Photovoltaic Materials at EPIR Technologies. "The company's two-junction II-VI on Silicon design will reach production efficiencies over 35% and will cost only a small fraction of the cost of three-junction III-V solar cells. Three-junction II-VI on Silicon cells will have even higher production efficiencies without much added cost."

Oerlikon Solar uses TCO contacts to reach 10% efficiencies with single-junction a-Si cell

Verified by the National Renewable Energy Laboratory (NREL), Oerlikon Solar has repeatedly reproduced amorphous silicon (a-Si) single-junction PV cells with stabilized conversion efficiencies of over 10%. This marks a new record for single-junction cells and was achieved with the use of the company's proprietary TCO front- and back-contact technology.

"We successfully implemented several innovative modifications of key processes, leading to this new record in stabilized cell efficiency which presents a historic milestone for amorphous silicon technology," noted Dr. Johannes Meier, CTO of Thin Film at Oerlikon Solar: "We are confident that our ability to repeatedly achieve record results can be transferred into mass production soon."

The company said that it expects to have customers in commercial production with this technology by the end of 2010 and to achieve module conversion efficiencies of 10% or more.

Applied Materials cuts IEC-certified SunFab materials costs by 22%

As developments to the company's SunFab thin-film module manufacturing line continue, Applied Materials has managed to cut the cost of materials on the line by 22%. The company's next-generation module technology was applied to establish some process efficiency updates, coupled with new lower pricing arrangements with materials suppliers.

Applied has also gained IEC certification from TÜV Intercert for SunFab panels that will be using these new lower-cost materials and processes for aperture area conversion efficiencies of up to 9.7%. The certification applies to both single and tandem-junction modules in all panel sizes. This is good news for those customers wishing to upgrade panel performance without having to seek additional certification.

Testing and Certification News Focus

Fraunhofer ISE certifies 6.07% conversion efficiency for Heliatek OPV cells

Fraunhofer ISE has certified a power conversion efficiency of 6.07% for tandem solar cells from organic photovoltaics developer Heliatek. The cells, which have an active area of 2 cm², were developed by the company in cooperation with the Institute of Applied Photo Physics of the Technical University of Dresden based on results of the projects "Innoprofile" and "OPEG", both sponsored by BMBF. Heliatek uses small molecule organic dyes synthesized from hydrocarbons to make proprietary tandem organic thin-

Solar and LED equipment bookings push Veeco's order backlog to record levels

Veeco Instruments has returned a small profit (US$1.3 million) for the first time in over a year, boosted by record quarterly bookings of US$226 million, which was dominated by LED and solar sectors, making up approximately 80% (US$179 million) of the bookings. Veeco noted that its equipment backlog now stood at US$287 million, with US$239M in LED & Solar.

"Momentum continued in our CIGS solar business in the third quarter, with a second key customer win for our 'FastFlex' Web Coating Systems and a repeat multi-million dollar order for thermal deposition components from a leading CIGS manufacturer," commented John R. Peeler, Veeco's Chief Executive Officer.

Veeco also said that it was seeing strong interest in its thermal deposition systems for CIGS thin film production and was well positioned to capture market share. Third quarter revenue reached US$99 million, well above its guidance of US$80-88 million.

Signet Solar, Tejados Fotovoltaica de Industriales sign 10MW TFPV module supply deal

Signet Solar and Tejados Fotovoltaica de Industriales Group have signed a definitive module supply agreement for Signet to supply to the Spanish EPC company, TIF, a minimum of 10MW of single-junction amorphous-silicon thin-film PV modules for shipments before the end of June 2010. The deal also calls for a continued panel supply relationship for the remainder of 2010 and in future years.

Signet, which has more than 15 solar farm and commercial rooftop installations in the U.S. and Europe, recently announced the introduction of its 400W single-junction a-Si TFPV module as well as the development of a 1.8MW project with BSC-Solar in the Czech Republic.

GroupSat places multi-million dollar order for CIGS equipment with Veeco

GroupSat has placed a multi-million dollar order with Veeco Instruments for its suite of 'FastFlex' Web Coating Systems used for CIGS deposition. The multiple systems order comprises of one TCO (Transparent Conductive Oxide) deposition system and two CIGS deposition systems. The tools will be shipped to GroupSat's factory in Suzhou, China. CIGS production capacity is estimated to grow from 264MW in 2009 to 1.7GW in 2012, generating a CAGR of 86%.

GroupSat places multi-million dollar order with RENA for new CIGS thin-film plant

As part of its plans to build a thin-film CIGS solar cell production line in Mudu, Suzhou China, GroupSat has placed an initial multi-million dollar purchase order with RENA for its complement of inline cleaning and inline CdS deposition systems. According to RENA, it expects a follow-on order after the first shipments are made during the fourth quarter of 2009. GroupSat wants to expand production capacity to 100MW by 2011. The equipment orders for RENA follow quickly after Veeco won a supply deal with GroupSat for its complete line of 'FastFlex' Web Coating Systems.

4JET receives multiple laser-based edge deletion system orders for CIGS, a-Si and CdTe

Laser-based equipment supplier, 4JET has said that it has received multiple new orders for edge deletion equipment used for thin-film cell processing. The orders came from CIGS, a-Si and CdTe thin-film manufacturers. 4JET also received an order for its proprietary MEX system, which is used for the exposure of molybdenum in CIGS solar panels. This system is an alternative process to abrasive brushing.

Start-up BrightView Systems integrates and validates TFPV process monitoring tool at Signet Solar

Israeli start-up BrightView Systems says it has successfully integrated and validated its wide-area metrology system for thin-film photovoltaics producers at Signet Solar's amorphous-silicon TFPV manufacturing line in Mochau, Germany. The WAM tool has demonstrated its contribution to both panel efficiency and line productivity via its unique in-line, true-cell-metrology and measurement capabilities and associated suite of control applications for excursion detection, chamber matching, and process window optimization, the companies said.

Signet recognized the value of improving line output and long-term panel reliability, and embedded the system into its production flow. The thin-film company says it was able, for the first time, to implement fully automated, continuous full-panel process monitoring and feedback on 100% of production panels and greatly reduced its reliance on offline measurements and special test panel cycles.

GroupSat places multi-SunLink enters supply agreement with Nanosolar

SunLink has announced its supply agreement with Nanosolar to develop and supply a custom, flat-roof system that is the favoured mounting solution for Nanosolar. The Nanosolar SunLink roof system was conceived as part of the largest single Solar America Initiative awarded by the U.S. Department of Energy.

XsunX and Intevac join forces to develop CIGS equipment and techniques

XsunX, developer of thin-film PV solar cell technologies and manufacturing processes, and Intevac, provider of magnetic media deposition equipment to the hard disk drive (HDD) industry, are working under a Joint Business Agreement to develop techniques and equipment for the production of commercially marketable processes and equipment for the manufacture of CIGS thin-film solar cells. Through the combination of cross-industry specialties, XsunX and Intevac plan to develop a new breed of thin-film PV manufacturing techniques to produce thin-film solar cells.

By joining forces, the companies plan to effectively combine their experience in each industry. Both companies are adapting high-rate production tools from the disk drive industry with process knowledge from the CIGS and thin-film industry. This approach focuses on maintaining a relatively small deposition area; initially about five-inch squares similar in size to silicon solar wafers, which the companies believe reduces a significant challenge that has faced the CIGS industry in the past: maintaining cell performance while scaling commercial production.

Manz Automation gains €5 million in bookings from EU PVSEC

In attending the 24th European Photovoltaic Solar Energy Conference and Exhibition, held in Hamburg in September, Manz Automation has said that it has secured orders and orders of intent worth €5 million. Manz expects the orders to be recognized in revenues and earnings in the coming fiscal year. This year, EU PVSEC attracted over 40,000 attendees.

Manz secured €20 million in direct new orders from last year's event. Manz also said that it had gained a new customer in the form of thin film start-up, Malibu GmbH which is focused on the BIPV market. Malibu is a joint venture of E.ON AG and Schüco International KG.

film cells, which it hopes to integrate into flexible, lightweight (about 0.5kg/m_2) solar modules that will be manufactured on foil substrates in a continuous roll-to-roll vacuum coating process. The company, which calls the results an "important milestone" on the way to commercialization of its OPV cells, has a medium-term goal of increasing the conversion efficiency to 10%. Heliatek will work with Fraunhofer IPMS, home of the Center for Organic Materials and Electronic Devices Dresden, to make the technology ready for mass production, leveraging expertise garnered in similar efforts with the development of organic LEDs and other electronic devices. Other technology partners of Heliatek include Novaled, Bosch, and BASF; the latter two have also invested in the company along with Wellington Partners and others.

MiaSolé receives certifications for thin-film solar modules

MiaSolé has received ceritification of standards UL 1703 and IEC 61646 and 61730 for its 100 and 107W CIGS thin-film solar modules. The three certifications were given simultaneously. MiaSolé is a California-based manufacturer of solar panels, utilizing thin-film CIGS semiconductors.

HelioSphera receives TÜV certification

HelioSphera's micromorph thin-film PV modules have received IEC61646:2008 and IEC61730:2004 certification and their factory has passed inspection by TÜV Rheinland. The TÜV certification is applicable to the standard glass on glass laminate and the new Venus series module, which was tested at TÜV and received a positive result for the IEC norms.

"This qualification is a major milestone in our business journey. The TÜV certification is the internationally leading standard for quality, and testifies our operational excellence and ability to supply our customers with high reliability, high efficiency thin-film modules at top quality standards. HelioSphera's vision is to provide high return beautiful solar power solutions, everywhere, everyday. Today is another critical step on realizing our vision", said Thierry Bodiot, CEO at HelioSphera.

Source: HelioSphera

HelioSphera's micromorph module.

Module Production News Focus

Signet introduces 400W single-junction silicon module

In conjunction with the celebration of its first full year of production, Signet Solar is releasing its 400W single-junction thin-film module. The TÜV-certified module's volume production began in October 2008 with commercially available equipment. The SJ thin-film module is reported to provide 15% higher output and reduce balance of system costs by 7-10%. Signet says its production line is operating at full capacity.

Signet Solar's thin-film PV modules.

Masdar PV starts shipping thin-film modules: 3MW production capacity

Shipments of Masdar PV's first 5.7 m² a-Si thin-film solar modules have begun from its fab in Ichtershausen, Germany. The modules are being used in an unidentified ground-mounted solar park, also in Germany. The thin-film start-up also said that the ramp of production would reach 3MW by the end of 2009 and is considering locating a further manufacturing plant in North America, subject to market demand and not before the end of 2010.

News

Product Briefings

Product Briefings

BTU International

BTU International's 'Perseas' Platform handles pilot to production CdTe thermal processing

Product Briefing Outline: BTU International has launched a product platform designed specifically for the thermal processing steps of cadmium telluride (CdTe) thin-film photovoltaic cells, dubbed 'Perseas.' The Perseas platform is designed as a solution for companies at both stages in their growth plans.

Problem: CdTe thin-film manufacturing requirements are rapidly evolving and require machines capable of pilot line and full volume production with the necessary scalability and yield. Not only is complete atmospheric containment a prerequisite, but process parameters independent of production throughput are also required.

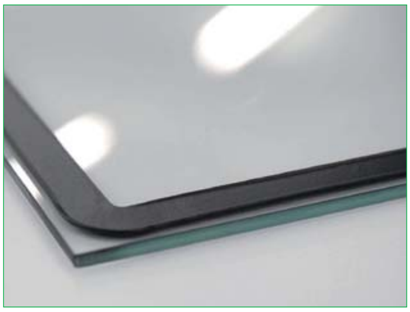
Solution: The platform is scalable from R&D to pilot and to production-sized units. The Perseas-CA is designed for the chlorine annealing process while the Perseas-CF is for the contact formation process with maximum operating temperatures of 300°C and 600°C respectively. Complete atmospheric containment is provided while cross-belt uniformity of ±5°C or better is achieved, enabling consistent yield results. An ultrasonic belt cleaner reduces particle build-up in the system. In addition, the platform is compatible with both glass and web substrates.

Applications: CdTe thin-film photovoltaic cells. Perseas-CA is designed for chlorine annealing and Perseas-CF is for the contact formation.

Platform: Each of the tools is scalable for R&D, pilot, and volume production-sized operations with a maximum throughput of between 50-150 panels per hour. Unique Active 'Load Monitoring' technology can increase yield by reducing the likelihood of scrapped panels. The platform can handle glass substrates of up to 1.3m in width and can have custom heated lengths configurable between nine and 24 zones. Features include: cooling lengths configurable between three and nine zones; profile cooling rates from 0.5°C/sec to 1.5°C/sec; adjustable profile dwell time; profile ramp rates up to 3°C/sec. Profile soak times up to 40 minutes.

Availability: Currently available.

Komax



New hot melt sealing equipment by Komax enables precise and continuous application of butyl

Product Briefing Outline: Komax has developed new sealing equipment for thin-film modules that enables a continuous and precise hot melt dispensing of high-viscous butyl. The hot application of the butyl improves the adhesion and therefore the protection of the module against humidity. The higher accuracy of the hot melt butyl placement (compared to the commonly used butyl stripes) allows a simpler system for the EVA or PVB cutting and marriage. In addition, the dispensing out of barrels enables a 24-hour operation without material exchange.

Problem: Thin-film solar cells are sealed with butyl tape to protect the active layers from humidity. The commonly used butyl tape is extruded onto a liner and provided on a reel. However, the tolerances of the liner as well as of the tape are high and the small reels need to be exchanged several times per operating shift. In addition, the adhesion of the tape is very sensitive to the cleanness of the glass.

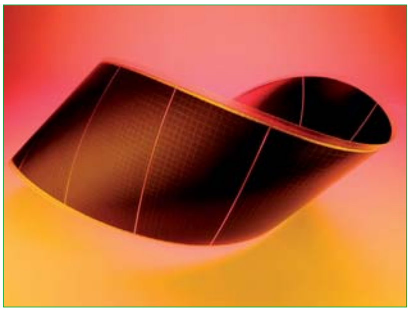
Solution: With the new hot melt sealing equipment from Komax, the butyl is not extruded onto a liner, but directly onto the glass. Through this method, one process step can be eliminated and material costs are reduced. The high-viscous butyl is pumped from a barrel to dispensing head. The shape of the butyl can be easily adapted to the required width and height. A 200kg barrel will be consumed in approximately two days, whereas a butyl reel lasts only for about one hour. In addition, the application with the hot melt dispenser leads to an improved adhesion and a higher accuracy. A higher accuracy enables the use of a simpler foil cutting and marriage equipment.

Applications: Thin-film photovoltaic modules (substrates as well as superstrates).

Platform: Komax supplies equipment for crystalline module production and for thin-film back-end module production.

Availability: Currently available.

DuPont



DuPont's Solamet PV412 PV metallization paste handles flexible thin films

Product Briefing Outline: DuPont has introduced its new 'Solamet' PV412 photovoltaic metallization paste, the latest in a line of silver conductor materials specifically developed for thin-film PV technologies. DuPont collaborated with Ascent Solar Technologies (ASTI), a developer of flexible thin-film solar modules, as it developed the new metallization paste.

Problem: The main purpose of the low temperature curing silver paste is for use as a front-side current collector grid and bus bar to reduce the resistive losses due to the relatively low conductivity of the transparent conductive oxide (TCO) layer used in thin-film PV devices.

Solution: Solamet PV412 photovoltaic metallization paste is designed for use on devices where a transparent conductive oxide (TCO) is utilized. It is ideal for use with CIGS, a-Si on flexible substrates, and heterojunction with intrinsic thin layers (HIT) PV cells, and is also suitable for any PV application where a low temperature curing conductor is required. Key features include fine line printing down to 80µm resolution, long screen residence time for robust printer operation, low contact resistance, low gridline resistance, high adhesion to indium tin oxide, and strong compatibility with most transparent conductive oxides.

Applications: Microcrystalline silicon (µc-Si)/a-Si - silver grid & bus bar, CIGS - silver grid & bus bar, Heterojunction - silver grid & bus bar, Cadmium Telluride (CdTe) - carbon ink (back contact).

Platform: Low temperature curing silver paste.

Availability: Currently available.

Product Briefings

Schenk Vision

Schenk Vision's I-V Curve Tracer enables correlation of optical inspection and efficiency tests

Product Briefing Outline: Schenk Vision has launched the I-V Curve Tracer from the SolarMeasure product family that enables correlation of optical inspection and efficiency tests (I-V curve) for thin-film PV production lines. Schenk has developed a new technology that is complimentary to flashers but enables an early feedback on the module efficiency.

Problem: 'Indirect metrology tests' – for example the measurement of pinhole density, layer thickness or haze monitoring – enable the manufacturer to evaluate the module quality and give an early warning as soon as a process step no longer meets the preset tolerances. These indirect measurements alone cannot make a prediction about the final electrical efficiency of the solar panel.

Solution: The I-V Curve Tracer is intended to meet challenges that flashers cannot overcome on a thin-film PV production line. Unlike conventional flasher tests, this measurement can be performed in-line before the lamination step and can thus serve as a GO/NO-GO tester to decide whether a panel is further processed. By matching the efficiency results with data from the indirect measurements of the SolarInspect and SolarMeasure systems, manufacturers can make immediate and long-term correlations between local defects and panel efficiency. Corrective actions can be taken as early as possible and production costs can be reduced.

Applications: Measurement of the I-V curves of thin-film modules before lamination.

Platform: The fully-automated system is based on a proprietary LED illumination technology which enables an evaluation of the electrical characteristics of the entire thin-film panel, as well as the detection of local variations. It enables uniquely electrical characterization via Space-Resolved Measurement; Wavelength-Resolved Measurement and Irradiance-Resolved Measurement.

Availability: Currently available.

Dunmore Corp.

Dunmore Corp. introduces new backsheet product for flexible thin-film PV

Product Briefing Outline: Dunmore Corp. has introduced a new backsheet product for flexible thin-film PV, the 'DUN-SOLAR'1700 TAPE, which has a four-layer construction (Tedlar, aluminum, polyester and polyethylene). Although other photovoltaic modules currently offer higher efficiencies, lower manufacturing costs make the thin-film PV cells made with DUN-SOLAR 1700 TAPE more economical. The new product is in full production and available for use in thin-film photovoltaic solar cell manufacturing.

Problem: Flexible thin-film materials are more difficult to seal compared to glass/glass and aluminum fixed-frame assemblies. Problems have existed with moisture entrenchment as well as bonding with new encapsulants.

Solution: This new backsheet product effectively creates a high vapour barrier measuring at less than 0.5mg/m^2 per day to protect the thin-film technology. The backsheet is economically viable while at the same time bonding to a new breed of low Moisture Vapor Transmission Rate (MVTR) encapsulants like the DNP Thermoplastic to hermetically seal in the cells.

Applications: Encapsulation of flexible thin-film PV, including CIGS, a-Si, CdTe and dye-sensitized solar cells (DSSC).

Platform: Dunmore has just received UL recognition for DUN-SOLAR 1100 FPE, its fluorinated polyester backsheet for c-Si modules. This 290µm film laminate provides improved resistance to extreme weather conditions and dielectric performance in a PET film with a fluorinated surface construction.

Availability: Currently available.

VAT

VAT's roll coater transfer valve ensures tight seal on foil without damage

Product Briefing Outline: Vacuum valve specialist VAT introduced a new transfer valve for high vacuum roll coater systems. One challenge for roll coater valves is to reach a small leak rate at the gate during clamping of the foil (metal or plastic foils). VAT is able to offer for this difficult sealing configuration a quad O-Ring seal with intermediate pumping port. With the quad seal differentially pumped sealing configuration, it is possible to achieve a leak rate of 1x10^{-7}mbar l/s at foil thickness up to 0.2mm. The combination of the MonoVAT sealing technology with the quad seal configuration delivers a vacuum tight seal between the process chamber and the roll load/unload chambers while clamping the foil without causing damage.

Problem: The main challenge with roll coater valves is to seal the clamped foil in a closed valve position. High leak rates can result in process equipment failure and increased down time.

Solution: The key element of a roll coater valve is the seal configuration between the gate (moving part) and valve seat (static part). These two components define how the foil is clamped and sealed. The new roll coater valve is equipped at the seal points (seat and gate) with double O-Rings and an intermediate pumping port. For sealing of the foil on the bottom and top side over the whole width, it is essential to place a seal on each side. A further improvement of the vacuum performance has been reached by using a second seal on each side (four in total) in combination with an intermediate pumping port. By pumping between the four seals, the leak rate especially at the edges of the foil can be reduced.

Applications: Vacuum-based thin-film roll coater systems (CIGS, a-Si, CdTe, Organic cells, etc.).

Platform: The valve is available in aluminium or stainless steel with a wide range of options, including slit sizes from height 15-50mm x length 300-1750mm in both full body and insert configurations.

Availability: Currently available.

Product Briefings

Solar Metrology

In–situ XRF tool for CIGS from Solar Metrology caters for high volume production

Product Briefing Outline: Solar Metrology, a provider of X-Ray Fluorescence (XRF) analysis tools, has expanded its SMX XRF tool portfolio for film composition and thickness measurement of CIGS photovoltaic depositions with the addition of the System SMX-ISI.

Problem: The properties of TFPV films are notoriously difficult to measure due to their special optical properties. This is compounded by the high-volume production requirements of thin-film substrates and the impact the wrong composition can have on decreasing efficiency and manufacturing yield.

Solution: Solar Metrology's System SMX-ISI is an in-situ x-ray fluorescence (XRF) metrology tool platform that provides composition and thickness measurements for thin-film solar PV metal film stacks on flexible roll-to-roll substrates such as stainless steel, aluminum and polyimide or rigid substrates such as float glass. SMX-ISI is incorporated into the process at a clean vacuum insertion point. The x-ray head is bolted to a specially designed port (see picture), allowing x-rays to pass in and out of the process vessel. The free-standing X-Ray Control Station (with available light pole alarm system) may be positioned either adjacent to or removed from the process. A single SMX-ISI control station is capable of controlling multiple Ethernet-linked x-ray head modules. Static SMX-ISI configurations position the x-ray head at a stationary location along the web or glass panel line. Linear SMX-ISI configurations are designed to facilitate cross-web or panel gradient analysis, and may incorporate multiple vacuum/x-ray interface ports

Applications: Typical measurement applications include Mo thickness and all CIGS combinations (including all CIG alloys and/or film combinations and final CIGS formulations).

Platform: SMX-ISI is fast, flexible and easily integrated into any vacuum deposition tool or vacuum process station or point of a vacuum process line. SMX-ISI utilizes x-ray fluorescence – an enabling technology for CIGS manufacture – that delivers yield management and yield improvement by allowing in-situ process control. The SMX-ISI tool Platform does not affect the process since all SMX-ISI tool components reside outside of vacuum for optimum performance and serviceability.

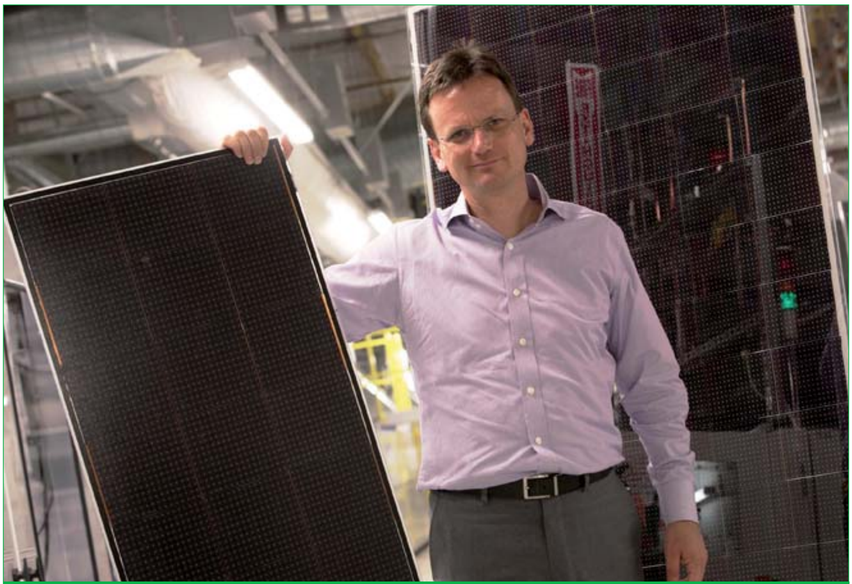
Availability: Currently available.

News

Printed PV: Nanosolar unveils 640MW utility-scale panel fab, high-efficiency CIGS cell production

By **Tom Cheyney**

After staying relatively quiet for much of the past year, thin-film PV manufacturer Nanosolar came out with a full docket of announcements on 9/9/09: the completion of its major panel-assembly factory near Berlin; the start of serial roll-to-roll production of its flexible copper-indium-gallium-(di)selenide cells in the company's San Jose facility; $4.1 billion in panel purchases from customers – including some of the world's largest utility companies; NREL-verified cell efficiencies up to 16.4%; and new technical details of both its printed CIGS cell technology and utility-scale panels.



Photos by Wilhelm Breuer, Courtesy of Nanosolar

Nanosolar president/CEO Martin Roscheisen stands tall next to CIGS modules.

The panel-making facility, located in Luckenwalde (about 60 kilometres south of Berlin), can operate at a production rate of one panel every 10 seconds and is capable of reaching a peak capacity of 640MW when operated around the clock, according to Nanosolar.

Referred to by TÜV Rheinland inspectors as "a factory unlike any we've ever seen," the plant incorporates a fully automated robotic line integrated with a sophisticated in-line quality control measurement system to string and assemble the individually sorted and tested cells into panels. One innovative part of the production line is a high-throughput stack lamination technique developed with a "leading provider of lamination equipment."

The German panel factory is supplied with flexible aluminum-foil cells produced at the venture-backed company's fab in San Jose. Nanosolar, which prints its cells using a proprietary CIGS ink in a mostly non-vacuum, low-cost process sequence, says it began serial production on its R2R processing line earlier this year.

"Getting to the point of serial production with the unusual extent of innovation and leapfrog cost reduction involved in our technology and delivering a product that out of the gate meets and exceeds the high bar set by the industry's existing volume manufacturers on performance and reliability is an accomplishment due to the incredibly hard work and perseverance of our team," said Nanosolar president/CEO Martin Roscheisen.

"As far as process complexity, we almost never ever had a problem with the nanoparticle printing process," he elucidated. "This process basically always works. High-vacuum tools, which we still use for the electrodes, turned out [to be] more hassle than we wished for. So in a curious way, this surely validated our business plan.

"There's a host of R&D activities to continue to drive the agenda we have had of simplifying the manufacturing of thin-film solar cells. In fact, through the five generations of pilot tools we have developed, we have basically reinvented many processes more than once already."

Nanosolar has worked "strategically with production tooling partners on each tool," noted Roscheisen. "We only build pilot tools in-house. We do not find it scalable to build production tools ourselves, so we have a best-of-breed partner in each category."

Although the San Jose facility is calibrated for rapid growth, current production is running at a subcapacity baseload rate of about 1MW per month, according to Nanosolar. Web widths run up to 1500mm on the cell line, while certain process steps can attain throughputs as high as 40m/min, he explained. A full roll of processed, unsingulated PV foil is equivalent to 100KW.

"We see excellent down-web uniformity almost naturally," Roscheisen said of the R2R line. "We have also achieved sufficient cross-web uniformity but only after some tooling modifications."

The exec also spoke of the "huge amount of inline metrology in place, including things that are unprecedented. It's been a huge effort and investment area of ours. According to engineers on our team who have worked at First Solar and other leading manufacturers, what we have on that is on a completely different level, (although) I cannot comment further as this is a very proprietary area."

The San Jose plant will be ramped in sync with the company's market-introduction plan, which it says focuses on achieving "product bankability" with commercial banks and delivering on the company's $4.1 billion in contractual customer commitments.

"With almost all large solar installations credit financed, broad-based product bankability is our key next commercial goal," stated Roscheisen. "We have long prepared for this, including through the technology choices we have made, the strong balance sheet we have maintained, the quality of customers we have secured, and the local production we have built."

The product coming off those automated assembly lines in Luckenwalde is Nanosolar's initial commercial offering, the Utility Panel – what it calls the industry's first solar electricity module specifically designed as well as electrically and mechanically optimized for utility-scale solar power systems.

Nanosolar's fully automated panel assembly factory is rated at an annual capacity of 640MW.

Featuring an innovative design scheme, the company says the IEC 61646-certified panel effectively eliminates the "balance-of-system penalty" that medium-efficient thin panels from First Solar and others have conventionally carried relative to higher-efficiency, more-expensive crystalline-silicon panels.

The Utility Panel is the industry's highest-current thin module, by up to a factor of six, according to Nanosolar, and is also the first PV module certified by TÜV for a system voltage of 1500V – about 50% higher than the next highest certified device. The combination of enhanced current and voltage enables utility-scale panel array lengths and results in a host of substantial balance-of-system cost savings, the company says.

On the mechanical side, the panel package employs a dual-tempered glass/glass design housing the flex cells, which is distinctly stronger than that of conventional thin-film-on-glass modules, achieving about 70% greater mounting span, thus facilitating substantially lower mounting costs, the company states.

The full panels as well as their components and materials have been put through a wide range of rigorous indoor and outdoor reliability and performance testing, done internally and with third-party firms, in a variety of geographic and climate conditions, and are certified under various IEC, UL, and other standards, according to Nanosolar.

One of Nanosolar's customized internal testing procedures is a thermal freeze stress test, which led the company to make changes in the panel materials in order to optimize the coefficients of thermal expansion across all layers. "We don't mind others copying this test, in fact would suggest so," Roscheisen explained. "Our attitude is that if others' panels fail in the field, this only hurts everyone else too."

"We have a huge effort on testing and are in fact expanding this even further," he continued. "We believe the standard tests are limited in some ways. We are interested in looking at combinations of stresses as well as various forms of dynamic behaviour."

While the company exec said that his company has "all of the certifications we require," he did note that "we obviously need to resubmit panels on an ongoing basis for recertification as we change process or components or power ratings."

The company has run side-by-side comparisons with both First Solar's cadmium telluride units and crystalline-silicon panels. Roscheisen said the results are indicative of "the usual thing one would expect: First Solar has atypically good low-low-light efficiency, which is in part an artifact of their semiconductor and their cell series resistance not being optimized for full-sun irradiation. But given that 0.1 suns only contribute a tenth of the kilowatt-hour as a full sun, this is of limited impact. The critical zone is at 0.3 to 0.4 suns, where it gets more interesting."

Nanosolar's gameplan includes taking on the thin-film PV market leader and pulling away from its compatriots in the CIGS sector. "We are planning to demonstrate that we are three times as capital efficient as First Solar," he explained. "By depositing thin films directly onto glass, First Solar is limited in the types and sizes of glass it can use with existing cell production investment. We believe this will be limiting."

Citing what the company believes to be the lowest-cost foil substrate, a proprietary metal wrap-through architecture, high materials utilization, and a mostly non-vacuum cell-making process among Nanosolar's differentiating advantages, Roscheisen believes that "just because it's CIGS, does not mean it's lower-cost than CdTe and First Solar specifically. In fact, according to our cost models, it takes quite a lot of innovation and effort to make CIGS actually come in at lower cost than the First Solar baseline."

"People at times forget that First Solar does have a very high throughput

Nanosolar uses a proprietary ink-based process on its roll-to-roll CIGS solar-cell production line.

semiconductor deposition process–more economic than any high-vacuum process as typically required for CIGS," he pointed out. "I don't see how high-vacuum CIGS can compete with First Solar."

Roscheisen thinks that "for solar to go to big scale at low price points, there is no way of doing so without supreme capital efficiency of production. If your price point to capex ratio is one, you can't grow even at 30% a year without being an eternal black hole for cash flows.

"We are quite pleased about the extent to which we are beating our original business plan on capital efficiency; we are on a very good track there and have many more things in the pipeline along these lines," he said.

Although Nanosolar has not as yet installed megawatt-level amounts of its panels in the field, Roscheisen does not see this as a disadvantage. "Our past installations were more focused on the quality with which we obtain accurate and independently verified data from them than their quantity and size," he said. "So in terms of watts, this doesn't add up to all that much. But it's very accurate data in many different locations."

"We are presently completing a first megawatt-scale project and have several further ones in the pipeline," he said, adding that the company has "a solution for commercial rooftops using our Utility Panel and we are planning to offer a solution for the residential market."

On the cell side, the National Renewable Energy Laboratory (NREL) has independently verified that the company's metal-wrap-through, back-contact, printed-CIGS-on-metal-foil devices produced on its Gen 3 line have reached active-area conversion efficiencies as high as 16.4% during tests conducted earlier this year. "Our lab and production teams have managed to make more progress on efficiency than we had planned on in any of our business plans," smiled Roscheisen.

Noting that "we print CIGS onto inexpensive metal foil, something that some have been skeptical can work while others have been wondering whether it can deliver cells better than 6% efficient," he explained that the latest efficiency numbers for the foil cells actually "represent two world records in one: It's the most efficient printed solar cell of any kind (all semiconductor and device technologies) as well as the most efficient cell on a truly low-cost metal foil (with a material cost of only a cent or two per square foot and mil thickness)."

Going beyond the champion cell results, Roscheisen reveals that "in terms of our current baseline production process, our best production rolls now achieve higher than 11% median efficiency measured as equivalent to panel efficiency, with very tight cross- and down-web uniformity."

Moving forward on the conversion efficiency improvement curve, the company exec said Nanosolar "obviously has some rather detailed plans and models on this," although he would not go into detail on which engineering pathways – optical, contact, grain boundary, band, and dopant – were being exploited to drive those efficiencies higher. "We believe we can gain a few more points within the existing framework through a number of known knobs."

NREL's Miguel Contreras, the senior scientist who supervises the CIGS group at the national lab, said that his team has supported Nanosolar "with official measurements, characterization, transferring the know-how we have in making 20% solar cells in the labs. We showed them what the [film] structures look like, what they should shoot for, to improve their own processes and materials – that was our strongest contribution to them."

But he gives full credit to Nanosolar, saying "truly, it's to their merit on most or all of the work that's been done. We just helped a little bit in their success, and I'm proud and honoured to be part of that effort."

This feature is an edited version of two Chip Shots blogs originally published at PV-Tech.org, where the entire exclusive interview with Nanosolar President/CEO Martin Roscheisen can be found. Free, downloadable technical white papers about the company's CIGS solar cell and Utility Panel technologies are available at www.nanosolar.com.

Comparison of different ceramic Al-doped ZnO target materials

V. Sittinger, **W. Dewald**, **W. Werner** & **B. Szyszka**, Fraunhofer Institute for Surface Engineering and Thin Films (IST), Braunschweig, Germany; **F. Ruske**, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany

ABSTRACT

Highly conductive transparent films are of significant interest in the field of thin-film photovoltaics. ZnO-based films in particular have attracted much interest due to the low cost of materials with good film properties for CIGS and a-Si/μc-Si solar modules. Investigations have been ongoing at Fraunhofer IST into ceramic ZnO:Al_2O_3 targets from different manufacturers. This paper presents a comparison of target material, sputter characteristics and film properties of ZnO:Al. Sputter characteristics are in this case determined by voltage and current data showing arcing rates at different power loads and process pressures. ZnO:Al films are deposited by DC magnetron sputtering with various deposition parameters (e.g. oxygen flow, total pressure, sputtering power and substrate temperature) and investigated with respect to optical and electrical properties. A correlation between film properties, sputter characteristics and target material can therefore be determined. As it appears that arcing has the biggest influence on film properties, the ceramic target material can be optimized for minimal arcing.

Introduction

On a global scale, around 30 different companies use Cu(In,Ga)$(Se,S)_2$ as the absorber material for their thin-film solar modules [1]. Reduction of production cost is desirable for future production, either at the deposition process of individual films or by lowering the encapsulation effort. The final film deposited in the module stack is a transparent front contact on top of the absorber and intermediate layers, usually consisting of Al-doped zinc oxide (AZO) and deposited by magnetron sputtering. This process is crucial for overall performance, as high sheet resistance, low transmission or insufficient damp heat stability can severely limit module performance.

In industrial production of chalcopyrite solar modules, magnetron sputtering is the standard deposition technique for transparent front contacts. It is easy to scale up, for example, substrates of up to 18m^2 in area are coated by sputtering

Thin Film

Process	DC excitation at 0kHz, AE Pinnacle Plus generator, PK 750 cathode		
System parameters	Distance target-substrate	dST	90mm
	Target material		$ZnO:Al_3O_3$ (A-D)
	Argon gas flow	qAr	200, 198, 196 sccm
Process parameters	Mixing gas flow		
90% Ar, 10% O_2	qMG	0, 2, 4 sccm	
	Substrate temperature	TS	150, 200°C
	Discharge power	P	4, 6, 8kW
	Total pressure	ptot	0.2, 0.6, 1Pa
	Substrate		Float glass, AF45 glass, Si

Table 1. Deposition parameters for the Al-doped ZnO films presented in this paper. Deposition was carried out in the A700V vertical in-line coater at Fraunhofer IST.

	Result
Density	95–99% TD
Resistivity	0.8–7.0*$10^{-3}\Omega$cm
Phase composition	96% ZnO (hex.) 4% $ZnAl_2O_4$ (cub.)
Impurity	Purity 3N

Table 2. Result of different target material properties.

with architectural glazings. For the TCO film, the cost is determined by both the film quality that can be obtained and the process involved. If a the conductivity of a TCO film can be doubled by a certain deposition process, in general a film of half the thickness will be sufficient for the solar cell in general. This is not only beneficial for the saved material, but thinner films will also absorb less light.

"In industrial production of chalcopyrite solar modules, magnetron sputtering is the standard deposition technique for transparent front contacts."

In the AZO deposition process, the films can be deposited by sputtering of ceramic $ZnO:Al_2O_3$ targets or by reactive sputtering of metallic Zn:Al targets [2]. In the latter case, oxygen is introduced as reactive gas. Consequently, a metallic target of the same thickness as a ceramic target can reach longer operation times and more absorber area can be coated without the need for changing the target. Coupled with the much lower cost for a metallic target, this means that the cost for the TCO film will be considerably lower for films sputtered from metallic targets as compared to films sputtered from ceramic ones.

Unfortunately in the case of reactively sputtered TCO films it is more difficult to realize homogeneous electrical and optical properties on large-area substrates [3,4]. It is also more difficult to stabilize the operating point at low substrate temperatures (i.e. below 200ºC). Furthermore, the substrate temperature during deposition of AZO on chalcopyrite absorbers is limited to 200ºC. Therefore ceramic targets are still used, preferably as rotatable tube targets.

Experimental

AZO target materials from four different manufacturers have been benchmarked at Fraunhofer IST. This process involved the target materials being evaluated for structural analysis by XRD measurements with a Panalytical MRD Pro using Cu K_α radiation. GDMS (glow discharge mass spectrometry) was used for elemental analysis. Resistivity of the target materials was determined by Hall measurements at room temperature using van der Pauw geometry. The microstructures were investigated using a LEO 1530 field emission scanning electron microscope (SEM).

We operated a PK750 cathode in the Leybold A700V in-line coater with DC excitation by an Advanced Energy Pinnacle Plus power supply operating at pure DC. For evaluation of the sputter behaviour, current-voltage characteristics as well as arc characteristics were determined using the detection system of the power supply.

In order to get a correlation of target material, sputter conditions and the film quality, a screening design of different parameters like pressure, oxygen gas flow and power was carried out at two different temperatures (150°C and 200°C) (see Fig. 1).

The gas flow of argon and oxygen was always kept constant at 200 sccm (standard cubic centimetres per minute). The deposition conditions using ordinary float glass as substrate are summarized in Table 1. In order to determine if there are disturbance variables, the sequence of depositions with different screening parameters were randomized and the series was repeated. This was done for temperatures of 150°C (series 1 and 2) and 200°C (series 3 and 4).

Film thickness was determined by setting optical transmittance and reflection from 250 to 2500nm (Varian Cary-5) and spectroscopic ellipsometry at variable angle (SEVA) from 250 to 850nm (Sentech SE 850). The dielectric function was established using a model for the fundamental absorption proposed by Leng and a model for the IR free carrier absorption as proposed by Sernelius [5]. The visual absorption α_V was determined by convolution of the measured spectral transmission with the spectral sensitivity of the human eye. Sheet resistance was measured with a four-point probe and the resistivity calculated from the obtained thickness and sheet resistance.

Results

Characterization of the target material

The application of AZO in different products, e.g. thin-film solar cells (CIGS or micromorph silicon) or architectural glazing can vary the role of the target material. Therefore the material has to be optimized for its special purpose. It is also important for customers that material from different producers shows film properties that are as comparable and constant as possible. For this reason the target material of the four different target producers was characterized in order to find a correlation between the ceramic materials, the sputter behaviour and the obtained film properties.

Table 2 shows the results of different target material properties. The target density showed no influence on the arcing behaviour of the sputtered target material in the measured range, nor was there any correlation of the varied target resistivity on arcing or on the target voltage.

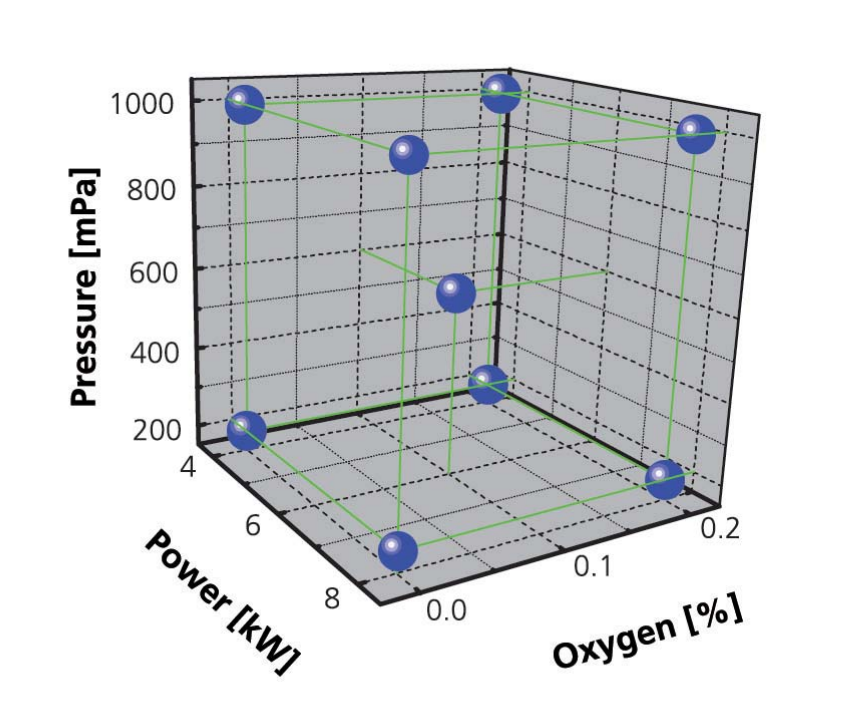


Figure 1. Chosen parameter variation for screening.

> "All targets examined by XRD showed an identical phase composition consisting of the same amount of ZnO and gahnite ($ZnAl_2O_4$)."

All targets examined by XRD showed an identical phase composition consisting of the same amount of ZnO and gahnite ($ZnAl_2O_4$). The impurity level of the ceramic materials determined by GDMS was 3N or better. The majority of the elements are below 10 ppm. One target showed a slightly higher Fe and Si content, which probably has some influence on arcing. All materials' microstructures (SEM) and element distribution (EDX) were measured, which showed a broad range of variation, thus proving the main influence of the arcing behaviour.

Sputter characteristics

Prior to film deposition, the targets were first pre-sputtered under different power and pressure conditions in order to obtain information on the current-voltage characteristics and their arcing behaviour. All materials were problem-free during the pre-sputtering process; micro-arcing was the only behaviour exhibited, which correlates with the different material characteristics. The micro arcs increased with higher pressure and higher power.

However, the targets showed slightly different current-voltage behaviour (see Fig. 2). Although target A showed a lower voltage, which was not reproducible during the sputtering of the films, it also showed an extremely small micro-arc rate, which was reproducible. Thus all targets demonstrated similar current-voltage behaviour, leading us to conclude that the resistivity of the target material has no influence on arcing.

Film properties

All targets were sputtered under the same conditions using the aforementioned screening. Sputtering was carried out on every target at one temperature and varying pressure, power and oxygen flow within one day to restrict potential troubles from disturbance variables. By default, the deposited films were then evaluated with respect to their optical and electrical

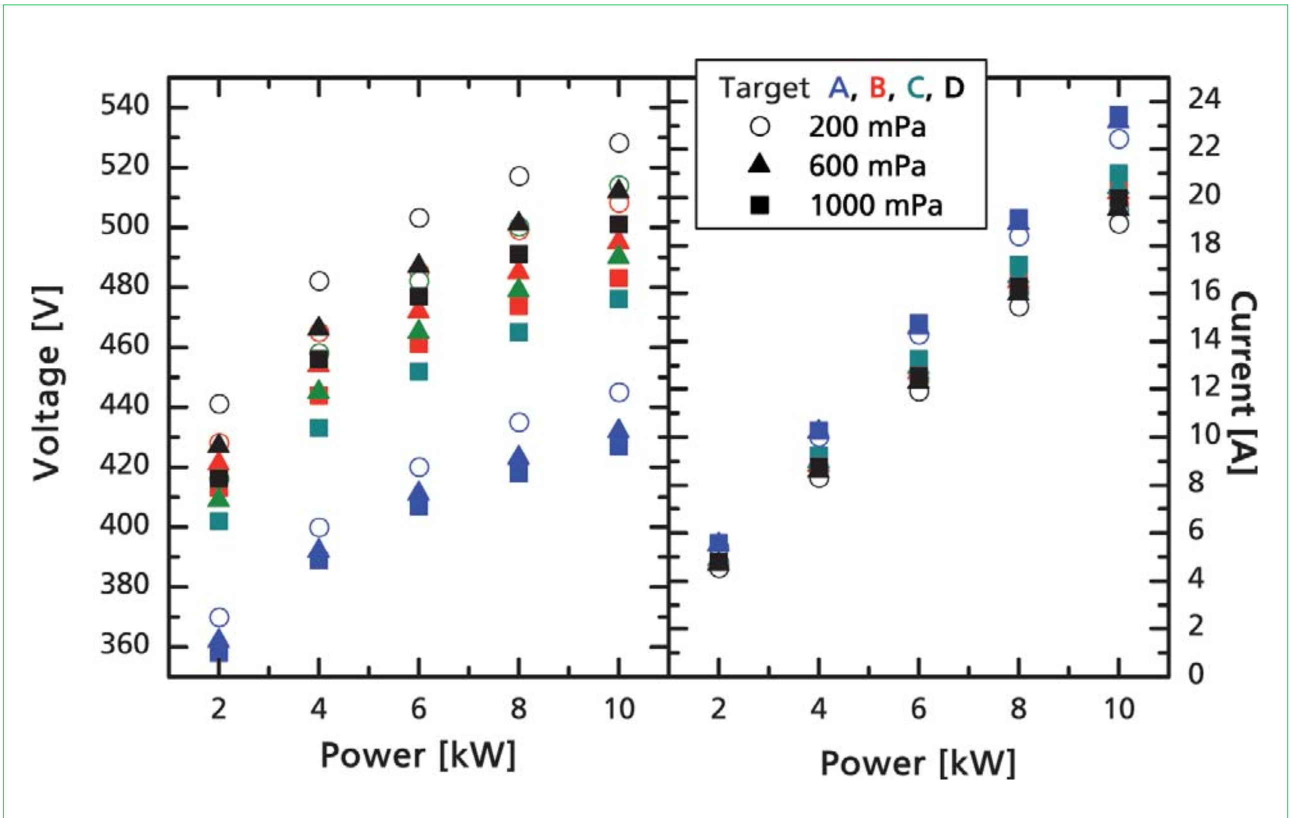


Figure 2. Target voltage and current as a function of power for different total pressure and target material.

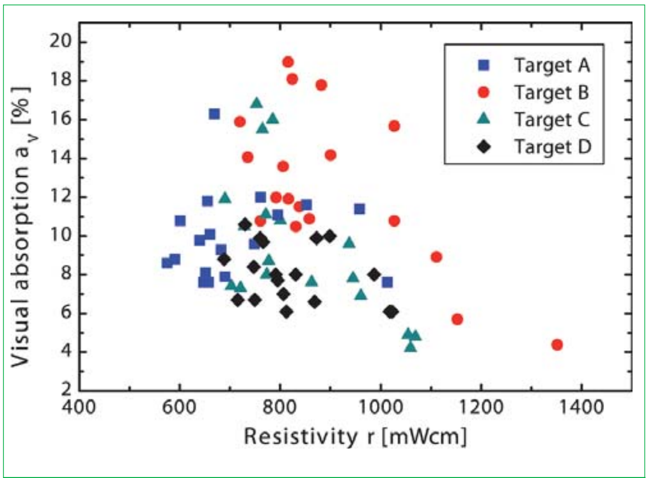


Figure 3. Performance of ZnO:Al films deposited by using various sputtering parameters at a substrate temperature of 150°C for different target material.

properties. All films had a similar thickness of 900nm, which was adjusted by different carrier velocities for the different power levels. For the replicate, a block construction was used to determine the main disturbance variable. It was found that the behaviour of equally deposited films changes rapidly when comparing a new target with the same target in the eroded state with a deeper race track [6]. On examination of the accumulated data, it appears that this change occurs in the middle of the replicate of the first series (not shown here). It can be deduced that properties are quite stable and any change is minimal.

An examination of the films for different target materials was carried out, which provided an overview of the determined variables' resistivity and visual absorption (Figs. 3 & 4). Target erosion was the main influence during the first two series at 150°C.

The behaviour of the varied parameters was also evaluated. In series 3 and 4, the target state was no longer relevant at 200°C. It was found that temperature had the main influence on lowering the visual absorption drastically and reducing resistivity for all targets in all four series. As depicted in Fig. 5, the arcing of the targets had the greatest influence on the film properties. The graph shows the micro-arc behaviour that occurred during the film deposition of series 3 and 4 at 200°C as a result of the applied target voltage. The micro-arc rate is normalized to 1kW for comparability. As mentioned before, the target voltage of target A during deposition is nearly the same compared to the other targets, but the arc rate was drastically lower. The increase of the micro-arc rate was dependent on the material itself.

"All targets have a non-linear behaviour in regards to the amount of oxygen present and thus require individual optimization for each target."

Fig. 3 and Fig. 4 show a strong correlation between micro-arc rate and film properties. Target A with the lowest micro-arc rate shows the lowest resistivity overall.

The optimized sputter conditions for every single material were determined. Fig. 6 and Fig. 7 show the response surface of resistivity and optical absorption for the different parameters (variables) using target A.

A response surface shows extrapolated data. Two variables are free; the other two are fixed to the centre point conditions, and for this reason, no real data point except that of the centre points (q,P,p) can be found in these plots. Nevertheless, the effects of each variable are properly shown.

For all material types, a low pressure is important for low

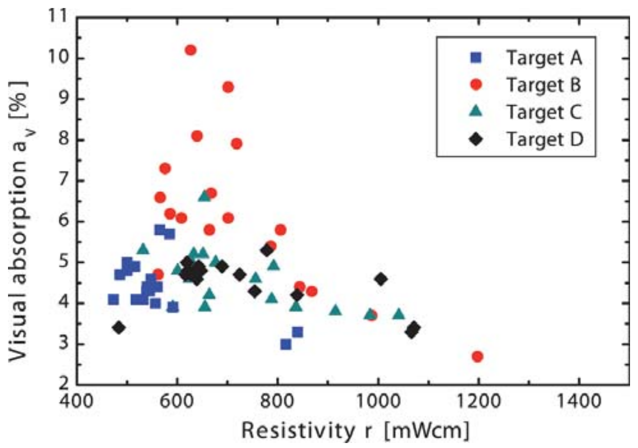


Figure 4. Performance of ZnO:Al films deposited by using various sputtering parameters at a substrate temperature of 200°C for different target material.

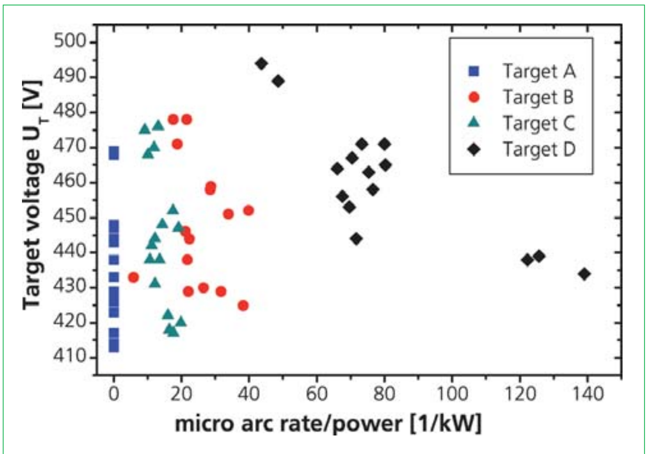


Figure 5. Target voltage as a function of normalized micro arc rate.

resistivity. The oxygen dependence was, however, more complicated. All targets have a non-linear behaviour in regards to the amount of oxygen present and thus require individual optimization for each target. Three out of four targets showed an optimized resistivity at low power, but in an industrial environment high power is necessary for high throughput. In the screening process, resistivities below 480μΩcm were reachable with visual absorption lower than 4% by standard DC sputtering at 200°C.

Conclusion

The main influences on resistivity and absorption are the target material's arcing behaviour, high temperature and low pressure. Power and oxygen amount are highly dependent on the target material. The ceramic target material could be optimized for minimal arcing during this project with the help of the different target producers. If the target material cannot be further improved in relation to arcing, the arc handling of the power supply can also be enhanced. All in all, the higher the temperature, the better the result. Our low temperature process technique for ZnO:AL deposition meet the constraints of CIGS thin-film photovoltaics.

Acknowledgment

We thank the target producers **GFE**, **GFE Fremat**, **Heraeus** and **Senvac** for providing the different target material on behalf of our project. Also, we are grateful for the input from our other project partners, namely **Advanced Energy**, **AMAT**, **Avancis**, **FHR**, **IFU**, **Interpane**, **Würth Solar**, **Solarion**, **Sontor**, **Sentech**,

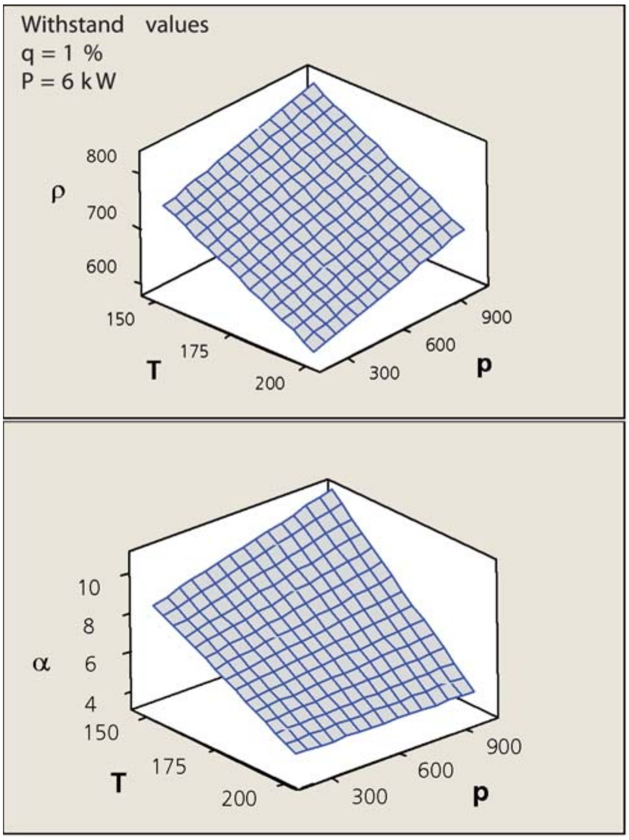


Figure 6. DOE analysis example for target A. Resistivity and visual absorption as function of temperature and pressure at fixed withstand values.

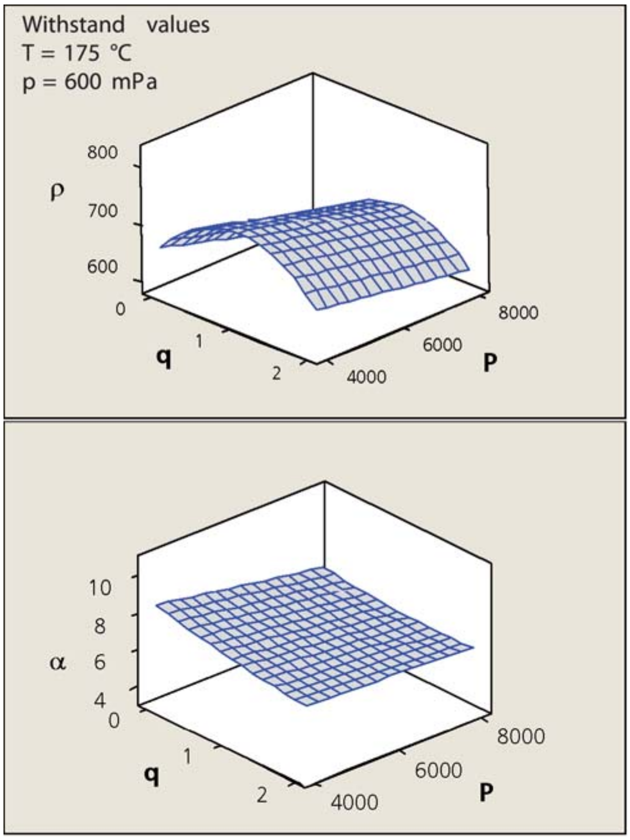


Figure 7. DOE analysis example for target A showing resistivity and visual absorption as a function of oxygen amount and power at fixed withstand values.

Von Ardenne Anlagentechnik, and **Zirox**. This work was supported by IGF industrial community research under contract AIF No. 14770N.

References

[1] Jäger-Waldau, A. 2009, "PV-Status Report 2009: Research, Solar Cell Production and Market Implementation of Photovoltaics", *European Commission, DG Joint Research Centre*, DOI 10.2788/22576, p. 18.

[2] Sittinger, V., Ruske, F., Werner, W., Szyszka, B., Menner, R., Powalla, M. & Dimmler, B. 2006, "Stability of CIGS mini modules with ZnO:Al films prepared by reactive mid-frequency magnetron sputtering", *Proceedings of 21st European Photovoltaic Solar Energy Conference*, Dresden, Germany, pp. 1814 1818.

[3] Sittinger, V., Ruske, F., Pflug, A., Dewald, W., Szyszka, B. & Dittmar, G. 2009, "Optical on-line monitoring for the long-term stabilization of a reactive mid-frequency sputtering process of Al-doped zinc oxide films", *Proccedings of 6th TOEO*, Tokyo, Japan.

[4] Ruske, F., Pflug, A., Sittinger, V., Werner, W. & Szyszka, B. 2006, "Process stabilisation for large area reactive MF-sputtering of Al-doped ZnO", *Thin Solid Films*, Vol. 502, pp. 44-49.

[5] Pflug, A., Sittinger, V., Ruske, F., Szyszka, B. & Dittmar, G. 2004, "Optical characterization of aluminum-doped zinc oxide films by advanced dispersion theories", *Thin Solid Films*, Vols. 455-456, pp. 201-206.

[6] Dewald, W., Sittinger, V., Werner, W., Jacobs, C. & Szyszka, B. 2009, "Optimization of process parameters for sputtering of ceramic ZnO:Al_2O_3 targets for a-Si:H/µc-Si:H solar cells", *Thin Solid Films*, doi:10.1016/j.tsf.2009.04.068

About the Authors

Volker Sittinger is a senior scientist at Fraunhofer IST in the Large Area Coating department. He works on magnetron sputtering for photovoltaic applications. Formerly he was a scientific assistant at the Institute of Solar Energy Research GmbH (ISFH). Volker received his doctoral degree in optical and electrical characterisation of electrodeposited $CuInSe_2$ solar cells from the University of Oldenburg in 2003 and studied physics at the University of Karlsruhe.

Bernd Szyszka is head of the department of Large Area Coatings at Fraunhofer IST in Braunschweig, which he founded in 2003. After completing his studies in physics at the TU Braunschweig, he started work on reactive magnetron sputtering of TCOs at Fraunhofer IST in 1995, and received his doctorate Dr. rer. nat. in 1999.

Wilma Dewald has been junior scientist in the Magnetron Sputtering group at Fraunhofer IST since 2008. She is currently working on her doctoral thesis on electrical and optical properties and light management of TCOs in thin-film solar cells. She studied physics at the University of Göttingen and received her diploma degree in 2007.

Florian Ruske studied physics at the University of Bonn and moved to Fraunhofer IST as a Ph.D. student in 2002. He worked on magnetron sputtering of zinc oxide layers and received his doctoral degree from the University of Gießen in 2008. Since 2007 he has been working as a scientist at the Helmholtz-Zentrum für Materialien und Energie Berlin in the Institute of Silicon Photovoltaics. His main research topics are light trapping structures for silicon-based solar cells and material properties of TCO layers.

Enquiries

Fraunhofer Institute for Surface Engineering and Thin Films (IST)
Bienroder Weg 54 E
38108 Braunschweig
Germany

Helmholtz-Zentrum Berlin für Materialien und Energie GmbH
12489 Berlin
Germany

Achieve new heights in PV performance
It's no wonder Targray is known as an expert in thin film photovoltaics; we have twenty years of experience manufacturing high-yield sputtering targets. Our full line of advanced PV materials combine to lower your manufacturing cost per watt; this is our promise to you. Our global team is in place to serve you, in your country and in your language. Visit us at www.Targray.com.
TARGRAY
Peak Materials. Peak Targets. Peak Watts.

Photovoltaics International
JobsinPV.com Recruitment
PV-tech.org Daily News
SolarLeaders Television

Photographic electroluminescence analysis of CIGS thin-film solar modules

Uwe Rau & **Thomas Kirchartz**, IEF5-Photovoltaik, Forschungszentrum Jülich, Germany; **Anke Helbig** & **Jürgen H. Werner**, Institut für Physikalische Elektronik, Universität Stuttgart, Germany; & **Raymund Schäffler**, Würth Elektronik Research GmbH, Schwäbisch Hall, Germany

ABSTRACT

During the past few years, electroluminescence imaging has become a standard characterization technique for failure analysis and qualification of silicon wafer-based solar cells and modules. In contrast, the same analysis is not yet widely used for thin-film modules. This article demonstrates that electroluminescence analysis is a highly suitable tool for the in-depth investigation of $Cu(In,Ga)Se_2$ thin-film solar modules as well as for standard quality control. The reciprocity between the photovoltaic action and the electroluminescence emission of solar cell devices is used to derive quantitative relations that describe the voltage distribution within a solar module. Individual shunt spots in a module are not only visualized but their influence on the current voltage curves of the individual cells is quantitatively analyzed. Furthermore, device parameters like the sheet resistances of the window layer and the back contact are derived from the electroluminescence images.

Introduction

Less than four years after the pioneering work of Fuyuki et al. [1], photographic electroluminescence (EL) imaging has become an important tool that is almost routinely applied to the characterization of silicon wafer-based solar cells and solar modules [2-9]. Fig 1a depicts the simple experimental setup needed for the EL imaging of a solar cell. Besides a cooled Si-CCD camera, the only requirements are a power supply for the solar cell and an appropriate shielding against parasitic electromagnetic radiation. In some setups, an infrared filter helps to eliminate stray light from the visible part of the spectrum.

"All important physical processes that influence the photovoltaic performance of a solar cell – like recombination, resistive and optical losses – are complementarily reflected in the EL of the same device."

The attractiveness of EL imaging results on the one hand from its simplicity and swiftness combined with the high spatial resolution that is provided by this technique. An EL image is obtained in less than one second and the technique can be used to survey entire modules but also to visualize microscopic defects on the micrometer scale. On the other hand, EL, i.e. the emission of light by application of an electrical bias, is just the complementary reciprocal action of the photovoltaic effect used in solar cells and modules. Therefore, all important physical processes that influence the photovoltaic performance of a solar cell – like recombination, resistive and optical losses – are complementarily reflected in the EL of the same device, a fact warranting the relevance of the method. In addition to spatially resolved methods, spectrally resolved EL [10-13] has proven to be a suitable tool for the analysis of solar cells. However, the present article concentrates on the photographic, i.e., spatially resolved EL analysis of $Cu(In,Ga)Se_2$ (CIGS) modules.

Basics

Electroluminescence, or the emission of light in consequence to the application of a forward voltage bias, is the reciprocal action to the standard operation of a solar cell, namely the conversion of incident light into electricity. According to the reciprocity theorem, the EL intensity ϕ_{em} of a pn-junction solar cell emitted at any position $\mathbf{r} = (x,y)$ of the solar cell's surface is given by [14]

$$\phi_{em}(E,\mathbf{r}) = [1-R(\mathbf{r})]Q_i(\mathbf{r})\phi_{bb}(E)\exp\left(\frac{qV(\mathbf{r})}{kT}\right) = Q_e(E,\mathbf{r})\phi_{bb}(E)\exp\left(\frac{qV(\mathbf{r})}{kT}\right), \quad (1)$$

where kT/q is the thermal voltage, $V(\mathbf{r})$ is the internal junction voltage, E is the photon energy, and $Q_e(\mathbf{r}) = [1-R(\mathbf{r})]Q_i(\mathbf{r})$ is the local external quantum efficiency determined by the front surface reflectance $R(\mathbf{r})$ and the internal quantum efficiency $Q_i(\mathbf{r})$. The spectral photon density ϕ_{bb} of a black body

$$\phi_{bb}(E) = \frac{2\pi E^2/(h^3c^2)}{\exp(E/kT)-1} \quad (2)$$

depends on Planck's constant h and the vacuum speed c of light. Recording the EL emission of a solar cell with a charge-coupled device (CCD) camera, the EL signal $S_{cam}(E,\mathbf{r})$ in each camera pixel is

$$S_{cam}(\mathbf{r}) = \int Q_{cam}(E)Q_e(E,\mathbf{r})\phi_{bb}(E)dE\exp\left(\frac{qV(\mathbf{r})}{kT}\right) \quad (3)$$

where Q_{cam} is the energy-dependent sensitivity of the detecting camera. Since in Equation 3 $\phi_{bb}(E)$ and $Q_{cam}(E)$ depend on the energy but not on the surface position $\mathbf{r}$, lateral variations in the detected EL intensity emitted from different surface positions originate only from the lateral variations of the external quantum efficiency Q_e and of the internal voltage V. Hence, Equation 1 and thus Equation 3 consider all losses occurring in solar cells: the external quantum efficiency Q_e expresses the recombination and optical losses, while the internal voltage V reflects the resistive losses. Especially for the surveying of photovoltaic modules, the exponential voltage-dependent term dominates the image, making EL analysis a tool that is especially suitable to analyze resistive losses.

Results and discussion

Electroluminescence analysis of thin-film modules is not yet as common as it is for wafer-based solar cells. Nevertheless, the suitability and the potential of EL analysis of these devices is perfectly analogous to that of silicon cells. The following discusses the investigation of a CIGS module [15,16] as a general example of the analysis of a thin-film module. Variations of the material quality and stoichiometry in CIGS solar cells occur on relatively small length scales between

5μm and 20μm [17,18] and would therefore require microscopic investigations of the luminescence [19-23].

However, prominent features in EL images on the module level are predominantly due to resistive effects, i.e. either caused by series resistances or by shunts as can be seen from Fig. 2 where EL images of a CIGS module are displayed taken at two different current densities $J = 1.25\text{mA/cm}^2$ (a) and at $J = 50\text{mA/cm}^2$ (b). The module consists of $N_c = 42$ cells connected in series with a single cell area of $20 \times 0.4\text{cm}^2$. The image taken at the lower current (Fig. 2a) shows dark cells at the top of the module (i.e. for low x-values) as the most prominent feature. When increasing the current to $J = 50\text{mA/cm}^2$, all cells appear bright over their whole width (i.e. extension in y-direction). However, circular dark spots especially in the upper right corner remain visible. In addition, every cell in Fig. 2b shows a characteristic intensity gradient from high intensity at the top to low intensity at the bottom with only little variation in the y-direction. This intensity gradient is not visible in the image taken with the lower bias current (Fig. 2a).

The macroscopic analysis discussed in the following is an example of where it is reasonable to assume that $Q_e(E,\mathbf{r})$ is almost spatially independent, especially because the exponential dependence of the variations of the internal junction voltage $V(\mathbf{r})$ have a much stronger impact on the EL intensity than possible spatial variations of $Q_e(\mathbf{r})$. Thus, assuming a spatially- and voltage-independent Q_e rearranges Equation 3 to

$$S_{cam}(\mathbf{r}) = \int Q_{cam}(E) Q_e(E) \phi_{bb}(E) dE \exp\left(\frac{qV(\mathbf{r})}{kT}\right) \qquad (4)$$

Consequently, we can determine from S_{cam} the voltage drop over the junction (see Equation 5 [right]), except for a spatially constant offset voltage V_{offs}.

Fig. 3 visualizes the application of Equation 5 to the EL data from Fig. 2 to obtain the relative voltage ΔV as a function of the coordinate x across all cells in the module. Note that we have generated the line scan by averaging over the y-coordinate, i.e., over the whole length of the module. Two important features are immediately evident from these line scans: first, the relatively

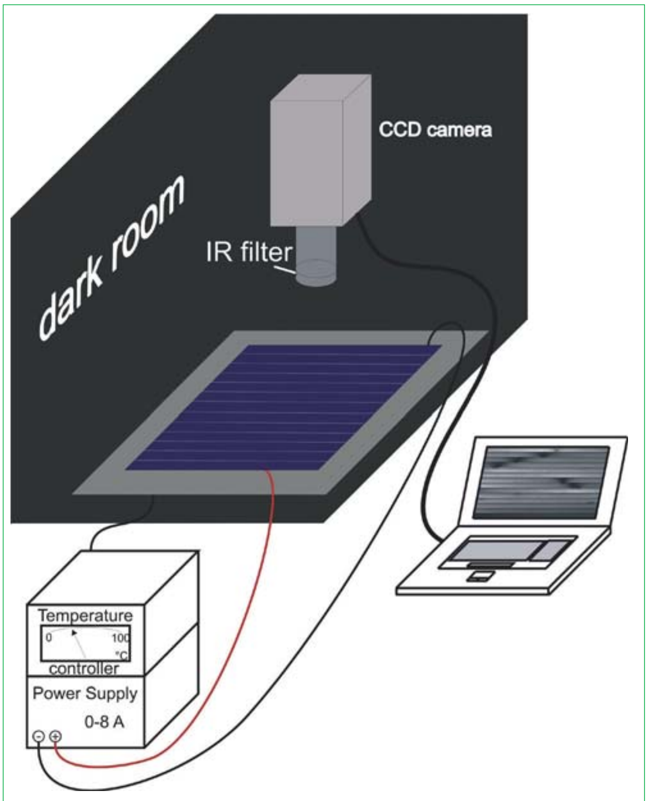


Figure 1. Sketch of the experimental setup for the photographic survey of solar cells or solar modules.

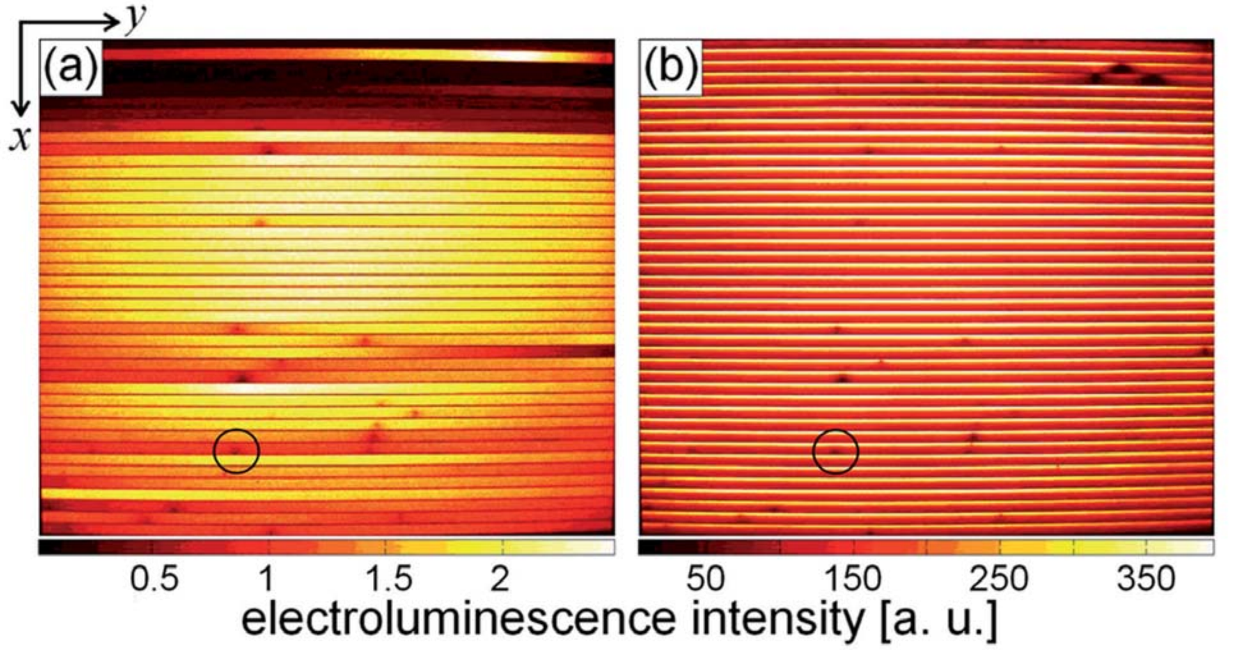


Figure 2. EL images at a) J = 1.25mA/cm² and b) J = 50mA/cm² of the same $Cu(In,Ga)Se_2$ module. Areas with quenched EL intensity are caused by shunts (see shunt highlighted by circle). Shunts have a larger influence on the current distribution through the cell when current densities are small as in (a), since the pn-junction has a non-linear J/V characteristic. For the same reason, the EL intensity drop in the x direction becomes steeper as the current density increases.

low voltage drop over some cells due to the shunts. This feature is especially visible at low current bias J = 1.25mA/cm² and tends to disappear with increasing bias. Second, there are voltage losses across individual cells due to the sheet resistance of window and back contact layer. This feature becomes increasingly important at larger current bias and is clearly visible for the curves corresponding J = 1.25mA/cm² and 25mA/cm² in Fig. 3.

"Fitting parameters are the sheet resistances ρ^{sq}_{ZnO} of the ZnO and ρ^{sq}_{Mo} of the Mo back contact as well as the differential junction conductance G_D at each bias point."

For a more quantitative access to the data in Fig. 3 we need to model the voltage distribution along the whole width w of one sub-cell. This requires the solution of the coupled current continuity equations in the window layer and in the back contact [16]. In one dimension, we have

$$\frac{d^2}{dx^2}V_1 = -\rho_1^{sq}\frac{d}{dx}j_1^p = \rho_1^{sq}J(V) \qquad (6)$$

and

$$\frac{d^2}{dx^2}V_2 = -\rho_2^{sq}\frac{d}{dx}j_2^p = -\rho_2^{sq}J(V) \qquad (7)$$

where $V_{1,2}$ denote the voltages, $j^p_{1,2}$ are the line current densities, and $\rho^{sq}_{1,2}$ are the sheet resistances of the window layer and the back contact, respectively. The solution of Equations 6 and 7 is given by the voltage difference (see Equation 8 [right]) with the inverse characteristic length $\lambda = [G_D(\rho_1^{sq} + \rho_2^{sq})]^{1/2}$ and $G_D = dJ/dV$ as the differential conductance at the given bias conditions.

For the investigation of the sheet resistances, EL images of a non-shunted region of the module were recorded with a higher spatial resolution. Figure 4 shows the ΔV values calculated from the EL signals across a single non-shunted cell in x direction for three exemplary different bias current densities J = 50, 25, 5mAcm^{-2}. Note that we have averaged the signals over 1376

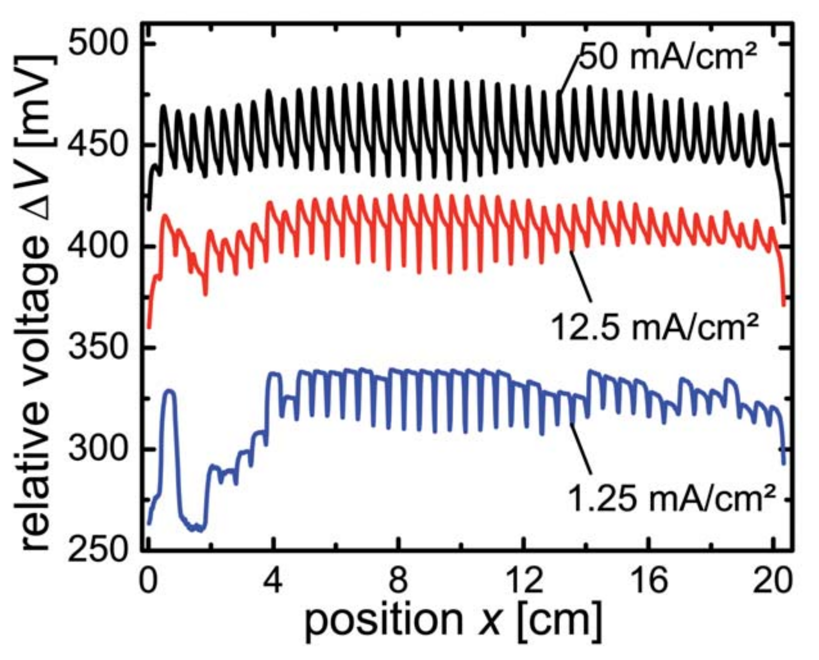


Figure 3. Internal voltage line scans (x-direction) of the whole module of Fig. 2 taken at different bias current densities J_D = 50, 12.5, 1.25mA/cm². The effect of shunts on the voltage is more pronounced for smaller than for higher injection current densities. This effect is most obvious for the cells located at positions 1cm < x < 4cm. The line scans are averaged over the whole module length l.

lines in y-direction (corresponding to a width of 3.8cm).

In order to fit the experimental data, we have the choice either to determine the junction conductance G_D from an additional measurement of J_{SC}/V_{OC} independently (as in [16]) or to include the G_D values at each bias point into the fitting procedure. The latter method is based on the EL experiment alone and has the advantage of not needing an extra calibration measurement. The solid lines in Fig. 3 show the result of a simultaneous fit of Equation 8 to the experimental data obtained for the different bias current densities. Fitting parameters are the sheet resistances ρ^{sq}_{ZnO} of the ZnO and ρ^{sq}_{Mo} of the Mo back contact as well as the differential junction conductance G_D at each bias point. It is interesting to note here that the extraction of the smaller of the two sheet resistances (ρ^{sq}_{Mo} in the present case) is possible as soon as a minimum in the $\Delta V(x)$ curves becomes visible as in the topmost curves of Fig. 3.

The fit to the data in Fig. 3 yields $\rho^{sq}_{ZnO} = 18.2\,\Omega/\mathrm{sq}$ and $\rho^{sq}_{Mo} = 1.1\,\Omega/\mathrm{sq}$. Since these values are very close to the results of the calibrated method ($\rho^{sq}_{ZnO} = 18.0\,\Omega/\mathrm{sq}$, $\rho^{sq}_{Mo} = 1.3\,\Omega/\mathrm{sq}$)[16], we conclude that the determination of the sheet resistances from the EL data alone, i.e. without additional calibration measurement, is reasonably reliable. Furthermore, the extraction of both sheet resistance values – that of the window and that of the back contact layer – are possible simultaneously, although the values differ by more than one order of magnitude.

The data in Fig. 2 allow us not only to analyze the voltage drop over individual cells in order to determine the sheet resistance of the window and the back contact layer. We may also compare the voltages that drop over different cells in order to evaluate the relative performance of those cells. These voltage differences are basically caused by the shunts on the various cell stripes of the module, seen as black spots in Fig. 2. As a valid representation of the cell voltage, we take the spatial average of the relative voltages ΔV determined across the cell. Again, we have the option to calibrate the measurement with an additional J_{SC}/V_{OC} measurement which allows us to deduce absolutely scaled J/V curves of all individual cells [16]. In practice, one might wish to avoid such additional measurements. In this case, only voltages shifted by an unknown offset are feasible because of the unknown offset voltage given in Equation 5.

However, determining the scatter of the individual cell voltages at different bias conditions is quite attractive for inline control during the production of thin-film modules. This possibility for a simple EL imaging-based quality control method is illustrated by the histograms in Fig. 5 for three different bias current densities. For these histograms, the cell voltages V_i^{meas} (for the cells $i = 1 .. N_{cell}$) are calculated from the measured EL signal converted via Equation 5 into $\Delta V\ (x,y)$ values and finally averaged over the entire cell area. As expected from our observations in Fig. 2, the influence of shunts on the voltage distribution is highest at low bias currents leading accordingly to a wide distribution of cell voltages. At higher bias currents the discrepancy between the voltages of shunted and non-shunted cells becomes smaller and the distribution becomes narrower. Such histograms as shown in Fig. 5 might provide a simple tool to judge

$$V(\mathbf{r}) = \frac{kT}{q}\left[\ln\{S_{\mathrm{cam}}(\mathbf{r})\} - \ln\left\{\int Q_{\mathrm{cam}}(E)Q_{\mathrm{e}}(E)\phi_{\mathrm{bb}}(E)dE\right\}\right] = \Delta V(\mathbf{r}) + V_{\mathrm{offs}}$$

Equation 5.

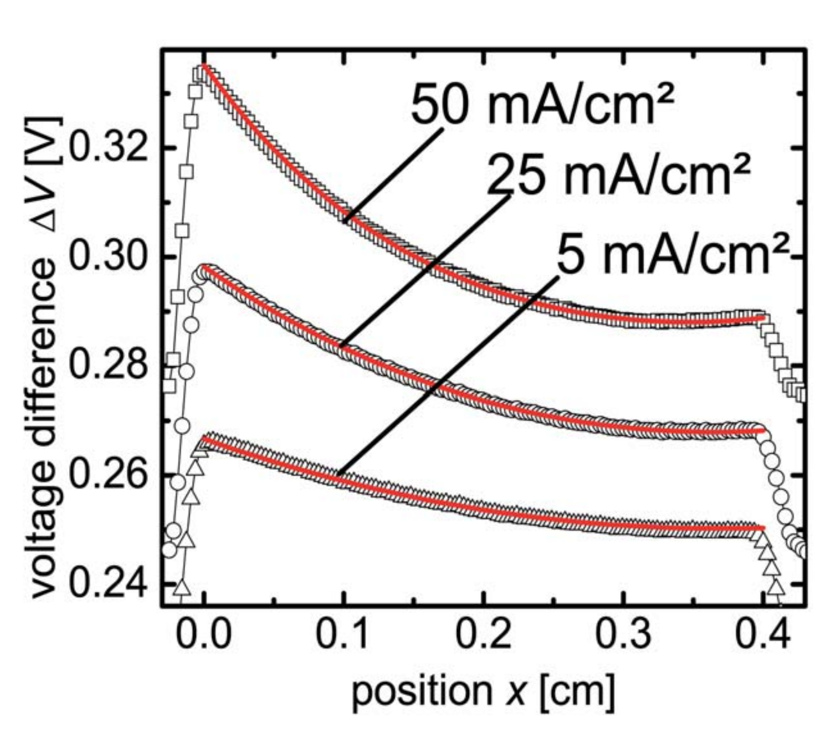


Figure 4. Line scans of the relative internal voltages ΔV calculated from EL line scans. The solid lines represent fits of Equation 8 to the experimental voltage data (open symbols). The sheet resistances used in all fits are ρ^{sq}_{ZnO} = 18Ω/sq and ρ^{sq}_{Mo} = 1.5Ω/sq for the ZnO window layer and for the Mo back contact, respectively. Note that the experimental data are averages over 1376 lines in *y*-direction (corresponding to a width of 3.8cm).

immediately the quality of the module, making EL imaging a suitable tool for inline control containing quantitative information.

> "Determining the scatter of the individual cell voltages at different bias conditions is quite attractive for inline control during the production of thin-film modules."

Finally, we demonstrate the possibility of reconstructing current voltage curves of the individual cells on an absolute scale. Hereto, we consider a series of images taken at different bias current densities and determine the cell voltages V_i^{meas} as described above. Since V_i^{meas} differs from the real cell voltage V_i by an unknown but constant offset voltage V_{offs}, we need to scale the experimental data by one additional measurement. For this purpose, we measure the open circuit voltage V_{OC} of the solar module under illumination. The illumination intensity is adjusted in such a way that the corresponding short circuit current density J_{SC} equals one of the bias current

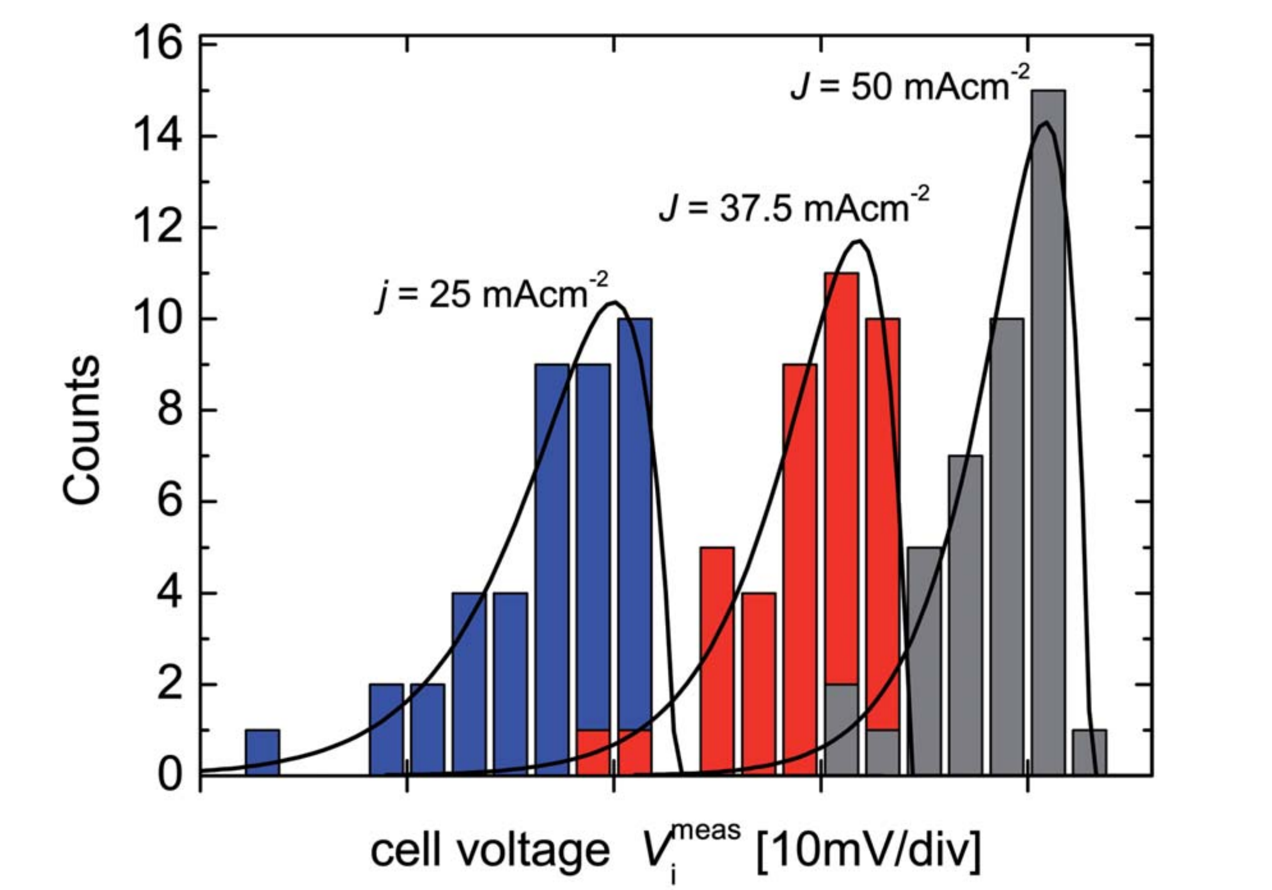


Figure 5. Histogram of the relative cell voltage V_i^{meas} over the cells of the module in Fig. 2. Note that the measured voltages V_i^{meas} differ from the real cell voltage by an unknown but constant offset voltage V_{offs}. The black lines are a guide, illustrating that the voltage distributions become narrower with increasing current bias *J*.

$$\Delta V = -\frac{j^{p}_{\max}\rho_1^{sq}}{\lambda}\sinh(\lambda x) + \frac{j^{p}_{\max}\left[\rho_1^{sq}\cosh(\lambda w)+\rho_2^{sq}\right]}{\lambda\sinh(\lambda w)}\cosh(\lambda x) + const$$

Equation 8.

densities J used for the EL images. The hitherto unknown offset voltage V_{offs} is then calculated from the equation

$$V_{OC} = \sum_{i=1}^{N_{cell}} V_i = \sum_{i=1}^{N_{cell}} V_i^{meas} - N_{cell}V_{offs} \quad (9)$$

It is important to acknowledge that taking the open circuit voltage V_{OC} as a reference is more suitable for a proper scaling than using the voltage V_{mod} that is applied to the module during the actual measurement. This is because V_{mod} not only contains the sum of the cell voltages V_i but also the voltage losses due to the series resistance R_S within the module that we have at a given bias current J instead of Equation 9

$$V_{mod} = \sum_{i=1}^{N_{cell}} V_i + JR_S = \sum_{i=1}^{N_{cell}} V_i^{meas} - N_{cell}V_{offs} + JR_S \quad (10)$$

The sum on the right-hand side of Equation 10 contains as an additional unknown quantity the series resistance R_s, that might even be different for each bias current J. The determination of V_{offs} from V_{mod} is therefore not easy and we use the J_{SC}/V_{OC} method with only one unknown quantity for all bias points, namely V_{offs}.

"Photographic EL imaging is a promising tool for routine inline inspection of CIGS thin-film modules as well as for in-depth failure analysis."

Fig. 6 displays the scaled current voltage curves J/V_i (open circles) of all cells obtained from a series of EL measurements at different bias currents J. Additionally shown is the $J/\Sigma V_i$ (open diamonds) curve obtained from summing up the internal voltages V_i and, for comparison, the J_{SC}/V_{OC} curve of the module (filled stars), which was used to scale the offset voltage according to Equation 9. As expected from our observations in Figs. 2 and 5, the voltages of the individual cells show a large scatter at low currents whereas at higher currents the discrepancy between the voltages of shunted and non-shunted cells becomes smaller and the data points increasingly coincide. We have thus demonstrated how to assess all individual current voltage curves of a thin-film module by analyzing EL images combined with a simple calibration process.

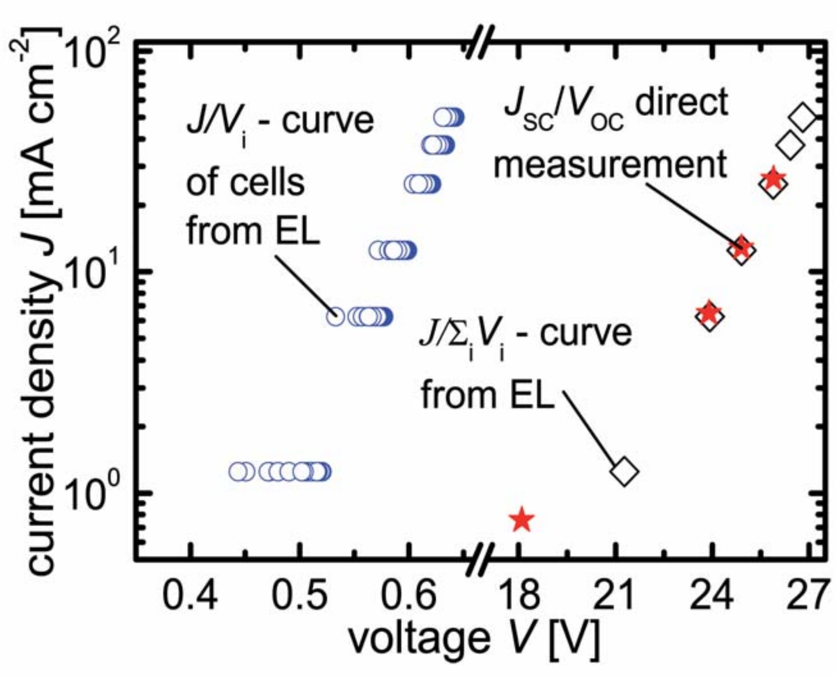


Figure 6. Current density/voltage (J/V_i) curves (open circles) of individual subcells of the module in Fig. 2 determined from their EL emission. For any given J, the corresponding relative individual voltages V_i are taken from line scans of the voltage difference ΔV as shown in Fig. 3. To correct the data for the unknown offset voltage, the sum ΣV_i (diamonds) of the internal voltages V_i of all subcells is adjusted to the J_{SC}/V_{OC} curve of the complete module (stars).

Summary and outlook

Photographic EL imaging is a promising tool for routine inline inspection of CIGS thin-film modules as well as for in-depth failure analysis. In this paper, we have demonstrated how to determine the sheet resistance of the ZnO window layer and of the Mo back contact directly from EL data. Further, we have shown that the voltages across all individual cells within a module at any bias current are measurable by EL imaging except for an unknown offset voltage. Thus, the relative performance of the cells can be judged immediately from an EL image. Scaling such results for various applied currents with a single additional measurement of the open circuit voltage enables us to determine the absolute current/voltage curve of each individual cell in the module. Thus, valuable and detailed information is gained in a straightforward way from easily and swiftly feasible measurements. We note that the present results are only a first step in employing the wealth of information contained in the EL images of CIGS thin-film solar modules. Furthermore, the methods outlined in this paper should be applicable to other types of thin-film modules as well.

References

[1] Fuyuki, T., Kondo, H., Yamazaki, T., Takahashi, Y. & Uraoka, Y. 2005, "Photographic surveying of minority carrier diffusion length in polycrystalline silicon solar cells by electroluminescence", *Appl. Phys. Lett.* Vol. 86, 262108.

[2] Ramspeck, K., Bothe, K., Hinken, D., Fischer, B., Schmidt, J. & Brendel, R. 2007, "Recombination current and series resistance imaging of solar cells by combined luminescence and lock-in thermography", *Appl. Phys. Lett.* Vol. 90, 153502.

[3] Kasemann, M., Schubert, M.C., The, M., Köber, M., Hermle, M. & Warta, W. 2006, "Comparison of luminescence imaging and illuminated lock-in thermography on silicon solar cells", *Appl. Phys. Lett.* Vol. 89, 224102.

[4] Würfel, P., Trupke, T., Puzzer, T., Schäffler, E., Warta, W. & Glunz, S.W. 2007, "Diffusion lengths of silicon solar cells from luminescence images", *J. Appl. Phys.* Vol. 101, 123110.

[5] Breitenstein, O., Bauer, J., Trupke, T. & Bardos, R.A. 2008, "On The Detection of Shunts in Silicon Solar Cells by Photo- and Electroluminescence Imaging", *Prog. Photovolt: Res. Appl.*, Vol. 16, p. 325.

[6] Hinken, D., Ramspeck, K., Bothe, K., Fischer, B. & Brendel, R. 2007, "Series resistance imaging of solar cells by voltage dependent electroluminescence", *Appl. Phys. Lett.*, Vol. 91, 182104.

[7] Bothe, K., Ramspeck, K., Hinken, D. & Brendel, R. 2008, "Imaging Techniques for the Analysis of Silicon Wafers and Solar Cells", *ECS Trans.* Vol. 16, p. 63.

[8] Kasemann, M., Grote, D., Walter, B., Kwapil, W., Trupke, T., Augarten, Y., Bardos, R.A., Pink, E., Abbott, M.D. & Warta, W. 2008, "Luminescence Imaging for the Detection of Shunts on Silicon Solar Cells", *Prog. Photovolt.: Res. Appl.*, Vol. 16, p. 297.

[9] Fuyuki, T. & Kitiyanan, A. 2009, "Photographic diagnosis of crystalline silicon solar cells utilizing electroluminescence", *Appl. Phys. A*, Vol. 96, p. 189.

[10] Kirchartz, T., Rau, U., Kurth, M., Mattheis, J. & Werner, J.H. 2007, "Comparative study of electroluminescence from Cu(In,Ga)Se_2 and Si solar cells", *Thin Solid Films*, Vol. 515, 6238.

[11] Kirchartz, T. & Rau, U. 2007, "Electroluminescence analysis of high efficiency Cu(In,Ga)Se_2 solar cells", *J. Appl. Phys.* Vol. 102, 104510.

[12] Kirchartz, T., Rau, U., Hermle, M., Bett, A.W., Helbig, A. & Werner, J.H. 2008, "Internal voltages in GaInP/GaInAs/Ge multijunction solar cells determined by electroluminescence measurements", *Appl. Phys. Lett.*, Vol. 92, 123502.

[13] Kirchartz, T., Helbig, A., Reetz, W., Reuter, M., Werner, J.H. & Rau, U. 2009, "Reciprocity between electroluminescence and quantum efficiency used for the characterization of silicon solar cells", *Prog. Photovolt: Res. Appl.*, Vol. 17, p. 394.

[14] Rau, U. 2007, "Reciprocity relation between photovoltaic quantum efficiency and electroluminescent emission of solar cells", *Phys. Rev. B*, Vol. 76, 085303.

[15] Rau, U., Kirchartz, T., Helbig, A. & Pieters, B.E. 2009, "Electroluminescence imaging of Cu(In,Ga)Se_2 thin film modules", *Mater. Res. Soc. Symp. Proc.* **1165**, M03-04.

[16] Helbig, A., Kirchartz, T., Schäffler, R., Werner, J.H. & Rau, U. (submitted), "Quantitative electroluminescence analysis of resistive losses in Cu(In, Ga)Se_2 thin-film modules", *Sol. Ener. Mat. Sol. Cells.*

[17] Grabitz, P.O., Rau, U., Wille, B., Bilger, G. & Werner, J.H. 2006, "Spatial inhomogeneities in Cu(In,Ga)Se_2 solar cells analyzed by an electron beam induced voltage technique", *J. Appl. Phys.*, Vol. 100, 124501.

[18] Bauer, G.H., Gütay, L. & Kniese, R. 2005, "Structural properties and quality of the photoexcited state in Cu($In_{1-x}Ga_x$)Se_2 solar cell absorbers with lateral submicron resolution", *Thin Solid Films*, Vol. 480, p. 259.

[19] Romero, M.J., Jiang, C.-S., Noufi, R. & Al-Jassim, M.M. 2005, "Photon emission in $CuInSe_2$ thin films observed by scanning tunneling microscopy", *Appl. Phys. Lett.*, Vol. 86, 143115.

[20] Romero, M.J., Jiang, C.-S., Abushama, J., Moutinho, H.R., Al-Jassim, M.M. & Noufi, R. 2006, "Electroluminescence mapping of $CuGaSe_2$ solar cells by atomic force microscopy", *Appl. Phys. Lett.* Vol. 89, 143120.

[21] Gütay, L. & Bauer, G.H. 2005, "Lateral variations of optoelectronic quality of Cu($In_{1-x}Ga_x$)Se_2 in the submicron-scale", *Thin Solid Films*, Vol. 487, p. 8.

[22] Gütay, L. & Bauer, G.H. 2007, "Spectrally resolved photoluminescence studies on Cu(In,Ga)Se_2 solar cells with lateral submicron resolution", *Thin Solid Films*, Vol. 515, 6212.

[23] Bothe, K., Bauer, G.H. & Unold, T. 2002, "Spatially resolved photoluminescence measurements on Cu(In,Ga)Se_2 thin films", *Thin Solid Films*, Vol. 403, p. 453.

About the Authors

Prof. Dr. Uwe Rau obtained his Ph.D. degree in physics from the University of Tübingen in 1991, and subsequently worked as a postdoc at the Max Planck Institute for Solid State Research, Stuttgart, at the Sony Research Center, Yokohama, and at the University of Bayreuth. From 1997 to 2007 he was scientific group leader at the Institute of Physical Electronics, University of Stuttgart. In 2007 he became a full professor at the RWTH Aachen as well as director of the Institute of Energy Research – Photovoltaics (IEF-5) at Research Centre Jülich.

Dr.-Ing. Thomas Kirchartz studied electrical engineering and information technology in Stuttgart and graduated in 2006. Since 2004, he has been doing research on characterization and modelling of different types of solar cells in the group of Uwe Rau in Stuttgart and later in Jülich. He finished his doctoral thesis in 2008 since which time he has been a post-doctoral researcher in Jülich.

Dipl.-Nat. Anke Helbig studied applied natural science at TU Bergakademie Freiberg and received her diploma in 2006. She then worked in the photovoltaics group of Prof. Dr. Hans Joachim Möller in Freiberg. Since 2007 she has been a Ph.D. student at the Institute of Physical Electronics, University of Stuttgart, working on solar cell characterization.

Prof. Dr. Jürgen H. Werner received his Ph.D. degree in physics from the University of Stuttgart in 1983. After working as a scientist at the Max Planck Institute Stuttgart, he was a guest scientist at the IBM T. J. Watson Research Center, in New York and at AT&T Bell Laboratories, New Jersey. In 1991, he moved to the University of Munich. Since 1996 he has been director of the Institute for Physical Electronics, University of Stuttgart, researching and teaching in the field of photovoltaics, micro- and optoelectronics.

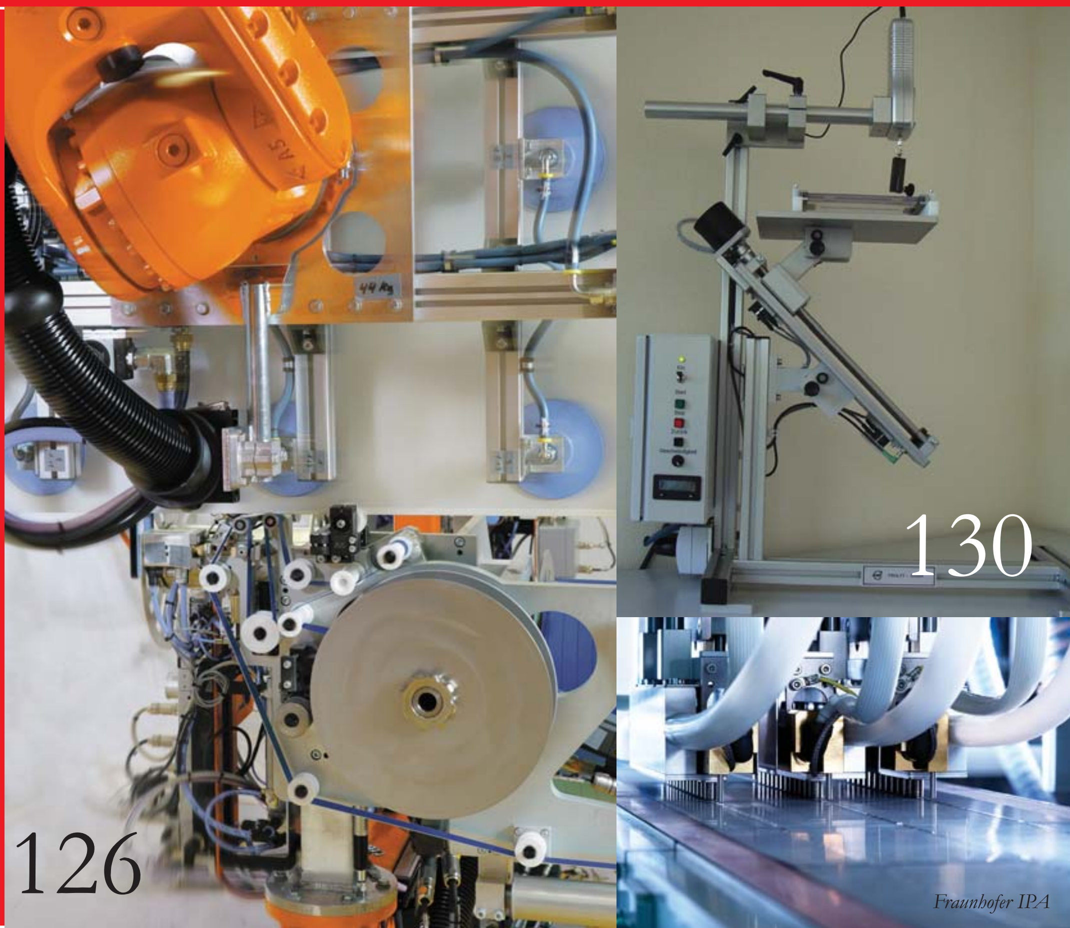
Dipl.-Ing. Raymund Schäffler received his degree of electrical engineer (physical electronics) from the University of Stuttgart. He worked as a scientific assistant at the Institute of Physical Electronics (University of Stuttgart) from 1988 to 1996 and at Zentrum für Sonnenenergie und Wasserstoffforschung (ZSW) from 1996 to 1999. Since 1999 he has been working at Würth Solar in such fields/roles as product manager, technology and R&D.

Enquiries

Prof. Dr. Uwe Rau
Institut für Energieforschung-5
(Photovoltaik)
Forschungszentrum Jülich
52425 Jülich
Germany

Tel: 49 (0) 2461 611 554
Fax: 49 (0) 2461 613 735
Email: u.rau@fz-juelich.de
Web: www.fz-juelich.de/ief/ief-5/

PV Modules



SunPower panel reaches record 20.4% total-area efficiency

A solar module prototype developed by SunPower has clocked 20.4% efficiency in tests, confirmed by the National Renewable Energy Lab (NREL). The 333W full-sized solar panel consists of 96 third-generation cells with a total panel area of 1.6m2. The prototype was funded the U.S. Department of Energy (DOE) under its Solar America Initiative (SAI), which was awarded to SunPower approximately two years ago.

Using the company's technology, which yields cells that boast a minimum of 23% efficiency, the company used larger area cells cut from a 165mm diameter ingot. The prototype was also treated with an anti-reflective coating for maximum power generation. The company expects to launch the new 20.4% efficiency module on the market within the next two years. SunPower has announced its intention to initiate a solar panel manufacturing facility in the U.S. utilizing automated equipment designed and created using the SAI funding.

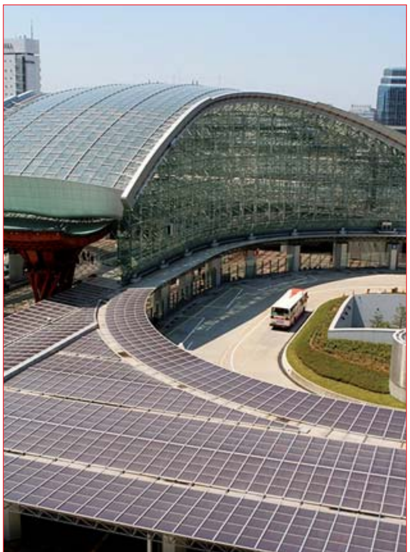
SunPower's 333W, 20.4%-efficient panel combines 96 large-area cells on A/R glass.

Module Sales News Focus

Suntech publicizes North American Partner Program

At the Solar Power International conference, Suntech revealed its new North American Partner Program. The program, which will be formally launched in 2010, aims to boost its current network of around 200 domestic installers and help dealers create more sales. The Suntech Partner Program will offer selected dealers a co-marketing fund, training and services, financing and priority access to its product line.

Applications will be open to all North American solar installers and feature a Partner Portal, which will simplify the installer sales process. The portal will allow Suntech dealers to manage their account, retrieve and track leads and access several sales and marketing resources. In addition, Suntech collaborated with Clean Power Finance to design a proposal tool/CRM service that allows Suntech partners to make and customize proposals, make use of an updated, comprehensive database of utility rates, incentives and rebates, track and mange their customers and provide accurate quotes using pre-loaded Suntech solar modules.



Source: Suntech

Suntech integrated modules.

Source: aleo solar

aleo solar S_18 modules.

850-kilowatt solar farm in Bavaria to receive aleo solar modules

Continuing the cooperation with GSW Gold SolarWind Management in Aiterhofen, aleo solar will supply solar modules to be installed at an 850kW solar farm in Straßkirchen in the Straubing-Boden district of Bavaria. A total of 3,300 aleo type S_18 modules will be installed on a fixed mounting system supplied by Krinner Schraubfundamente based in Straßkirchen. The S_18 modules are expected to yield 900,000kWh of energy annually. A building permit has been granted for the solar power plant, which is expected to be connected to the grid by December 2009.

Next stop for aleo solar: Israel

Working with its local partner, Solenergy, aleo solar will be supplying modules for numerous solar power facilities in Israel. This year, the company will have provided more than 200kW of their modules to various projects in the country. One of the more recent aleo solar projects in Israel was a 50kW poultry farm in Moshav Gan HaShomrom. The project was connected to the grid in late October when aleo supplied 227 of its S_18 modules.

The rooftop installation in Moshav Gan HaShomrom was put in place by Solenergy and with their help aleo will install three more photovoltaic power plants before the end of this year. Israel has seen a recent boom in the PV sector since the introduction of a feed-in subsidy last year. Operators of rooftop solar systems with a rated output of under 50kW receive the equivalent of €0.36/kWh (US$0.53) over 20 years. Due to the increase in the photovoltaic industry, aleo is confident with its move into the Israel market.

Trina Solar enters into sales agreement with Proinso

Trina Solar has entered into a sales agreement with Proinso (Proyectos Integrales Solares). Trina Solar will provide Proinso with around 108MW of PV modules at predetermined prices. Proinso has an option to purchase an additional 12MW in the first quarter of 2010. Shipments are projected to start in the fourth quarter 2009 and continue through the first half of next year, with 38MW delivered first followed by the 42MW delivery in 2010. The modules will be used in solar projects in European markets such as Italy and Spain.

Canadian Solar raises PV module shipment guidance, could surpass 300MW for 2009

Canadian Solar says it expects to beat the high end of its prior guidance for module shipments for both the third-quarter and fiscal-year 2009 and will raise its projections for both periods. Annual shipments could be as much as 45MW above earlier guidance forecasts and surpass 300MW, the vertically integrated solar manufacturer states.

Based on its selected unaudited financial results, Canadian Solar believes that its net revenues for the third quarter will be approximately CAD$210 million to CAD$215 million, with shipments of about 101-103MW, compared to prior

Jinko

- **One of the Few Vertically Integrated Suppliers of Wafer, Cell and Module, with Annual Capacity of 300MW Respectively**
- **World's Leading Production Technology**

  Fully automatic production line by NPC Japan
  Wide output range, from 155W to 280W offer perfect solutions to our clients

- **First Class Production Performance**

  Excellent power conversion rate; lower voltage temperature coefficient; a small range of power output tolerance

- **Effective Control over Quality and Cost**

  64 strict quality monitoring processes from IQC/LQC/OQC/SCM to T5S

- **The Most Reliable Product Insurance**

  5-year warranty on material and workmanship; 12-year warranty on power output of no less than 90%; 25-year warranty on power output of no less than 80%
  Export Credit Insurance

- **Full Compliance with International Quality Standards**

CE UL TÜV IEC VDE ASU PTL

www.jinkosolar.com
module@jinkosolar.com

Source: Canadian Solar

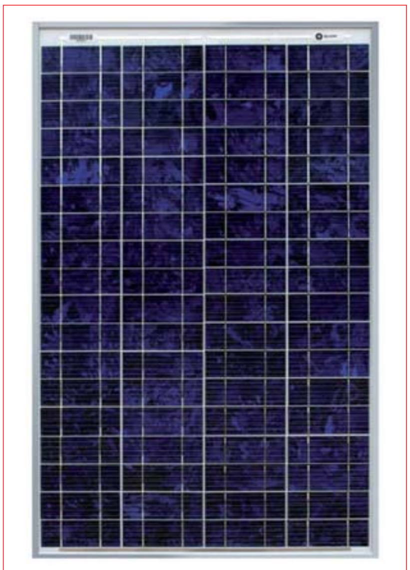
Canadian Solar integrated modules.

guidance of approximately 90-100MW. The company says it expects a gross margin of 16% to 17% for the third quarter, attributing this rise to the high level of interest in its crystalline-silicon-based products at the EU PVSEC trade show.

It now sees FY09 shipments coming in between 295 and 305MW, including expected shipments of 127-137MW for the fourth quarter. This represents a significant increase compared to the prior guidance for shipments of approximately 260-270MW for the full year and earlier 2009 guidance of 200-220MW. The company claims to be making continuous improvements in its cost structure, which it expects will positively impact ongoing profitability.

BP Solar sees recovery in sales

BP Solar saw a recovery in sales in the third quarter of 2009, reflecting a recovery in business BP reported in its latest quarterly results statement. Module sales in the quarter reached the equivalent of 73MW, compared with 47MW in the same period of last year. BP Solar's results were impacted by weaker margins, due to the collapse in prices throughout the supply chain as demand remains significantly out of balance with supply. BP Solar has been shifting its business model away from heavy investments in production capacity, preferring to close older, now uncompetitive plants, while outsourcing production to third parties to reduce operating expenses. The company is also pushing its project business, which could generate higher margins, especially in the current overcapacity environment, which is depressing prices and margins.



Source: BP Solar

BP Solar module.

CNPV's 72-cell monocrystalline PV module.

CNPV enters long-term 100MWp agreement with SET

CNPV has entered into a long-term strategic sales agreement with SET, German project development and distribution company. The agreement specifies that CNPV will supply SET with a total of 100MWp of PV modules from 2010 to 2012. This includes 20MWp of scheduled delivery during 2010 at fixed prices. This fixed price will be reviewed on a quarterly basis, with each company's concurrence. This price change will however depend on the market situation. The remaining 35MWp and 45MWp is scheduled for delivery during 2011 and 2012 respectively.

3S Industries Group expands international reach

To spread its global influence, the 3S Group has created a 100% owned subsidiary of 3S Industries, in Barcelona, Spain. Previously a representative office of the company, 3S Industries will now provide sales and service to people in Latin America, Greece and Africa. This is the latest of 3S's most recent expansions, with established subsidiaries in China, Hong Kong and Singapore.

Jabil Circuit to manufacture 45MW of BP Solar modules at Polish plant

BP Solar has signed an agreement with Jabil Circuit to manufacture BP Solar modules for the European market in Jabil's plant in Poland. The deal calls for an initial capacity of 45MW in 2009, with the opportunity for expansion as demand increases. BP, which is increasingly outsourcing its production, joins SunPower and Day4 Energy as customers of Jabil's PV module contract-manufacturing program. BP's executive stressed that Jabil will manufacture modules designed by BP Solar and that the company's quality assurance standards will be integrated into Jabil's processes.

Testing and Certification News Focus

Fraunhofer USA's Center for Sustainable Energy Systems opens PV module innovation lab

During ribbon-cutting ceremonies held in Cambridge, MA, Fraunhofer USA's Center for Sustainable Energy Systems (CSE) officially opened its first laboratory, a PV module innovation facility. The new lab facilitates R&D, testing, and evaluation of new materials and production processes for photovoltaic modules with the goal of boosting panel energy yield, reducing cost, and enhancing module durability. An extensive suite of state-of the art fabrication equipment and characterization tools has been installed, which the Center says will be used by CSE scientists in their mission to make PV technology affordable for widespread use.

Solar module testing and innovation forms the cornerstone of the Center's photovoltaics research, according to its website. Using on-site equipment as well as the resources of Fraunhofer ISE (Institute for Solar Energy Systems), the CSE has the ability to simulate and accelerate the extreme conditions that would be encountered outdoors over the typical 25-year life span of a solar module, testing modules under various conditions of illumination, climate, and mechanical loading. These activities will be supplemented by module fabrication services that focus on new designs and manufacturing methodologies for solar modules, as well as new materials such as encapsulants and antireflective coatings.

The new facility will be complemented by the CSE Building Energy Efficiency Group, which performs work related

Bürkle supplies Scheuten Solar with Ypsator laminator

Scheuten Solar Technology, the Dutch solar module and glass manufacturer, has announced an order for Bürkle's Ypsator laminator, which will increase the company's capacity by an estimated 50%. The machine has a surface area of 1700 x 2200mm, a length of 17m and width of 7.5m working with six openings, and is designed for production of 12 solar modules per cycle. This corresponds to an annual capacity of approximately 50MWp. The investment volume including the conveying equipment is €1.6 million.

The multi-opening technology has enabled Scheuten to double its production capacity using an Ypsator lamination line that only requires 30% of the surface of a traditional single-opening laminator. The two-stage Ypsator is equipped with a hot press and a cooling press. During the lamination step, a membrane presses solar modules made of glass, a solar cell and foil with a pressure of up to 900 mbar. The line reaches a maximum operating temperature of up to 180°C.

China Sunergy enters framework agreement to deliver 100MW solar modules to Opsun

Opsun Technologies and China Sunergy have announced a framework agreement for the delivery of Sunergy's solar products to Opsun between 2009 and 2014. Their agreement includes the delivery of 100MW of solar cells, solar panels and custom-designed solar modules to Opsun. The companies aspire to stimulate their relationship by facilitating sales of Sunergy's solar cell products while increasing the development of specialized solar cells for future projects.

Opsun will integrate Sunergy's solar cell technology into their PV panel, structural PV modules and 3x concentrated modules. At the outset, sales will be focused in Ontario and Quebec, Canada and the northeastern U.S. In regard to the developmental portion of the agreement, Sunergy will enhance existing solar cell technology based on Opsun's specifications, which will allow the delivery of specialized solar products directly to Opsun.

Suntech to supply enXco with up to 115MW of modules for U.S., Canadian projects in 2010

EDF Energies Nouvelles company enXco has signed a deal with Suntech Power for the photovoltaics manufacturer to supply up to 115MW of crystalline-silicon solar modules in 2010. The EDF unit says the supply agreement will enable it to execute on its growing portfolio of rooftop and ground-mounted utility-scale projects in the United States and Canada in 2010.

Shipping timelines, specific project information, and financial terms of the agreement were not disclosed. Suntech has also rolled out Reliathon, what it calls the industry's first fully integrated utility-scale solar platform, which combines the company's latest module innovations and a new utility-grade module warranty, as well as pre-agreed preferential pricing and business terms with industry-leading inverter and tracking companies.

aleo delivers 10,000 solar modules for 2.3MW solar farm in Italy

aleo solar has delivered 10,000 of its S_18 modules for use in a 2.3MW solar farm in Corinaldo, Italy, in the country's Marche region. The farm, which uses a fixed mounting system, was connected to the grid in mid-September and was developed and constructed by General Building S.p.A. General Building, an Ancona-based solar energy company, has a portfolio of 3MW of installed solar power to date. Project investor E-Production has installed around 25MW of solar power in Italy, primarily the Apulia region.

Solar Power signs second supply agreement for its 200W modules

Solar Power announced its second supply agreement with German solar installation company Bayer and Raach, SPI's third 2009 order with the German company. SPI will provide 1.5MW of its 200W modules for the initial phase requirement of a 5MW system Bayer and Raach is installing in Bavaria. Since the system will be a multi-phase project over the 2009 and 2010 calendar years, it will ultimately call for a total of 5MW of SPI's 200W modules. Bayer and Raach serve a wide European market including Germany, Italy, the Czech Republic and Slovenia and are in a prime position to further SPI's reach into the European market.

Bosch acquires majority stake in aleo solar; six board members walk

The Bosch Group has now acquired 68.70% of aleo solar stock, placing the company as the majority shareholder. This acquisition occurs alongside Bosch's 60% interest in Johanna Solar Technology, in which aleo currently holds an approximate 17% stake. The antitrust authorities have already granted the necessary approval. In other, possibly related news, aleo solar has announced that the following members of the supervisory board have resigned with immediate effect: Marius Eriksen, Claus von Loeper, Volkswirt Jörg Friedrich Bätjer, Jürgen Parisi, Stefan Reineck and Betriebswirt Gerold Heinen.

to energy-efficient buildings and components. Areas of focus include deep energy retrofits, residential energy management, and building-integrated PV. To support these activities, an additional laboratory is under development, incorporating indoor as well as field-testing capabilities.

Intertek expands Lake Forest CNPV receives IEC certification for premium PV modules series

CNPV announced that ICIM/Euro Test Lab, Italy has awarded them the International Electro Technical Commission (IEC) certification for their premium PV modules series with power ranging from 190Wp to 200Wp. The modules are made with high efficiency 125x125mm mono crystalline cells and were launched and displayed at the 24th EUPVSEC in Hamburg, Germany. Currently, CNPV has shipped 8MWp of the modules to customers in Germany, France, Belgium and the Czech Republic for rooftop installations.

The 72-cell premium module series include large area, high-efficiency monocrystalline silicon solar cells, anti-reflection coated glass and high conductivity interconnected materials. The larger 165mm diameter of the cells, compared to the standard 150mm, is said to outperform the industry average of 8%, which equals a module efficiency

CNPV's crystal growing machines.

of 15.25%+. Their anti-reflection coated glass guarantees transmittance at STC level and provides an additional 3% performance at field level installations. The use of soft ductile and high-conductivity interconnected ribbons warrant minimal resistive power losses both at standard testing and field levels.

CNPV backs their premium module series with their 25-year power output and 10-year product workmanship warranty. The modules in this series have been given the IEC 5400Pa certification, which authenticates their ability to withstand high wind pressure and heavy snow load. The premium modules are in production and available at 190Wp to 195Wp power rating.

IECEE CB scheme testing laboratory

Intertek has announced that its Lake Forest, California, facility has successfully increased its IECEE CB scheme testing laboratory (CBTL). The facilities new capabilities now include product safety and conformity assessment testing and certification of PV modules to IEC standards.

The accreditation will let Intertek conduct one set of tests that will provide manufacturers with market access to the more than 40 countries that take part in the IECEE's CB scheme. It will also let the company test and issue IECEE CB test certificates to IEC 61730, 61215, 61646, 60897 and 60904 standards for monocrystalline, polycrystalline and thin-film modules.

Intertek's Lake Forest facility has the solar simulator, environmental chambers, rain and hail testers, impact and the mechanical loading apparatus among many others and the lab is accredited by the State of California Energy Commission for the Solar Home Program, CEC certifications and has agreements with Florida State Energy Centre for data acceptance.

Westpak offers specialized testing services for PV

Specialist testing firm Westpak is offering testing services for the solar photovoltaic and thermal products markets. With test facilities located in San Jose and San Diego, the firm can now handle damp heat, freeze-thaw, and thermal cycling tests called out in IEC 61215/61646/62108 and UL1703, along with distribution testing commonly referred to as "Package Performance Testing" designed to help guarantee damage free shipment of PV products.

UL introduces new services to streamline certification of turnkey solution production lines

Underwriters Laboratories has announced its Master and Fast Track Certification Programs, which have been developed to help PV module manufacturers and production equipment manufacturers move products to market faster by using an original approach to certify complete turnkey solution production lines. Participants in the UL program will be able to supply PV module manufacturers with pre-certified designs, which will reduce project turnaround time and offer better efficiency by avoiding the unnecessary testing, leading to fewer submitted product samples.

The programs will test both international and international UL International Electrotechnical Commission standards including UL1703, UL61730, IEC 61215, IEC 61646 and IEC 61730. All will be made available to global markets in North America, Europe and Asia.

DuPont adds new ionomer-based encapsulant materials to UL list

Ionomer-based backsheet materials that were launched by DuPont earlier this year for use as thin-film module encapsulants have now been recognized by Underwriters Laboratory. UL recognition assures that encapsulants have been manufactured using well-documented control practices resulting in predictable performance and consistency and eliminates the need for PV manufacturers to separately test the materials. DuPont's 'PV5200' Series PVB-based sheets and 'PV5300' sheets are now UL recognized.

"Today's module manufacturers are in a high-stakes race to create the ideal assembly of materials for economically installed

and operated solar power systems," noted Penny Perry, DuPont marketing manager for photovoltaic encapsulants. "Our goal is to remain the industry's most relied-upon source of ready-to-use, UL-recognized raw materials that help get the most from new designs."

DuPont claims that its ionomer-based sheet includes improved moisture resistance and extra stiffness for lower module deflections under windy conditions in the field.

DuPont PV Solutions' photovoltaic encapsulant sheets.

Other News Focus

3S, CEA Liten join forces for development of heterojunction solar cells

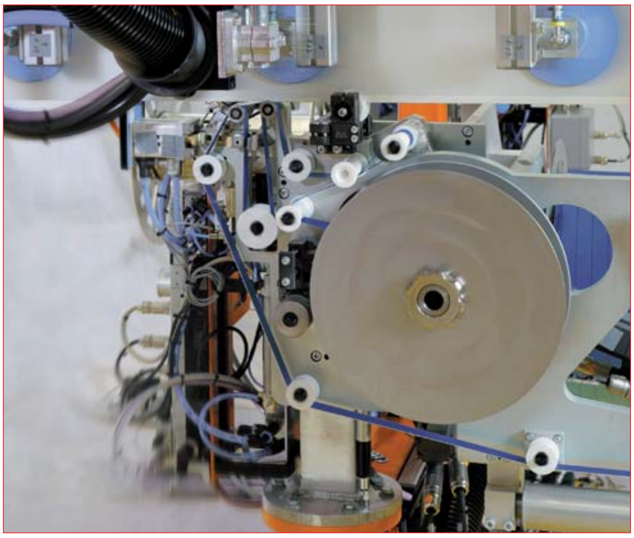
3S Industries and CEA Liten (Laboratory of Innovation for New Energy Technologies) - the French technological research organization - have signed a three-year agreement to collaborate on the development of PV modules based on silicon-based heterojunction solar cells and the tools needed to produce this type of module.

CEA Liten uses the National Institute of Solar Energy (INES) to conduct research on improving the performance of Si cells through the optimization of manufacturing processes and the introduction of new cell designs based on micro and nanotechnologies. The joint development program between 3S and CEA Liten is aimed at improving the speed of the development of innovative applications such as CEA's 20% efficiency heterojunction solar cell.

The next step on from the 20% efficiency in this joint development program is to develop the inherent bifacial potential of the heterojunction cells, offering the possibility to harvest the solar energy from both sides of the cell. If this development process is successful, the resulting module efficiency could be increased by as much as 30%.

Product Briefings

KUKA Systems/tesa SE



KUKA Systems and tesa SE's Robo Tape head module provides automated tape application

Product Briefing Outline: KUKA Systems has partnered with tesa SE to develop a new tape head module, ROBO TAPE R, which is used in the final automated application of adhesive tape to solar modules.

Problem: The ROBO TAPE R is used after the laminating process. Once the modules have been trimmed, the laminate is covered with tape to insulate and protect the solar module.

Solution: The adhesive tape ideally suited for use with this new type of tape head was developed and supplied by tesa SE. After taping, the modules are framed using ROBO FRAME, a patented KUKA Systems process. The double-head system increases process reliability as well as eliminating changeovers, ensuring greater output quantities and fewer rejects. Order accuracy is assured by the technology itself and is not affected by the stand-by head system. A further advantage is that the ROBO TAPE R tape head allows a variety of cutting methods to be used, such as rotating blade or hot wire, depending on the type and quality of the material. Another new feature is that the tape is separated from the liner, attached to the edge of the laminate and folded directly around the laminate while the liner is being automatically removed.

Applications: Adhesive tape for insulation and protection of solar PV modules.

Platform: Automatic application of gasket tape or insulation tape. In this station the tape is applied, cut to length and the liner pulled off. Includes an automatic liner take-up and rotary knife for precise cutting. Tape and liner tension are independently controlled by means of servo motors. There are different models available to suit different applications and products. Footprint 5m x 6m. Cycle time 60 seconds.

Availability: Currently available.

ACC Silicones

ACC Silicones adhesives and encapsulants offer protection for modules and components

Product Briefing Outline: ACC Silicones has launched its range of PV products, including adhesives and encapsulants that are compatible with most materials commonly used in the assembly of PV modules and concentrator cells.

Problem: Protecting delicate circuitry and components from long-term exposure to sun and the elements requires proven materials that will not change their physical properties over time. Adhesion to the materials used within the manufacture of PV cells is essential for frame sealing and fixing control boxes in place on the rear of the module. Newer CPV units require the use of optically clear encapsulants to maximise the amount of light reaching the PV cell.

Solution: ACC has selected specific products that will meet the challenges of PV installations and offer additional benefits to both production and design engineers.
PV5700/& PV5701: Non-corrosive RTV adhesives have excellent adhesion properties, suitable for frame and junction box sealing and the attaching of control boxes to the rear of panels.
PV2300 (Gel) & PV2218 (59° Shore A encapsulant): For use in CPV units to improve light transmission and provide environmental protection. They are both optically clear, UV stable and non-yellowing. These materials can be used to minimise light refraction by encapsulation the void between PV cell and lens.
PV2553: Thermally conductive potting compound to aid the fast and efficient removal of heat from electronic circuitry whilst also providing environmental protection for sensitive components.
PV2430: Tested and approved to meet UL 94 V-0 for electrical potting.

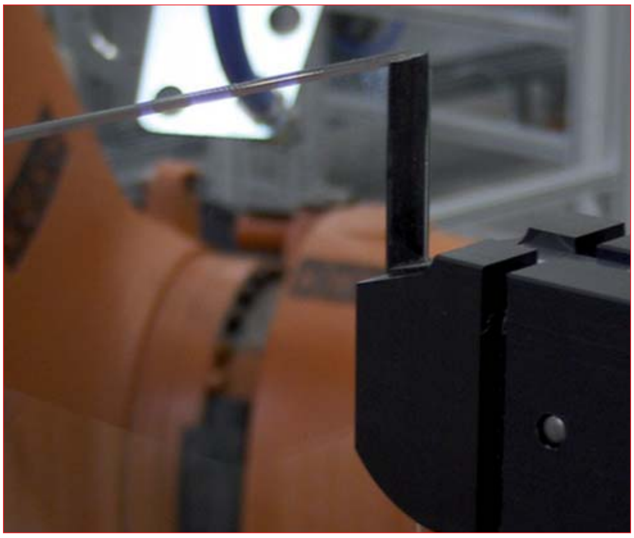
Applications: PV modules – manufacture and installation; CPV cells – manufacture, electronic control units.

Platform: Frame sealing and fixing control boxes in place on the rear of the module, compatible with most materials commonly used in the assembly of PV modules and concentrator cells.

Availability: Currently available.

Product Briefings

2BG



2BG's TP200AR enables perfect adhesion on the contact surface between tape and module

Product Briefing Outline: 2BG has launched the new TP200AR, a fully automatic system for applying ribbon on the perimeter of the laminated module. With an innovative system of preparation, tensioning and formation, it is possible to guarantee a perfect adhesion on the complete contact surface between tape and module in short execution times. The new concept allows module manufacturers to have low maintenance and a precise repeatability in performances in order to ensure a usage time of 99%, according to the company.

Problem: Reducing cycle times, increasing overall throughput and lowering the Cost of Ownership of tools used for module assembly are critical to competitive and market requirements, while maintaining the quality of the finished product. 2BG notes that the trimming of the photovoltaic module is a key area where costs and cycle times can be reduced.

Solution: The TP200AR's solution is that module manufacturers can select the best type of ribbon for a given module and its application. The auto-centering system of the photovoltaic module counteracts possible lamination mismatch and reduces time taken to correct alignment. The control of the pressure and trajectory of the modules coupled to the complete contact surface between tape and module enables high quality finished products.

Applications: The system can be used both for crystalline and thin-film modules.

Platform: TP200AR is designed to enable easy changeover of module types without having to effect any mechanical operation. The system is managed by software that helps reduce production time to a minimum, and can easily handle modules of dimensions 500 x 1100mm up to 1000 x 2000mm.

Availability: December 2009 onwards.

Schmid Group

Schmid's Tabber Stringer provides high precision combined with minimum handling

Product Briefing Outline: The Schmid Group has launched a new Tabber Stringer created in cooperation with the Wolf company. The system is designed to offer high precision performance combined with minimum handling and a soldering method that is claimed to reduce the risk of cell damage during processing and handling.

Problem: Tabbing and stringing is carried out in two steps whereby minutely exact positioning of the solder ribbons on the rotating table of the tabbing unit and highest repetition precision are necessary – this can be a difficult task.

Solution: The accuracy of cell positioning along the linear axis in the stringer unit allows production of 100% straight and regular strings for the first time ever. The use of different stations for quality control prior to and during the process and the automatic rejection of defect cells ensure a constant level of high quality while preventing the production of faulty strings. The combination of soldering processes is a new feature of this application. Contact-free resistance heating is used to bond the ribbons to the cells. The uniform temperature profile generated along the entire solder ribbon-busbar connection during this process creates a homogenous, high quality solder result. The tabbed cells are then connected in series to create strings, again by means of non-contact laser beam soldering.

Applications: Crystalline solar cell tabbing and stringing.

Platform: The new Tabber Stringer has a strong output performance (1,200 cells per hour) with a minimum breakage rate (< 0.3%) and space-saving design. An upgrade from 25MW to 50MW can be accomplished at low cost and little effort, and does not require additional space. It incorporates the possibility of processing very thin cells from 130µm. The system has a space-saving foot-print of $3.3m^2$.

Availability: Schmid will deliver the first Tabber Stringer to customers in January 2010.

Snapshot of spot market for PV modules – quarterly report Q3 2009

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.

Still falling

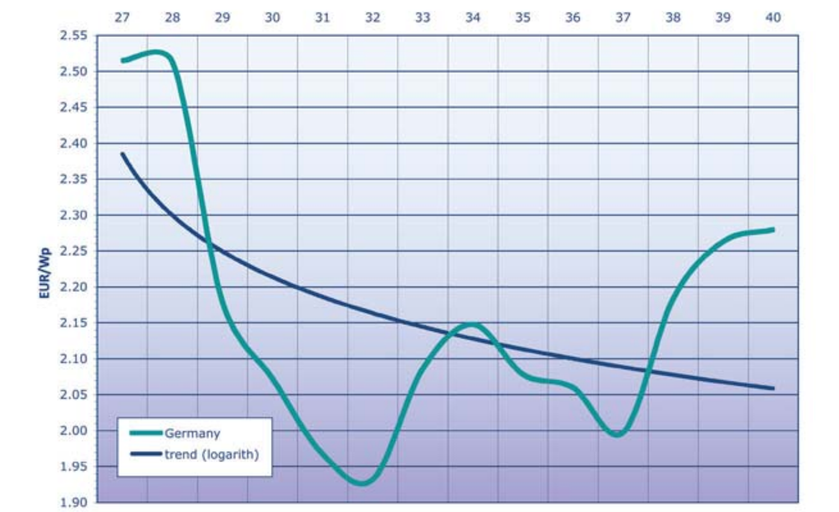
How long will this last? This is the big question on everyone's minds as the industry watched the unrelenting collapse of the price of solar modules in the third quarter of this year. For all technologies and regions, prices have fallen further since the first and second quarters of 2009. The watt-peak prices of many module types have now been almost cut in half since the summer of 2008. Although this decline still seems endless, some raw materials, such as solar silicon and certainly aluminium, are becoming more expensive. The glass industry says that solar glass prices have at times dropped below production costs. All options for cost reduction in the photovoltaics industry seem to have been exhausted.

In September 2009, more than 6.5MWp of PV modules were sold on pvXchange. This corresponds to a sharp increase in comparison to the previous month, which is less surprising as low trade volumes in summer are a common phenomenon on the spot market. Continuously strong demand in the German market has been the driver for such development. For the fourth quarter of 2009, pvXchange expects an ongoing strong increase in sales as a further growth of the whole industry is expected.

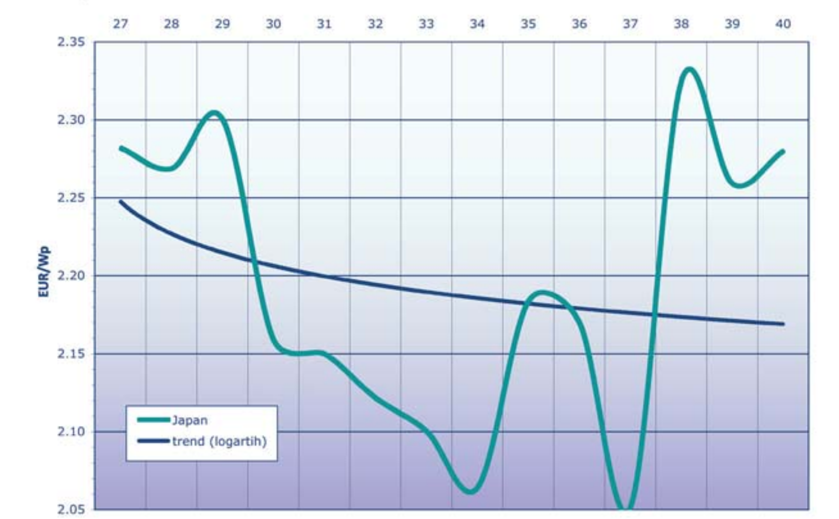
Over the past few months, the most traded technology was the CdTe thin film of First Solar, boasting a high market share on the spot market. This share is the result of high demand from companies seeking efficient modules for their projects in Germany. The good performance of CdTe modules, especially the good weak light performance for systems with a capacity of ≥ 10kW, is one reason for this dominant share on the market. In addition, a high demand for high-performance polycrystalline modules (200Wp and more) is also of note, as these modules are the most efficient solution for rooftop installations. The trend toward larger plants is not only in southern Europe or the U.S. At the start of this year, the average photovoltaic plant in Germany was 8.7kWp; late summer saw growth to over 21kWp – and this figure is rising.

Increasing price trend starts

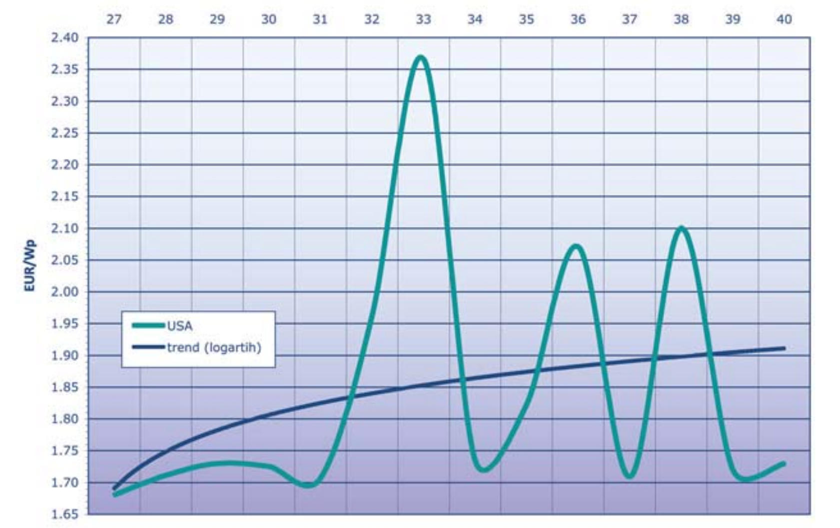
Despite advance bookings in July and August, the current course is beginning to turn and many well-known brands are sold out and currently not available on the spot market. Many buyers booked larger volumes in advance, so the price level in this snapshot is lower than the real price level for September. Such a tendency towards an increasing price level is again reflected by First Solar's modules, which were sold during the last quarter for 1.55€/Wp and are now up to 1.70€/Wp.



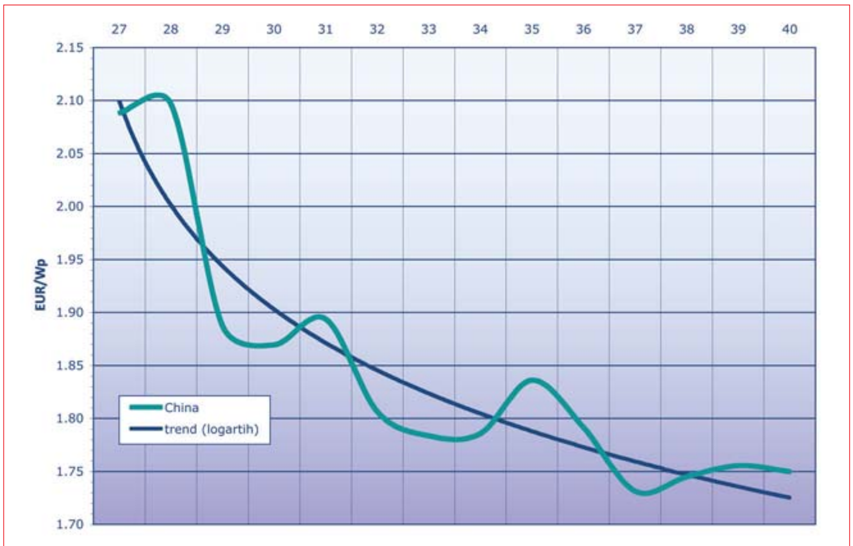
Development of market prices for modules produced by German manufacturers from July 2009 to (end of) September 2009 (in €/Wp).



Development of market prices for modules produced by Japanese manufacturers from July 2009 to (end of) September 2009 (in €/Wp).



Development of market prices for modules produced by U.S. manufacturers from July 2009 to (end of) September 2009 (in €/Wp).



Development of market prices for modules produced by Chinese manufacturers from July 2009 to (end of) September 2009 (in €/Wp).

While larger volumes of no-name products from China are still available on the spot market, the market for brand modules has been swept clean. High-performance modules from the likes of Suntech Power, Yingli and Sunpower, for example, will not be available on the European market until at least the end of the year. Thin-film modules are also showing a shortage of supply on the spot market, with delivery periods extending to as long as six or even eight weeks.

Over the next few months, a further sharp price increase of at least 10-15€ct/Wp for the most requested brand modules is expected, with an increase of up to 10€ct/Wp for Japanese, 10-15€ct/Wp for German and 10-15€ct/Wp for Chinese-brand modules. For no-name modules from China, a constant price development or even slightly decreasing prices are to be expected.

Furthermore, in the last reporting period, the following observations can be made:

- During the last few months, there was no remarkable difference in prices between mono- and polycrystalline modules, even though the latter saw a higher demand.
- The price for HIT modules was relatively stable, trading only in small volumes and mainly used for small BIPV systems.
- a-Si modules are the cheapest modules available on the spot market and are often used for larger installations in Eastern Europe.
- The price level for CdTe modules was relatively stable but is currently increasing due to high market demand.

Many big-name manufacturers and system providers are currently reporting a slump in sales or even considerable losses in the first half of 2009. Ambitious plans to expand in Asia nevertheless show that European firms – such as Q-Cells and REC – have not yet abandoned hope of an imminent upturn in demand. It is expected that First Solar will sell its entire annual production of about 1GW, which would see First Solar surpass the production of the world market leader for crystalline silicon modules, Suntech Power, almost twice. Future production capacities look virtually unlimited; nevertheless, inventories are still growing everywhere.

Similarly, Chinese manufacturers' prices are almost 20% cheaper than those of European competitors. The argument that the quality of modules from China is lower than those of the West is no longer enough to defend the benefits of Western industry. Some of the major Chinese manufacturers are qualitatively and technologically among the industry frontrunners. Monocrystalline cells Suntech, for example, reach an efficiency of 18.8% and 17.2% using polycrystalline cells. Moreover, the prices of crystalline modules from China have almost caught up with those of thin-film panels, making them more and more attractive for large projects.

Some manufacturers have apparently found a way out by building their own megawatt-scale plants. Rather than pushing modules onto a saturated market at low prices, they are using these modules in their own project installations. A current example is a joint venture between Q-Cells and MEMC that is now investing in a 50MW project in Lower Bavaria. The U.S. market is also likely to absorb a noticeable share of worldwide module production soon; large projects are no longer exclusively planned for California, Texas or Arizona.

It remains to be seen whether prices will stabilize in the short term. The price war is likely to pick up again, in the fourth quarter at the latest, if many of the thin-film factories currently in start-up mode can produce enough high-efficiency modules.

About the Authors

Founded in Berlin in 2004, **pvXchange GmbH** has established itself as the global market leader in the procurement of photovoltaic products for business customers. In 2008, the company procured solar modules with an output of around 100MW. This represents a trading volume of approximately €300 million. With its international network and complementary services, pvXchange is constantly developing its position in the renewable energy market, a market which continues to grow on a global scale. Based in Europe, pvXchange also has a presence in Asia and the USA.

Enquiries

pvXchange GmbH
Obentrautstr. 57, D-10963
Berlin
Germany

Tel: +49 (0)30 236 31 36 0
Fax: +49 (0)30 236 31 36 23
Email: info@pvxchange.de
Website: www.pvxchange.com

Yield management at the highest quality level

Ralf Lüdemann, Ute Mareck & Michael Eberspächer, SolarWorld, Freiberg, Germany

ABSTRACT

Yield and quality of a production process and quality of the final product are closely linked. To further improve yield and quality, cutting-edge technology and best-practice productions are necessary. Technology development and continuous improvement require, however, in-depth understanding of all materials, processes and equipment as well as their interactions. We propose a system of comprehensive quality assurance on different levels and both within and between all production steps along the value-added chain. Optimisation or changes in interstage products, i.e. supplies, must focus on the quality of the final product. For this reason, we must look at the production chain as a whole, from raw material to final product.

Setting the stage for quality and improvement

Quality matters; quality sells; quality is all-dominant. This simple principle can be applied to myriad situations, but for PV modules, which come with long-term warranties and bring a high degree of public awareness, quality is a vital criterion. Of course, cost is a major factor in this process, but ultimately, production cost and product quality do not conflict. Together with technology development and continuous improvement, cost and quality have the same roots and prerequisites. Quality assurance and yield management go hand-in-hand and improve product quality and production cost at the same time.

Besides a clear level of commitment and well-educated staff, a good set of tools and conditions is necessary to ensure high levels of quality in the technology industry. The most important basic condition is to know what you are doing and how it affects the final product. This sounds obvious, but is far from simple or even common in real-life mass production. Placing oneself in that (starting) position, one must establish:

- quality assurance on process level
- quality assurance on product level
- both within and between each value-added step.

Quality assurance on different levels

Quality control of products is common to all production scenarios. As suppliers and customers agree on a certain specification of the goods to be exchanged, testing against this specification is part of the business. However, specifications often arise from producibility considerations and, to a lesser extent, from specifications of the customer's customer. As is often the case, the guiding idea is 'what is possible' instead of 'what is necessary,' because it is not entirely known what level of influence properties of a supply material have on the processes during production and therefore on the quality of the production itself. Yield and productivity are very sensitive to

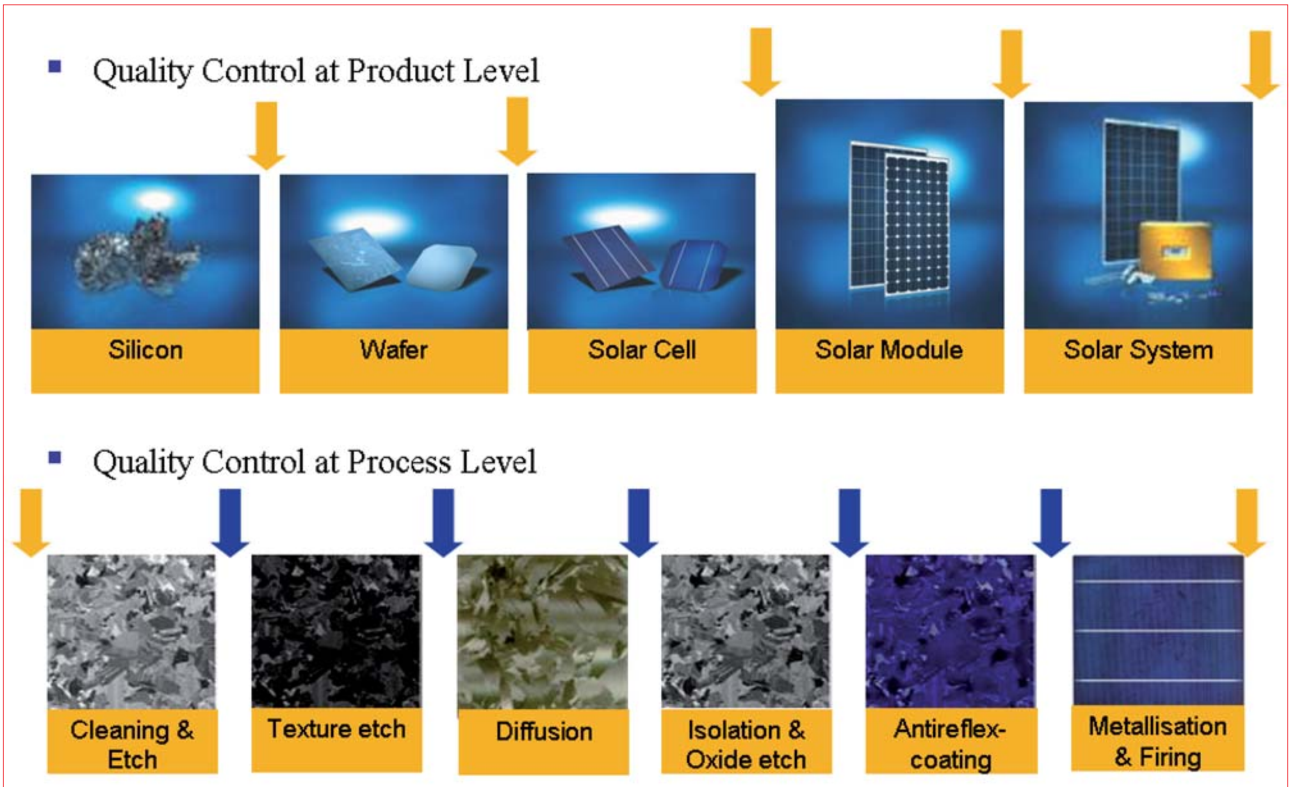
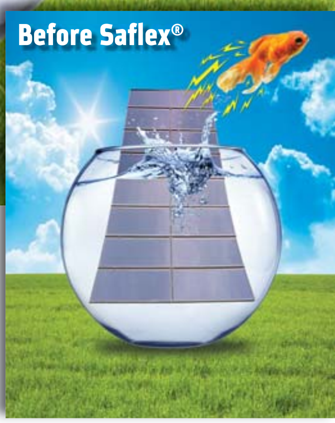


Figure 1. Quality assurance between the different product stages of the entire value-added chain and within one value-added step (solar cell production in this case).

Our Encapsulants Optimize Module Production and Keep the Energy Flowing After the Sale

- Enhanced Edge Stability
- Passes IEC 61646 Testing
- Outstanding Resistivity / Reduce Current Loss

Saflex® encapsulants help solar module manufacturers optimize production and improve panel moisture resistance. For more than 80 years, Saflex has been the world leader in protective interlayer for laminated glass, and today Saflex is the preferred encapsulant for the world's largest thin-film solar modules. Our technical expertise increases throughput, increasing yields.



Saflex®

www.saflex.com

SOLUTIA

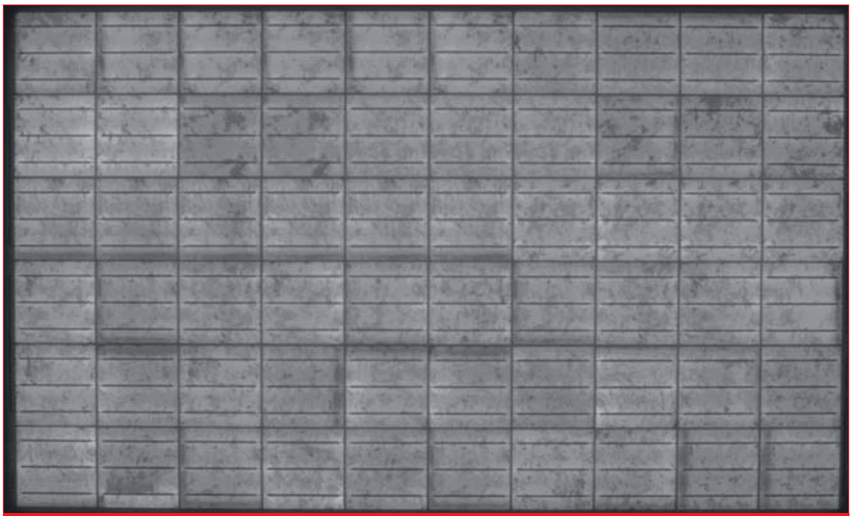


Figure 2. Electroluminescence image of a solar module.

some (but not all) properties as well as to variations of properties of input material.

Quality control of all processes during production has therefore a two-fold importance: control of every single process step is necessary to secure a stable production by identifying variations of even minuscule extent. With this control, preventive maintenance of equipment, readjustment of processes, and reject (or rework) of deficient products can then be performed at the earliest possible stage, which is the basis of high overall equipment efficiency (OEE), high product quality and low yield costs, as deficient products are not treated further before being rejected in the final inspection. In addition, comprehensive quality control at process level is the only way of identifying important material properties and the impact of their variations.

A high-quality product is made out of high-quality supplies in a quality-oriented way. Since all supplies are products of upstream productions, the interaction of productions along the value chain becomes apparent. All products are considered interstage products on the way to the final product for the end-user. Therefore, it is advantageous – if not even necessary – to be a fully-integrated company or at least to have access to the whole production chain, from raw material to final product.

"It is advantageous – if not even necessary – to be a fully-integrated company or at least to have access to the whole production chain, from raw material to final product."

In the following section, we provide an insight into quality assurance and yield management along the PV value chain, starting at the finished product, the solar module.

Yield management in module production

Both in terms of cost and technology, the solar module is the core of photovoltaic systems. Only a long-lasting functionality and durable high energy yield over several years can guarantee the calculated return on the entire investment. Consequently, particular stress should be placed on ensuring the longevity and quality of each individual solar module.

Function and longevity of the solar module

Numerous climate chambers are employed at SolarWorld's module factories to assess any possible fault sources that could potentially reduce the service life of the modules. Up to 14 modules are randomly selected from the production line, placed in a climate chamber that has been connected to the end of the production line, and subjected to rigorous, all-inclusive inspections based on the IEC 61215 certification. All modules that pass the several-weeks-long inspection process are then checked for possible errors in their entirety. As a result, faults can be reacted to in a prompt manner and the respective measures can be undertaken accordingly. In addition, further climate chambers are set up to simulate environmental influences such as heat, frost and humidity for even more thorough analysis. At SolarWorld, a separate company for global technology development and quality assurance supports the production companies in this regard, subjecting the modules to elaborate processes in which they are inspected for process or material changes before being granted approval for production.

However, important simulations of the natural aging process are for quality assurance of the production process; they are insufficient in terms of controlling all possible faults on a PV module. Subsequently, we utilize additional methods of quality control. One very novel method involves electroluminescence measurements. Taking advantage of the properties of solar cells, electrical stimulation involves light being emitted from all functioning cell parts. It is thus possible to create an image that describes the functioning of the individual cells both during the current flow through the solar module as well as during inverse operation.

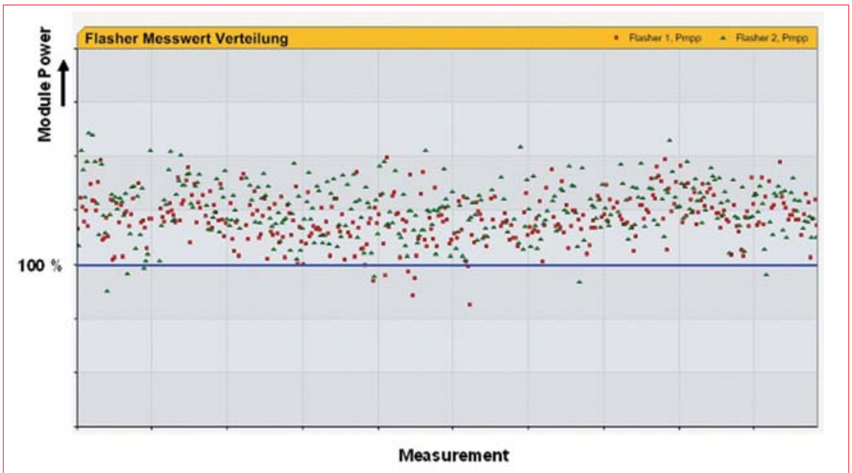


Figure 3. Trend chart of the measured module output on two flashers.

Figure 4. Device for performing a pull-off test on soldered solar cells.

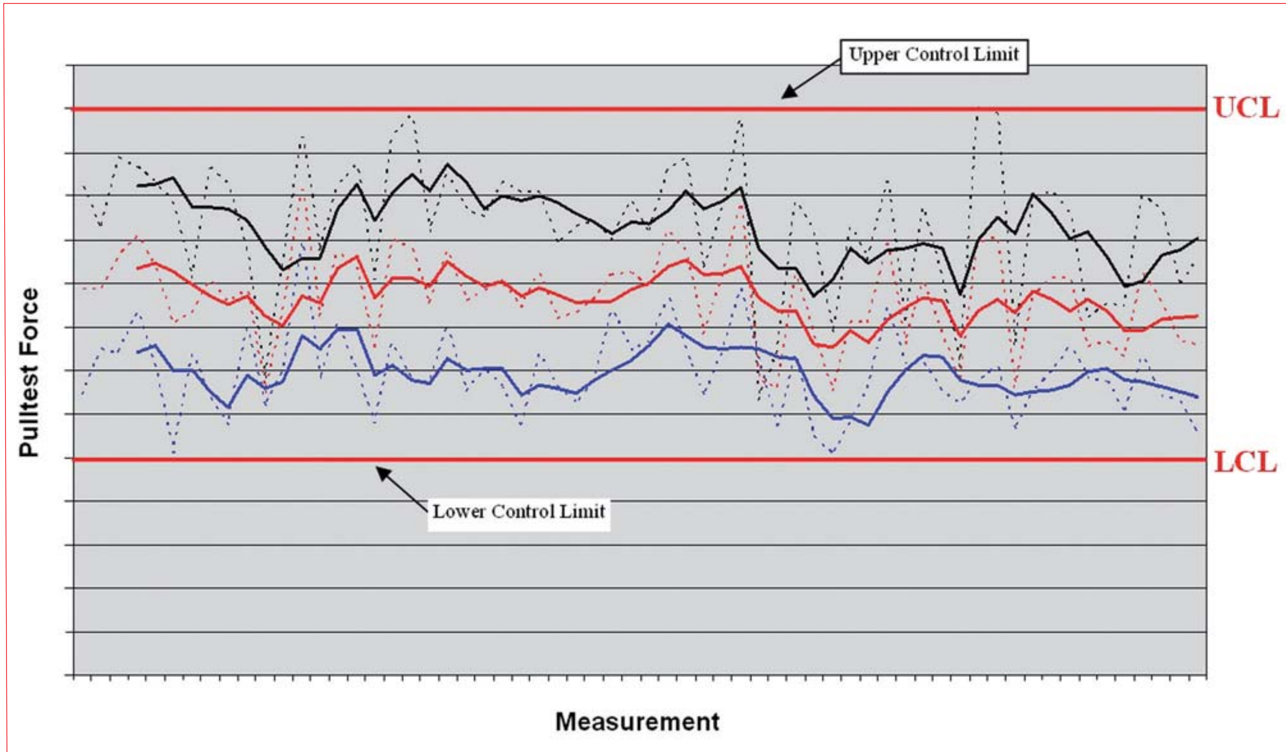


Figure 5. Process controls of the pull-off values on the front and rear side of the module.

If any solar modules are found to possess cells with breakage, shunts or other faults, we will subsequently remove them from production and they will not be sold.

The sun simulator: the most important measuring instrument

An essential parameter for customers is the module's output, which, in the end, influences the cost of the entire PV system. At the very minimum, all SolarWorld customers generally receive the output for which they paid. That is why, alongside practicing plus sorting (all 220W modules are always equipped with more than 220W), special emphasis is placed on the function and configurations of the sun simulator, or so-called flasher. External institutes regularly confirm the measured module output based on routine precision measurements. The continuous observation of the power curve of the produced modules ensures that the entire measuring system is functioning at all times. Several flashers are compared to one another via software and any deviations are automatically reported to the responsible engineer.

Continuous process controls

Good quality and performance cannot be 'tested into' a product; it must be manufactured. In consequence, each component of the solar module and every relevant production process are carefully observed, the primary responsibility of the employees at the highly automated factories. As soon as the solar cells are soldered to a so-called string, factory employees perform a 100% control through which any possible faults are discovered immediately. This is combined with camera inspections. The adhesiveness of the copper strips used to connect cells is routinely measured and documented via a measuring device specially developed in-house. Predetermined minimum requirements must be met. If not, the soldering system or the respective material must be decommissioned and the cause of the fault must be determined.

Figure 6. Qualification of uncured EVA film as part of the inspection of incoming goods.

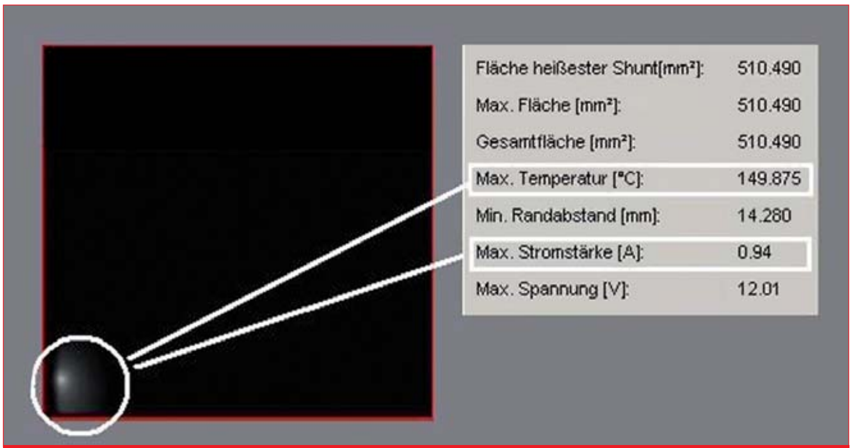


Figure 7. This specific cell passed all other final inspection tests but was rejected by a thermographic test for hot spot risk at the cell edge. The resulting test temperature here was 149°C.

Such inspections are constantly performed during the entire production process up until final production of the module. Whether soldering, laminating or placing the connections socket or frame, inspections are always required to demonstrate that the processes are stable and that their results are within the predetermined parameters – for each and every solar module. The results are continuously recorded, saved in a production control system and made available to the company for evaluation and control via intelligent presentations.

Alongside these processes, the 'ingredients' are also decisive for the quality of the end product. For this reason, all essential product properties are precisely defined in quality agreements and specifications agreed upon with suppliers. High-quality products can only be consistently produced in a highly automated factory when stable materials are used within the permissible tolerances. The agreed properties of the components such as films, glass or frames are continuously ensured through internal measurements. Specially trained personnel with no other productive responsibilities are on duty around the clock specifically for this purpose.

> "High-quality products can only be consistently produced in a highly automated factory when stable materials are used within the permissible tolerances."

The specially developed batch tracing allows the tracing of the materials in each

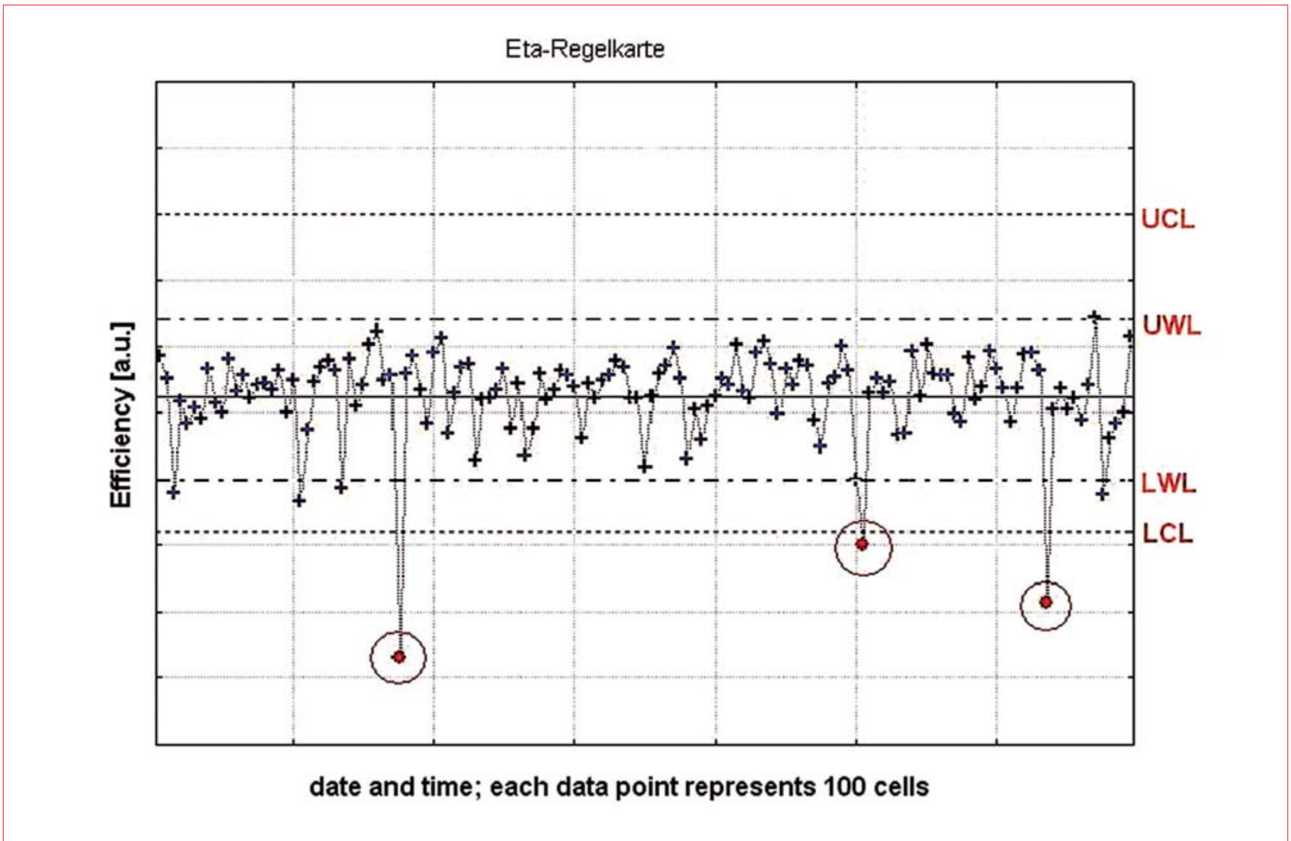


Figure 8. Real-time efficiency SPC control indicates an out-of-control situation but not the root cause.

module up to the batch number of the suppliers. The module factories maintain intensive cooperation with the solar cell productions, which are mostly located in the immediate vicinity, in terms of both current and future products. The concept of a comprehensive value-added chain and being a fully integrated corporate group pays off well.

Yield management in solar cell production

Solar cells are the core of crystalline silicon modules and the most important supply for module production. Their functionality basically determines both the module power as well as long-term behaviour of the modules. The best way of maintaining cell quality under control is by keeping each process step and the incoming material quality under control. SolarWorld cell manufacturing supports the quality control with an integrated MES and SPC system over the whole process chain.

Outgoing quality control

Before any cell leaves the solar cell manufacturing process for the module

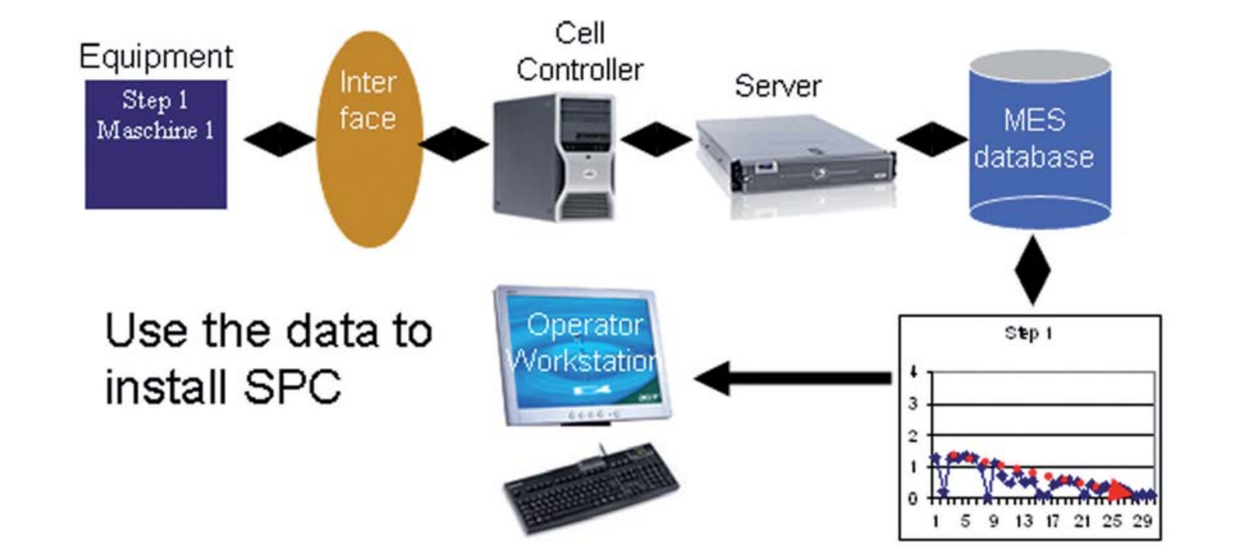


Figure 9. All measured data are collected in a database.

Figure 10. An automated variation analysis enables keeping different equipments of one process step under control.

manufacturing process, a final quality control takes place. This includes the measurement of its output power, the evaluation of its optical appearance and final breakage inspection. All data are stored to a database and can be recovered by reference to their shipping box.

Having passed all these tests, a solar cell still may have a small risk of generating hot spots when it is operated under the reverse current condition, for example, partial shading as a result of falling leaves or just a tree that casts a shadow. SolarWorld applies a thermographic test method to detect and reject such cells.

In-process quality control

The SPC control of completed solar cells just indicates out-of-control situations, but cannot support the root cause analysis. This can be done only with real time SPC for critical process parameters of individual process steps.

Following this approach, the SolarWorld cell manufacturing is covered with inline process control for each process step. All measured data are collected in a database. Key parameters automatically undergo analysis of variance (ANOVA) for the different equipments, with SPC or other analytic methods based on the data submitted to the MES database. This approach enables keeping several items of production equipment under control and supports the continuous improvement process.

As a result of having all individual process steps under control, the outcome in terms of yield and efficiency is very stable and predictable.

Incoming quality control and tracking

Wafer quality is key to cell quality. There

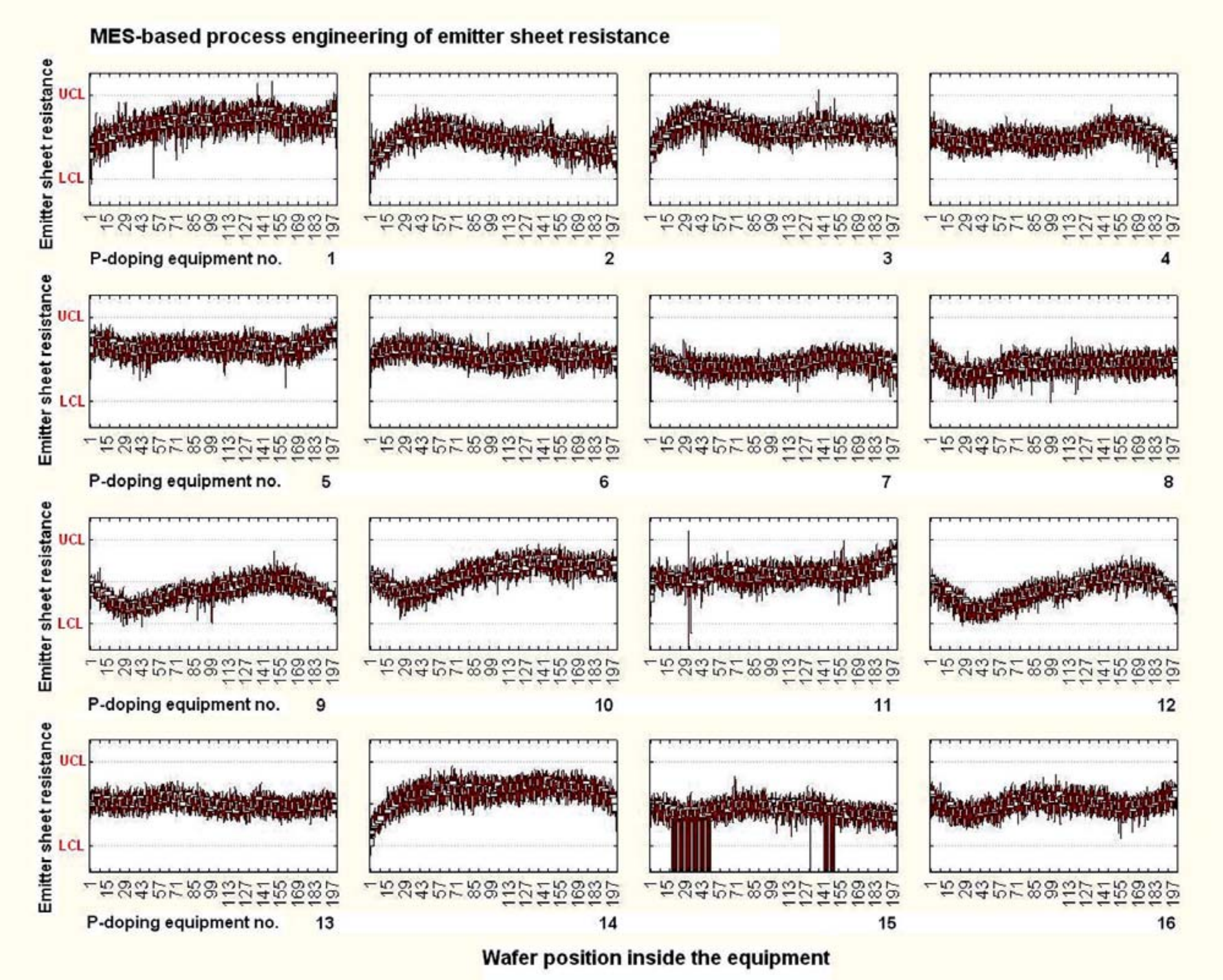


Figure 11. With MES support it is possible to visualize the wafer-to-wafer emitter sheet resistance within one process batch or as an average of many processed batches.

are different inspection tools available to inspect wafer quality characteristics such as dimension, resistivity, charge carrier lifetime (as an indicator to cell power), and micro crack (for breakage prevention). A standard approach, like in other industries, involves a final inspection on the part of the wafer supplier of the product quality. Together with our suppliers, we define and develop techniques and parameters and we audit our supplier regularly.

After incoming inspection, all of the wafers get a virtual identification number and a description of their wafer history when they are checked in to the cell manufacturing process. Wafer performance is thus tracked and in case of any deficiency followed up with its supplier.

Requirements for equipment

Yield management and quality assurance techniques and processes need production equipment that enables stable production processes and process controlling. The production equipment itself has to comply with highest quality standards: quality products can only be made using high-quality equipment.

Integrated equipment structure

First of all, the integration of quality control equipment into all process and handling equipment is mandatory. Integration means not only a physical build-in, but also a logical integration into the process control (rather than only a data connection), since a lot of hand-shaking between process, handling and quality control equipment is necessary. A production unit for a certain production step consists of several sub-units or equipments. However, it must work and feel like a unit, i.e. the user interface should be uniform and the manufacturing execution system should be connected via a single interface to the equipment, including all sub equipments.

> “Working under pressure to get a tool up and running, problems can be fixed ineffectually, and changes can be shoddily documented, or not documented at all.”

First pass yield and documentation

Nevertheless, even more basic requirements exist. The PV industry is still such a young and rapidly changing industry, and standards are rare. In addition, issues in yield or productivity in production often arise from errors during installation of the production line. The following set of rules must be adhered to in order to ensure a first pass yield for equipment:

- Equipment is built as specified (all deviations from guidelines or specifications have to be approved)
- All test protocols are available before installation (safety guidelines, process and equipment functions, etc.)
- After installation the equipment is ready for process start-up (no software corrections etc. necessary)
- Communications between sub-tools and other tools are tested before delivery
- MES communication is tested in-house.

Often, a kind of on-site development starts after installation of production equipment. This not only leads to delays in ramp-up, but can hamper production permanently. The manufacturer can only know what is happening in a process (first bullet point above) if they know how the tools work. Working under pressure to get a tool up and running, problems can be fixed ineffectually, and changes can be shoddily documented, or not documented at all.

Documentation can not be underestimated. It has to be prepared before shipment and should (at the very least) contain:

- Risk and hazard analysis; electrical and functional plans

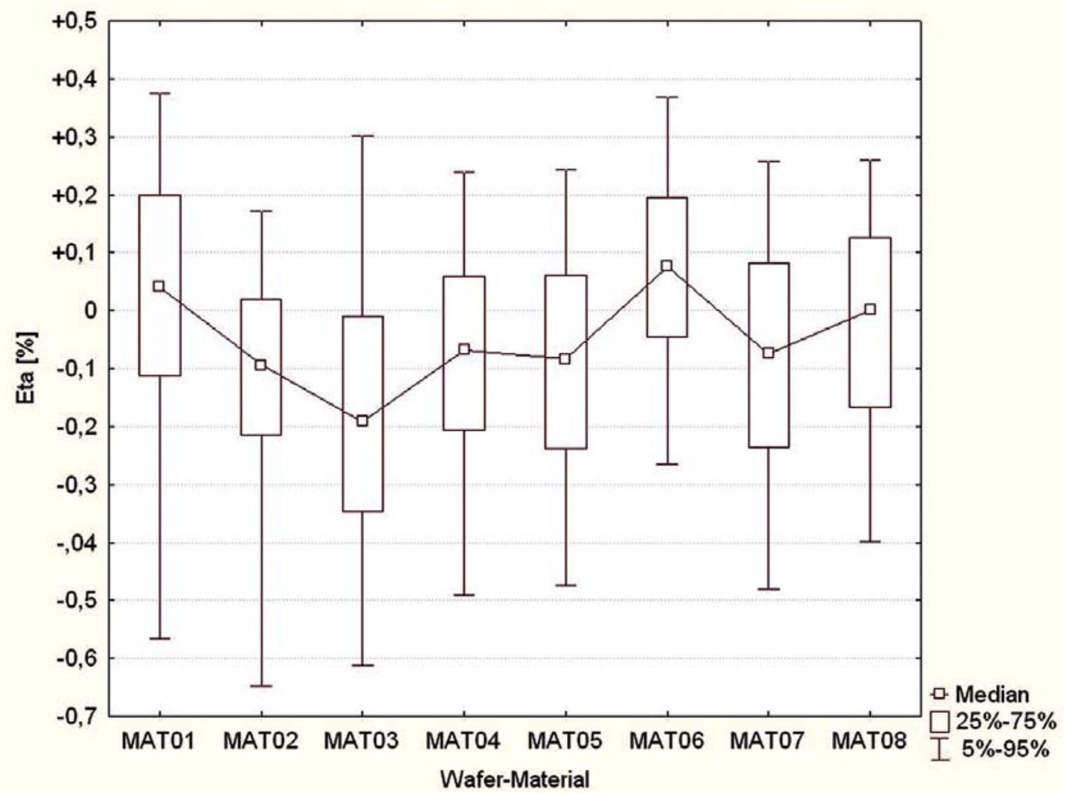


Figure 12. Tracing back cells to their wafer origin enables a real wafer quality control.

- Operating instructions, process and equipment functions, interface and hand-shaking protocol
- Maintenance plans and instructions, and detailed spare part lists with MTBF.

Support

To ensure the highest possible quality of a product, the producer and supplier must work together closely. What is true for material suppliers is also true for equipment suppliers, and this cooperation should not stop after the equipment acceptance test. A high-quality production needs qualified support, including qualified training of equipment engineers, service technicians, and operators (of all shifts) as well as on-site service at least in the first months after ramp-up and a 24-hour hotline, service response and spare parts delivery.

Outlook

Thirst for knowledge and the drive to establish solar energy supply at a competitive price have improved technology in photovoltaics in the past. With bright and dedicated people with good ideas, techniques for fabrication and for quality assurance have been established and yield management techniques have been adapted. At SolarWorld, we were the first to establish a sustainable quality assurance along the whole value-added chain, from silicon to system, by quality control of all (interstage) products and supplies as well as after every single process step. Together with comprehensive MES and thorough SPC in mass production, statistically sound analysis from individual process steps to the overall manufacturing is possible. We not only know what we are doing, we even control it. And a lot of others in the PV industry follow this approach.

Economical pressure is forcing all players in the industry to follow this route to higher quality and higher yield at an ever-increasing pace. Not only is there room for improvement; there is a burning need for improvement. The interdependency of supply material, process equipment and end-product is so important that the interaction between supplier and customer, between equipment manufacturer and production company, between the different stages in the value-added chain will increase further and the optimisation of all products and processes will strictly focus on the final product for the end-user. This customer-oriented, quality-focused, integral approach is the basis for yield management at the highest quality level in mass photovoltaics production.

About the Authors

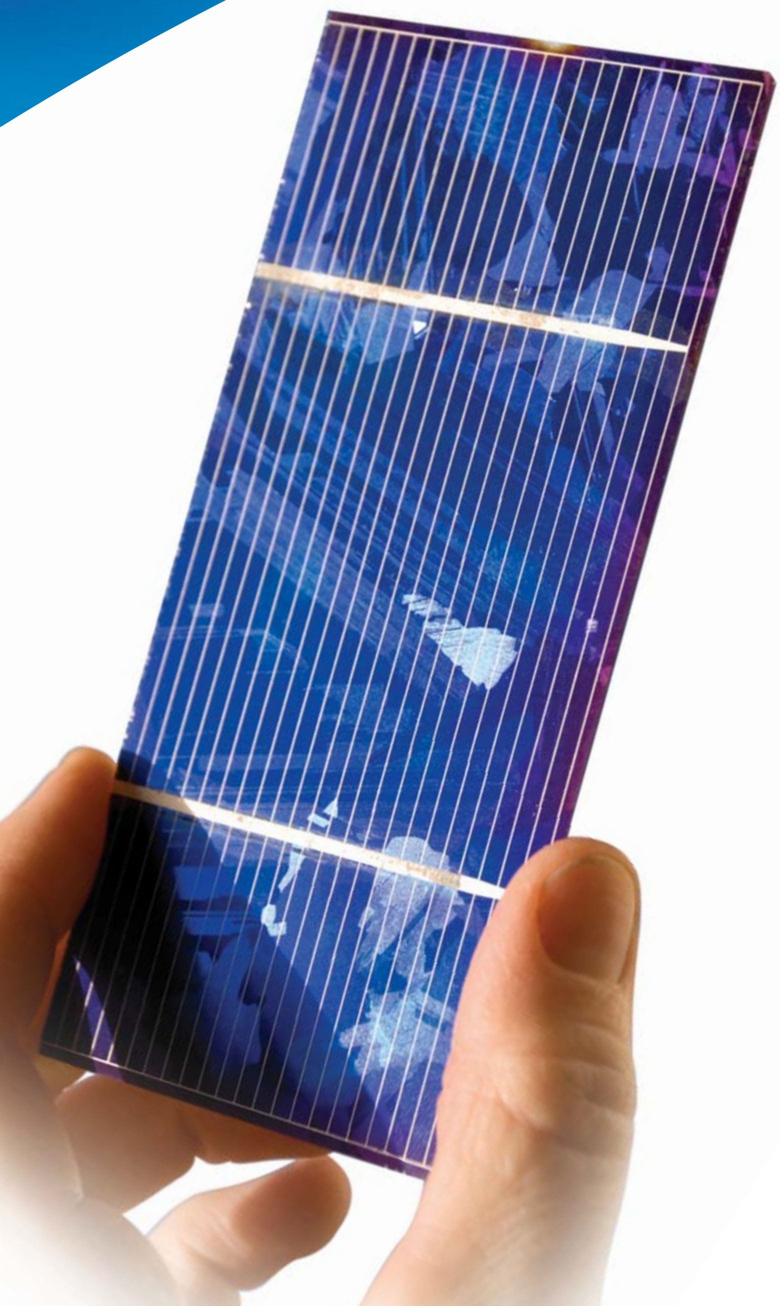
Ralf Lüdemann is Managing Director of SolarWorld Innovations and SolarWorld Industries Deutschland. Within the SolarWorld Group, he is responsible for global R&D and strategic technology and product development. Prior to this role, he was in charge of establishing and operating SolarWorld's solar cell production Deutsche Cell. Ralf Lüdemann is curator of several research institutions and gives lectures at the University of Freiberg.

Dr. Ute Mareck, Dr. rer. nat. studied chemistry and semiconductor materials at the University of Leipzig. From 1992-2007 she worked on wafer technology and quality assurance in the semiconductor industry. Since 2007 she has been responsible for quality assurance at Deutsche Cell, the German cell manufacturing company of SolarWorld.

Michael Eberspächer has a diploma in electrical engineering and completed his postgraduate studies with an M.B.A. For over six years, he has worked at Solar Factory GmbH, the module producing company of the SolarWorld Group. In his current position as Head of Quality Assurance (Module Production), he is responsible for, among other aspects, the MES (Manufacturing Execution System) and statistical evaluation.

Enquiries

SolarWorld Innovations GmbH
Berthelsdorfer Strasse 111a
D-09599 Freiberg
Germany
Email: info@sw-innovations.de
Website: www.solarworld.de



Trends and developments in the lamination process of PV modules (part 2)

Mark Osborne, News Editor, Photovoltaics International

ABSTRACT

Although much of the emphasis of Part 1 of this paper (in *Photovoltaics International* ed. 5) focused on material quality issues and attention to detail on process control, high-volume manufacturing requires a concerted effort to constantly improve productivity of the lamination process and in turn the productivity of the total module manufacturing line. Such is the competitive landscape that greater attention to these factors is becoming a key differentiator for both equipment suppliers and module manufacturers. In this, the second part of the lamination process focus, we will look closely at the dynamics impacting module prices and the developments being undertaken to improve cycle-times of the lamination process, overall productivity and optimization as well as costs to ensure future competitiveness.

The pressure on module manufacturing

A significant drop in module ASPs as a result of the global economic recession had a huge impact on the PV industry late in the third quarter of 2008. This inevitable reduction in overall demand for solar was also negatively impacted by the collapse of the Spanish market.

There seems to be a growing discrepancy between PV module production and actual installations. According to iSuppli, module production will now reach approximately 7.5GW in 2009. Although a wide range of installation forecasts have been suggested, even taking 2008's figure of 5.5GW installed as a guide, it is clear that a major disconnect is occurring.

iSuppli guided 4.2GW earlier this year, which still denotes a module overcapacity situation of over 160% for 2009, remaining above 100% through 2012. This scenario would bring silicon module prices crashing down to between US$2.50 and US$2.75 per watt. Nevertheless, concerns over module inventory build in recent quarters seems to be easing after module production has become better matched to market demand.

Module price declines have been more severe in the first half of the year than predicted by those 'in the know'. Many expected a decline in prices of between 10 and 15%, due to a combination of FiT changes in Germany and polysilicon price declines as overcapacity became apparent in the second half of 2008. REC noted in the third quarter of 2009 that it expected module prices to have fallen by 35% in 2009 as the glut in finished products continued. Module prices could yet show a 32% decline for the year, according to the latest figures produced by Photon Consulting.

The net result is mounting pressure to reduce module manufacturing costs such as materials, which represents a higher percentage of the cost of manufacture. Scaling facilities to greater economies of scale intensify along with greater need for improved productivity of the equipment.

Laminator innovations and process optimization

The laminator equipment market has seen significant growth in recent years as it has responded to this ramp in module production. As noted in part 1 of this feature, VLSI Research's data showed that the laminator equipment market exceeded US$300 million in 2008, a CAGR of approximately 100% compared to 2007.

> "The module market has changed significantly, which could shape the future of the lamination market in years to come."

Although figures are yet to be revealed for 2009, the continued capacity expansions should result in a stable market comparable to that seen in 2008. However, the module market has changed significantly, which could shape the future of the lamination market in years to come. This is perhaps part of the reason why recent new product announcements attempt to tackle the throughput and cost considerations that module manufacturers now face with rapidly declining prices.

The changing face of the laminator market is apparent in the move by some established PV equipment suppliers from other sectors to penetrate the market with new technology. One such mover is Bürkle which entered the market in 2007. From the perspective of Bürkle's Dagmar Metzger, Product Manager Photovoltaic, the laminator market was in need of a major rethink.

"Before Bürkle entered the PV market, we examined the materials to be processed and subsequently developed the corresponding machine types. Furthermore, we assumed at that time that the industry will have to get in the high-volume area and that larger capacity units would be required for this purpose."

However, Metzger was not too complimentary of what she described as 'traditional' laminators, noting that there were some fundamental issues with the equipment being used as recently as a few years ago.

"We had the impression that many of the laminators which were in use on the market at that time were mostly prototypes that have not been fully developed yet concerning many technical issues, originally intended for other purposes. Most of the lines were lacking automation and operated manually.

"Heating and vacuum systems which were in use were partly tainted with high tolerances. Consequently, the process window available for the user was highly restricted and no reproducible processes were possible." Metzger also believes that the knowledge on available materials was limited, forcing operators to carry out experiments on their own in order to obtain the necessary know-how. As soon as a process was reliable to some extent, it was frozen and not developed further.

Figure 1. Bürkle's 'Ypsator' stack system is designed for high-volume module applications.

Figure 2. Komax's XLam 3L-17/34 asynchronous (independent) stack laminator.

"Moreover, the traditional laminators require quite a high maintenance effort and cause still very high wearing part costs," commented Metzger. "Currently, the traditional laminators working with membrane are also used for glass-glass modules, which were not optimal due to the overpressure which the membrane creates at the edges of the modules and due to only one-sided heating from below."

The 'Ypsator' system that Bürkle introduced laminates up to 20 modules per cycle (Fig. 1). On a surface area of 3.5m² per opening with five openings, manufacturers can produce 10 photovoltaic modules per batch simultaneously. The total annual capacity of a tool is around 500,000 modules.

Using heating platens with thermal oil, process times are reduced considerably. The lamination process is separated in order to make the processes more flexible, thus increasing productivity. In a first step, the modules are pre-laminated. This means that the moisture and the air pockets are removed from the sandwich in the vacuum, creating a vacuum-tight compound. The lamination is finished in a subsequent press. In a third step, the Ypsator cools down the solar module from 150°C to hand warmth. Due to the structure of the three lamination steps, the glass modules can be laminated with less stress, resulting in less glass breakage.

"In the case of glass-glass, modules Bürkle offers a special three-step lamination concept which avoids an overpressure at the edges and supplies the heating of the modules from both sides," added Metzger.

Bürkle would seem to have had some market success with the Ypsator system, especially with thin-film module manufacturers. Shortly after the 24th EU PVSEC in Hamburg, the company announced a tool order from Taiwan-based Jenn Feng New Energy, the sixth such order from Asia-based customers within one year.

Bürkle has also started to penetrate Germany-based module manufacturers, recently sealing a deal with the newly formed and rapidly expanding Bosch Solar Energy AG. Bosch Solar Energy will start producing a crystalline module manufacturing in Arnstadt at the beginning of 2010, using two multi-opening Ypsator laminators with four openings each for its first 75MW line. The companies plan to collaborate further to improve module manufacturing in the future.

However, other equipment suppliers are not convinced that the multi-opening laminators provide what much of the industry is demanding. One of those is Mark Willingham, VP of marketing at Spire Corporation.

"We are not pushing into stack laminators; what we have done is watch that market segment and there is no reason to spend a lot of money in that market right now, though we understand very well how to do it. The first area of adoption we see for those laminators is the thin-film market.

Figure 3. 2BG's L900A automatic laminator.

"This is a good example of risk aversion in the market as the majority of module processes we see would rather use floor space than stacks," noted Willingham. "The risk is what they are trying to get away from. It is thin-film, however, that will adopt this technology first: because there are so many laminators required per megawatt of output, the payload is less efficient with more modules per minute, requiring more laminators.

"An aluminium heating plate with a large thermal capacity and an active pin-lifting system that does not require vacuum pumps further simplifies the tool mechanisms."

"I think a lot of innovation is going to be pushed off until rosier times. This makes us as equipment suppliers equally as conservative in our advancements. What we are trying to do is reduce cost. Our focus is on ramp-time, temperature

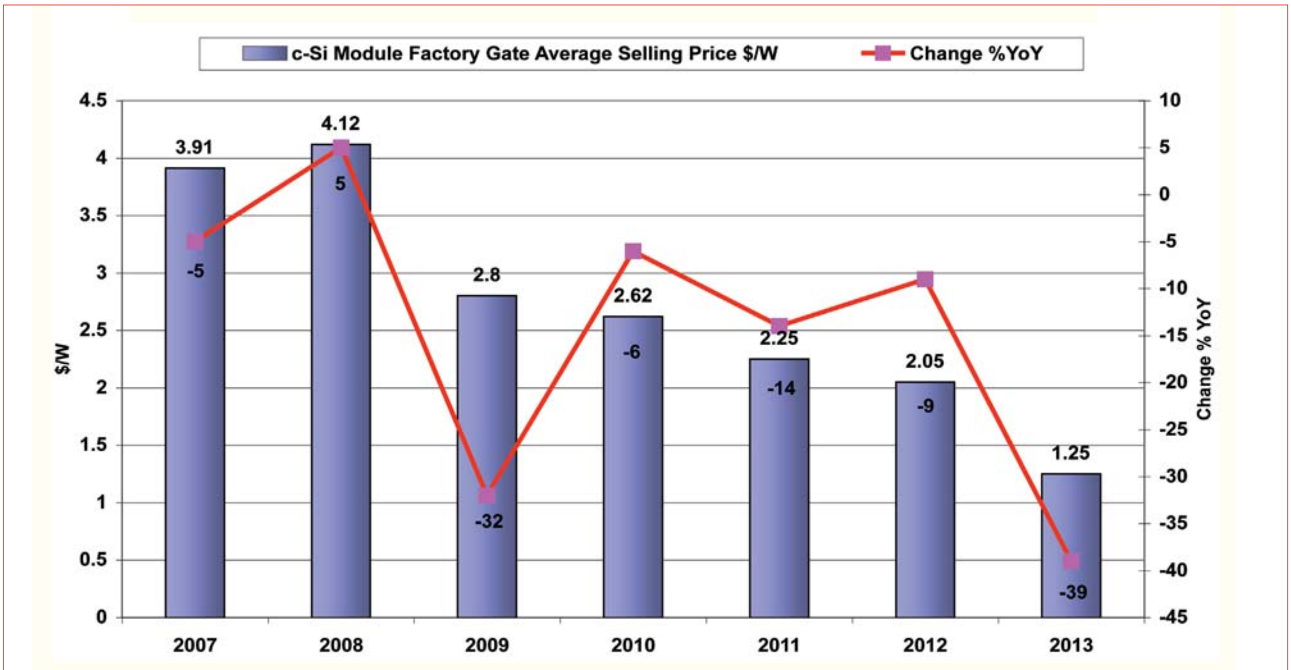


Figure 4. Photon Consulting: c-Si Module Factory Gate Average Selling Price ($/W).

uniformity and other areas that are on the cost-of-ownership side. With laminators we think the price of the tool isn't the real factor, cost of ownership is. Downtime is several magnitudes more important than the purchase price."

Willingham noted that Spire has developed a unique mechanism for removing the diaphragm and cover sheets in the laminator.

"Those are wear parts. Our system can now change diaphragms in 15 to 20 minutes. Typically this can take almost half a day!"

Another machine cost reduction program of Spire's is developing two new laminators in a lower cost region, not only from the material and labour cost perspective but also from the shipping cost perspective, especially seeing the significant market growth for equipment in Asia. Willingham remarked that it can cost US$50,000 to ship a laminator.

Komax Solar is another well-known equipment supplier that has launched a new laminator, the Xlam, as shown in Fig. 2. The tool is suitable for both crystalline module production as well as thin-film technologies and is designed from the bottom up for high volume production.

"We tried to keep the process as it exists but to improve the reliability and functionality of the machine," commented Claudio Meisser, CTO of Komax. "Looking at changing the process, you soon realise that there is a lot of work to do. A good example of this is our approach to temperature uniformity control, which is different from that of many other competitors. We are working with one temperature control loop. This enables a reduction in the complexity of the machine but retains best-in-class temperature uniformity of ±1°C."

To satisfy these requirements, the XLam platform incorporates hybrid heating featuring a unique and reliable induction heating system. An aluminium heating plate with a large thermal capacity and an active pin-lifting system that does not require vacuum pumps further simplifies the tool mechanisms and reduces machine cost, maintenance and replacement parts.

The hybrid inductive heating system integrated in the aluminium plate has meandering oil circuits that are designed to enable an ultra-high uniformity of temperature. Komax noted that it was using aluminium heating plates with larger thermal capacity than most of its competitors to achieve shorter process times.

These solutions are hugely beneficial, opening the way to high availability and low operating costs, according to Komax. With the three processing levels, operators can enjoy the benefits of continuous module production, the partial availability of the machine in the event of a malfunction at one processing level, and the adaptability of laminator capacity to less than full capacity utilization in the production line. The footprint for a specific production capacity is claimed to be much smaller than with standard laminators as it fits into a standard-sized shipping container.

"We feel we have an excellent product for continuous production requirements," added Martin Keller, Product Manager PV at Komax.

A leader in the laminator machine market is 3S Industries. Dr. Ronald Lange, Chief Innovation Officer at the company, remains enthusiastic about optimization and cycle-time reductions for laminators. Lange noted that its use of a partly transparent laminator in its complete pilot production line allows the separation of the various process variables as it allows the operator to physically see the process interactions in real-time, leading to a more cost-efficient PV module production.

Importantly, this leads to new innovations on the machine and has led to the reduction of lamination cycle time by more than a half, while increasing the quality of PV modules with a robust process window.

"Our approach may be different to others," remarked Lange. "We understand the processes and equipment to such an extent that we make productivity guarantees to our customers, eliminating long discussions on throughput, maintenance times etc. We are very confident of our processes that optimise the lamination process… our membrane clamping system is a good example of continuous product development cycles here at 3S."

Figure 5. P.Energy's laminator has evolved into a robust workhorse for module manufacturing.

The company developed its membrane clamping system to significantly reduce the impact of repeated stress caused by heat, cyclical stretching and chemicals on the membrane as well as to reduce the time for loading, which has been time consuming. Benefits include longer useful life for the membrane and therefore longer up-times for the machines as well as shorter handling times, boosting productivity of the laminator.

3S is not the only lamination equipment supplier that has continuous productivity improvement programs. Gabriele Pettenuzzo, President of P.Energy in Italy, noted that the company had focused attention on its laminators to reduce EVA curing times. This was being accomplished by installing larger vacuum pumps in order to reduce the required pumping time for each step. He also noted that a fast clamping system was important to productivity gains.

"We have already developed a fast clamping system in order to reduce the time for changing the silicon membrane in the laminator. At the moment, we are developing a new system in order to prevent damages in the silicon membrane and to obtain 5000 cycles before the need for replacement."

Emanuela Zecchinati from 2BG, also based in Italy, noted that, "All of our laminators are subject to continuous development in order to improve the quality of laminated product, with particular attention to time reduction, which is necessary for this process. Mechanical endurance of the structure, the compensation of delays, and the uniformity both of heating and pressure are key elements in laminator development."

Zecchinati also noted that in her opinion, the company's main effort will be geared towards further integration of process control parameters for increased overall laminator productivity.

Ecoprogetti's Lisa Hirvonen highlighted productivity improvements with the company's laminators and the route they have taken to solve certain problems with the lamination process.

"A limitation in the lamination process is that when the glass enters the laminator, it bows because of thermal dilatation. In this way, the glass touches the plate only in the centre," said Hirvonen. "During the first step of the lamination process – the so-called pumping time – the EVA starts to polymerize only in the centre, causing non-uniform gel content in the finished module."

Hirvonen said that Ecoprogetti designed their system specifically to avoid generating a uniform temperature.

"In this way we set different temperatures in different zones in the various steps of the lamination process to guarantee a uniform gel content of around 85% over the complete surface," remarked Hirvonen. "In this way we take advantage of being able to increase the temperature around the module, but most important of all, we can reduce the cycle time, thus improving our productivity."

Material developments and optimization

As noted in Part 1 of this feature, EVA has the longest track record of encapsulant material usage for modules, which have been dominated by crystalline technologies. As noted by Birgit Wernicke, Managing Director of Etimex Solar, the widest choice of lamination equipment is available for EVA.

"EVA is being offered in at least three different types concerning curing time, resulting in longer or shorter lamination cycle times," commented Wernicke. "A key requirement is the control of the process of the lamination and the resulting gel contents. Etimex UFC [ultra-fast cure] EVA is even suitable for a stack lamination process, thus resulting in the highest output of modules per time and laminator area."

Indeed, faster curing times have had an impact on lamination cycle-times. Alessio Maiocchi, Product Manager at 3S, noted that lamination process times about five years ago would typically take 40 to 50 minutes using a standard conventional EVA material. This can now be reduced to between 15 and 16 minutes with the range of fast-cure materials now available.

In this context, the knowledge and understanding of EVA materials is most comprehensive, and the widest range of material requirements can often be better met with EVA derivatives. This allows for focus on the all-important reliability requirements, but can also tackle the needs for short cycle times, overall improved productivity and the ultimate goal of cost reduction.

"Material cost – specifically EVA films – can be reduced to a certain extent by quantity and standardization of module dimensions," remarked Wernicke. "Thickness reduction has already been achieved with current standards as you have to consider technical limits for the mechanical strength required in modules."

Although not a technical innovation in the true sense, Wernicke also sees an opportunity for material cost reductions, simply from the point of industry standards, which would help to optimize output in the whole supply chain. EVA remains a very cost-effective solution.

> "Optimization of materials will continue only for the next several years and will definitely improve the productivity of the module production line."

While polyvinyl butyral (PVB) has been in use for decades in laminated glass applications, recent technology developments have made it a material of choice for certain PV module designs. This includes many thin-film technologies, which has over time become more robust to moisture absorption.

According to Christopher Reed, Global Business Director of Saflex, a unit of Solutia, Inc., a key attraction for thin-film manufacturers adopting PVB over EVA was not only the potential for cost savings but also the ability for suppliers to scale production quantities quickly. Furthermore, the material can be produced in long roll lengths (to minimize roll handling cost) and wide sheet widths. Such dimensions are necessary for the non-standardized nature of the thin-film module market, which also requires the capability to handle larger module sizes. According to Reed, PVB seems to be better suited to new processes.

In the case of large-area modules, a pre-nip oven heats and softens the PVB sheet before the de-airing process using nip rollers. The PVB is then baked to a higher temperature in the sequential ovens and pressed by a second set of nip rollers to seal the front and back glass panels. The autoclave process therefore evenly dissolves residual air into PVB.

However, it is not all plain sailing when new formulations are developed. Reed noted that to effectively evaluate material improvements for customers, it can often be challenging to arrange for time on the customer's production floor to test out the materials. This is compounded by the fact that even with the so-called thin-film 'turnkey' lines, nearly all of these lines operate and perform differently.

"This is not a simple recipe that can be acquired and dialled in. We try and discuss with customers requirements in productivity, in an effort to optimise the lines as well as long-term resistivity and longevity of the module.

"They have to open up the module design books to deal with the current cost competitiveness of crystalline modules. However, although polyvinyl butyral has a cost advantage over EVA, it also comes down to making the film more active compared to its traditional passive role."

Like others interviewed for this feature, Reed believes that optimization of materials will continue only for the next several years and will definitely improve the productivity of the module production line, such as film relaxation due to roll-handling tension generation. Reed also conforms to the argument that only the development of new materials and processes will see a step-function improvement in the laminator's ability to significantly lower costs.

A firm steeped in optimization of materials and processes for volume production environments is Mettler Toledo. While speaking with Michael Zemo, Market Manager for Materials Characterization at the company, it soon became apparent that with the continued process optimization work being carried out, there is a need for characterization tools – especially in the field of thermal analysis – that would aid both equipment suppliers and module manufacturers.

Zemo noted that by using differential scanning calorimetry (DSC) to provide structural information about the encapsulant material being processed, greater understanding of process parameters would enable improved process optimization.

"The most common question we are asked is 'I want to fully cure this material in the shortest time possible – how do I do this?' We end up taking engineers step-by-step through the process of how to go about modelling that approach using a DSC."

Gaining the correct curing profile of the material is the first step, according to Zemo, followed by correlating that information to your process flow and tool.

"When you are in a conservative industry and you chose a coating that allows for a reasonably wide process window, it can give you a false sense of security, especially in relation to overall product reliability once in the field."

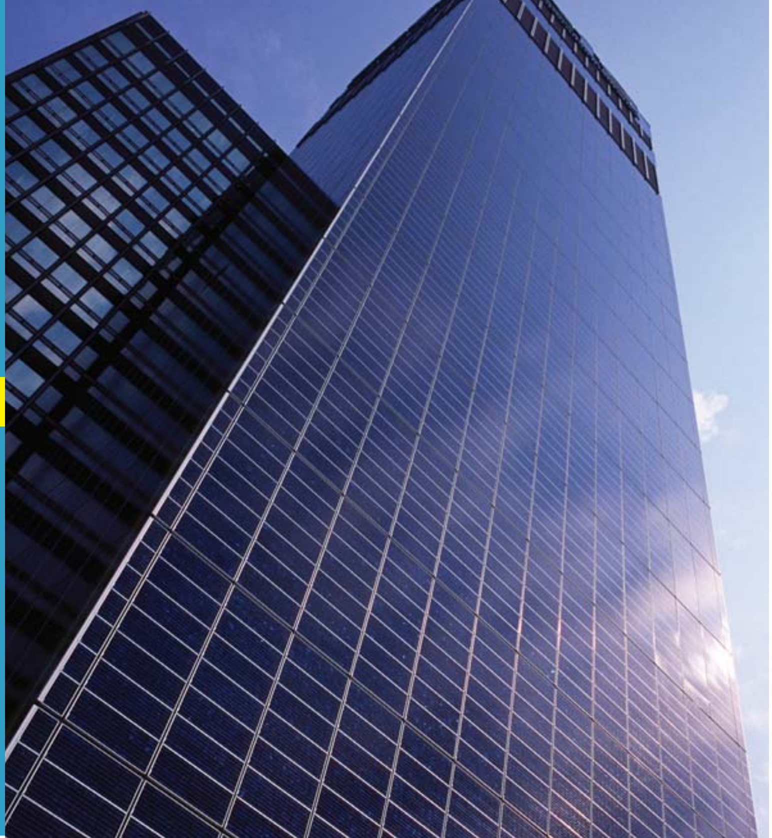
Ultimately, what is required is a complete drill-down on process optimization that eliminates all variability that could impact quality of process, while providing the lowest manufacturing cost.

Conclusion

Currently, machine and material innovation is ongoing, especially in respect to optimization of the lamination process, which is inline with the conservative approach of module manufacturers. It would seem that this strategy has several more years to continue to boost productivity and reduce costs. However, a step-function improvement will be required to deal with falling module prices and continued conformance with lifetime module guarantees.

Power Generation

164



152

Morocco to undertake US$9 billion solar energy project

Morocco looks set to become the next country to undertake an ambitious solar project. The country's planned project is slated to be worth US$9 billion and is anticipated to produce 38% of the country's installed power generation by 2020. Energy Minister Amina Benkhadra announced that the project will have five solar power generation sites throughout Morocco and will produce 2,000MW of electricity by 2020, according to a report.

At the ceremony to introduce the project to the public, Benkhadra was joined by U.S. Secretary of State Hillary Clinton and the Moroccan king. Benkhadra noted that the funding for said project would be a combination of private and state capital. As Morocco is the only North African country that does not produce its own oil, entering the PV industry is especially attractive as the country strives to find a way to cut its oil and gas imports, turning to renewable energy for the solution. No date was announced for the start of the solar project.

Source. maps.com

North America News Focus

First Solar to sell 20MW Ontario PV project to Enbridge

First Solar and Enbridge have signed a deal for the Canadian energy company to buy a 20MW solar farm that the PV firm has developed and is building near Sarnia, Ontario. The project, which will be the largest PV installation in Canada when it is completed by the end of the year, is being built by First Solar under a fixed-price engineering, procurement, and construction contract and will use more than 370,000 of the company's CdTe thin-film modules.

First Solar said it will also provide operations and maintenance services under a long-term contract. The power output of the facility will be sold to the Ontario Power Authority under the terms of a 20-year power purchase agreement pursuant to the Ontario Government's Renewable Energy Standard Offer Program. Subject to certain conditions, Enbridge may participate with First Solar in future solar energy projects at the Sarnia site.

Florida Power & Light set to flip switch on 25MW DeSoto solar PV plant

Florida Power & Light said that it will begin delivering electricity later this month from the 25MW DeSoto Next Generation Solar Energy Center in Arcadia. When activated, the solar power plant will become the largest photovoltaic installation in North America, overtaking Nevada's Nellis AFB facility. The DeSoto centre, which was built in less than a year and ahead of schedule, uses more than 90,000 SunPower high-efficiency crystalline-silicon PV panels mounted on tracking systems. It will be capable of generating approximately 42,000MWhr of electricity annually.

The DeSoto Next Generation Solar Energy Center is one of three new commercial-scale solar power plants that FPL is building in Florida. A 75MW solar thermal plant is being built in Martin County, while a 10MW PV-based facility is under construction at NASA's Kennedy Space Center. The combined total of the three plants –110MW – will make Florida the second-largest solar power-producing state in the U.S., according to the utility. Over the past year, more than 400 jobs were created during construction of the project. DeSoto county will also receive annual tax revenues that will amount to US$2 million for schools and other local services by the end of next year.

Starwood Solar I agreement terminated: Lockheed Martin pulls out

The long-term power purchase agreement (PPA) between APS and Starwood Energy Group has been terminated. This ends plans for the Starwood Solar I plant, as the engineering, procurement and construction firm, Lockheed Martin, pulls out. APS received notice from Starwood stating that it would no longer be able to go ahead with plans for the 290MW CSP plant in the Harquahala Valley, terminating the contract signed by both companies back in May 2009.

The size of the project, which was to be the second largest announced by APS, was always going to carry significant risk for the electricity utility. It appears that Lockheed Martin, which had partnered with Starwood on the project, saw the possible issues with the final risk profile of the engineering, procurement and construction contract, among other factors, and decided to pull out.

Work now begins on replacing the energy from the lost Starwood Solar I project. APS is expected to announce the results of two current solicitations for renewable energy: one for small-scale generation projects and one for distributed generation, by the end of 2009. The other project planned by APS, Solana, has been more successful. Financing for the 280MW CSP plant is expected to be announced in the first half of 2010. The Solana plant is planned to be built 70 miles southwest of Phoenix, near Gila Bend, Ariz.

juwi solar using First Solar modules in 30MW project program for U.S. utility PSEG

Three new solar projects totalling almost 30MW are to be built in New Jersey by juwi solar for PSEG Solar Source, a division of U.S. utility PSEG (Public Service Enterprise Group). All three projects will use a total of 380,000 of First

DeSoto Next Generation Solar Energy Centre, Arcadia, Florida.

Solar's CdTe thin-film panels in ground-mounted locations, and will cost a total of approximately US$100 million.

The projects include a 2.2MW facility located on 18 acres adjacent to Mars Snackfood's U.S. headquarters in Western New Jersey, which is targeted for completion in 2009. A 15MW solar farm in Jacksonville, Florida is expected to begin construction shortly and targeted to begin commercial operation in the summer of 2010, while the third project (12MW) is located in Wyandot, Ohio. Construction will start by the end of the year with commercial operation planned for 2010.

Satcon's 1MW Prism inverters selected for SunPower 10MW plant in Chicago

Touted as the largest urban solar power plant in the U.S. a 10MW facility on the south-side of Chicago, the new plant will use Satcon's 1MW Prism inverters. The site, owned and operated by Exelon Generation, was designed and is being constructed by SunPower Corp, using approximately 32,300 of its solar modules as well as SunPower's trackers.

Satcon's 1MW Prism inverters are an all-climate outdoor enclosure and designed as pre-packaged to connect to the PV array and utility grid. This is done to reduce installation time and costs through a modular design.

Satcon's 1MW 'Prism' fully integrated power conversion solution.

SolarEdge power products gain Intertek certification for North American market

Power conversion company SolarEdge Technologies has been granted certification of its inverter and converter products, gaining the ETL Mark for the North American market. Test and certification organisation company Intertek has completed all necessary safety and grid-connection testing according to the UL 1741 standard, and CSA C22.2 No. 107.1.

SolarEdge's power products are claimed to increase solar power systems' output by up to 25% by effectively removing system constraints across PV systems.

Phoenix Solar sees €150 million boost to solar project funding

Investment fund KG Allgemeine Leasing (KGAL) has extended and increased its solar project dealings with Phoenix Solar, which will see a minimum of an extra €150 million allocated to PV projects that Phoenix Solar undertakes as a project manager for the fund. Phoenix Solar said that the minimum contractual volume now amounted to €525 million through 2012. Phoenix Solar and KGAL have collaborated since 2005 with approximately 40MW deployed.

Solar Energy Initiatives solar installation.

Solar Park Initiatives signs contract for 100MW park, California

Solar Park Initiatives (SPI), wholly-owned subsidiary of Solar Energy Initiatives (SEI), has signed a contract securing land for the design, construction and operation of a 100MW solar park in California. SPI will be responsible for providing engineering, permitting, construction, operations and maintenance as well as obtaining the financing for this solar park while SEI will procure the solar panels and balance of system for the project.

SPI will have initial involvement in this project, zoning, permitting and making EPA approvals. The contract for the project will run for 25 years with additional renewal options; construction is expected in 2010, yet the project will be constructed in various increments over a three-year timeframe.

European Region News Focus

Sputnik commissions its first solar power plant with a new megawatt station

Coinciding with Sputnik Engineering presenting its the new megawatt station for the first time at EU PVSEC, the inverter company has announced the commissioning of its first megawatt station in Hemau, in the district of Regensburg and installed by SolaStrom Systems. Two of its 'SolarMax' central inverters feed the power directly into the transformer on a medium-voltage grid. The transformerless technology has enabled Sputnik to cut both the size and the weight of the system by half compared with the previous models while boosting efficiency by 1.5%, the company said. The PV system in Hemau is monitored by Sputnik's communications network, MaxComm, together with its internet-based data logger MaxWeb. SolaStrom will install SolarMax inverters with a total capacity of 3MW in 2009.

Solarig begins eight PV park installations in Italy

Over the next few months, Solarig will be constructing more than 30MW of PV installations in different regions of Italy. October saw the beginning of eight parks in the Puglia and Piedmont regions of Italy. Past projects have seen Solarig construct and maintain PV parks in Spain that total 25MW.

In the Puglia regions, Solarig is building seven separate parks. Six will be mounted fixed structures each with a 0.99MWp capacity. The seventh will use double-axis solar tracking and have a capacity of 0.68MWp. In the Piedmont region, the company is constructing a 1.5MWp park with fixed structures. Solarig will use its Italian subsidiaries to complete all phases of development, construction, connection and operation of the eight projects and expects to be connected to the grid in December 2009.

Solarig plant construction.

SunPower to build 100MW solar power plant; largest in Italy

The Italian photovoltaics market has just heated up with news that SunPower is to supply solar modules, trackers and project management services at a 100MW power plant to be built in Montalto di Castro, Italy with completion of a 24MW first phase expected by the end of the year. The project is planned to be fully operational in 2010. This would easily make the new solar power plant the largest in Italy and a major project in Europe. The project is being financed by a consortium of both international and Italian banks. The project is being built in collaboration with SunRay Renewable Energy, which will own the plant.

SunPower has noted in several quarterly conference calls that it expected to see growing business from the emerging Italian market but had not announced

any significant projects in the country. Competitors such as Suntech had already announced multiple projects in Italy for 2009, potentially capturing significant market share. SunPower had previously built a 5MW solar plant in Tolentino, Italy. PV installations in Italy, while growing year-on-year, have been falling in the second half of 2009. The new project at Montalto di Castro would indicate that installation activity would once again rise later in the year, a similar trend as was seen in 2008.

Q-Cells planning €400 million solar plant in Brandenburg-Briest

The PV project arm of Q-Cells is planning to construct the world's largest solar plant at a former military airfield in Brandenburg-Briest at an estimated cost of €400 million. The project could use approximately 730,000 solar modules and occupy a 400-acre area. A decision by the Brandenburg-Briest city council is expected this month. The airfield is located approximately 6.5 km northwest of Brandenburg center and southeast of Briest.

Q-Cells International will handle the project with partner ib Vogt, according to the reports. The project will be tackled on a fast-track level due to the need to complete the massive project by the end of 2010 as new FiT levels are expected to be introduced that could make such a project less financially attractive in the future.

Leoni to supply Lieberose solar farm with 1,000km installation cable

The Lieberose solar farm, in Brandenburg, developed by First Solar and juwi and recorded as the second biggest in the world, will now receive 53MW of output using special cables supplied by Leoni. The 1,000km of cable will carry the current from about 700,000 solar modules.

The BETAflam solar cable used is double insulated, halogen-free and suitably robust. It is also flame retardant as well as resistant to UV, ozone, hydrolysis and hot and cold temperatures ranging from -40 to +120ºC. The cable is also the first that can be universally utilised in both Europe and America for installation in PV

Lieberose solar farm, Brandenburg.

Source. SolFocus

SolFocus CPV trackers.

systems because it is approved by both the TÜV and the American Underwriters Laboratories. Marc Ziegler, purchasing coordinator of juwi Solar says that Leoni's cable is extremely weather resistant and has an expected life of at least 150,000 operating hours, which allows it to be used for more than 30 years.

Satcon teams with Canadian Solar in turnkey distribution deal

Satcon has signed a collaborative deal with Canadian Solar that will see the companies market their products to customers as a "best-in-class system solution". Canadian Solar's solar PV systems will be marketed with Satcon's solar inverters, providing a single solution for rooftop solar energy generation. The agreement also complies with the Ontario government's domestic content requirements in its recently announced feed-in-tariff program. As both of the companies have manufacturing plants in Canada and China, the collaborative move looks set to provide an opportunity in the emerging solar markets in those countries.

a+f builds on Italian market position with €36 million SunCarrier order

The Würzburg enterprise, a+f GmbH has received another order for its SunCarrier technology. The order has a total value of €36 million and builds on the company's market position in Italy. Eight SunCarrier solar parks will be constructed in Foggia of the Apulia region, on behalf of a German investor. The parks will cover a combined area of 33 hectares, with an output supplying 3,800 four-person households with electricity annually.

Petsch also said that a+f's current focus is directed towards southern Europe, with an aim to branch out shortly in the U.S. market. The company is also planning to construct individual SunCarrier plans in India, a region for which the system has been specifically designed.

Portuguese utility chooses SolFocus' CPV technology for 8.5MW of projects

With one of the largest ever CPV technology installations, SolFocus is rapidly becoming a major player in the CPV market, which has been more about promise than actual implementation. SolFocus is partnering with Dreen Europe and Portuguese utility Águas de Portugal (ADP) for the installation of 8.5MW at its company facilities in Portugal. ADP has plans to invest over €830 million in renewable energy projects over the next five years. The project deployment is expected to begin in early 2010 for the first 2MW phase with the balance of the project deployed in phases over the next four years.

Asia Region News Focus

Suntech 10MW utility-scale project: complete and grid-connected

Suntech Power has completed grid connection of the first 10MW utility-scale solar power project in China, located in Shizuishan, Ningxia Autonomous Region. The project involves a 10MW ground-mounted solar system and is the first phase of a 50MW solar plant that is targeted to be completed by 2011 with China Energy Conservation Investment Corporation (CECIC), a Suntech partner.

Approved by the Ningxia Autonomous Region Development and Reform Commission, the 10MW system is powered by over 37,000 Suntech panels and is estimated to dislocate 20,000 tons of CO_2 emissions per year. Suntech and CECIC plan to focus on the development of large-scale on-grid solar projects and urban building integrated PV projects. Throughout these projects, CECIC will be primarily responsible for project investment and solar project development and Suntech will supply the solar products, system design, installation and technical support.

Source: Sharp Solar

News

Enfinity, Titan Energy team for 1GWp PV installations in Andhra Pradesh, India

Enfinity and Titan Energy have announced their plans to work in partnership to finance and construct 1GWp of photovoltaic installations on 3000 acres of land in Andhra Pradesh, India, over the next five years. The Andhra Pradesh Industrial Infrastructure Corporation (APIIC) will distribute, in long lease, the 3000 acres in the villages of Thumalla, Dademavaripalli, Pulikuntapalli, Karimireddypalli and Lokogipalli and at the industrial park of Amadugur near Kadiri.

Enfinity will take on the development and financing aspect of the project while Titan will be the contractor and supplier of PV modules. The two companies have established a special-purpose vehicle (SPV) for this venture.

With India's increasing need for primary energy and electricity needs, the country is turning to renewable energy sources to take advantage of its average 300 days of sun per year. India's National Action Plan of Climate Change looks toward a National Solar Plan, which is expected to come into play this month. The solar plan sets an ambitious goal by the government to reach 20GW by 2020, 100GW by 2030 and 200GW by 2050.

Indonesia to build solar plants for electricity use in rural areas

Indonesia recently announced its plan to build 250 solar power plants that will total 2.2MW by 2014 so that they can supply the country's rural areas with electricity. The proposed project is expected to cost around $84 million. The proposed solar plants are part of Indonesia's alternative energy plan, which outlines the installation of solar panels on 192,000 homes, building 570 small-scale hydroelectric plants and the construction of 270 wind farms. The Indonesian government looks forward to the solar project being part of their alternative energy plan since it will power villages, while reducing their CO_2 emissions.

Ausra is selected as steam boiler provider for 100MW CSP plant

Moving forward the development of the proposed 100MW JOAN1 concentrated solar thermal power (CSP) project, Ausra has been selected as the supplier of solar steam boilers. With this selection, the development of the plant in Ma'an, Jordan is going ahead as planned.

Ausra's selection was announced in Berlin during SolarPACES, the CSP industry's largest conference, following a competitive tender offer. The announcement was made by Samer Zureikat, Managing Director of Germany-based MENA Cleantech. Ausra's Compact Linear Fresnel Reflector technology will power the plant's solar steam cycle and generate up to 100MW of electricity. JOAN1 will use dry cooling to conserve water.

The solar steam boiler provider plans to install an advanced manufacturing facility in Jordan in order to efficiently supply the project with this technology. The project is scheduled for financial close in the fourth quarter of 2010, with construction beginning in early 2011. Operation is scheduled for 2013 and once complete will be the largest CSP project in the world using direct solar steam generation. The development of JOAN1 will also include a back-up fossil-fuel boiler to guarantee 24-hour dispatchable electric power.

Other Region News Focus

Energy Innovations to install Sunflower system in Masdar City

Energy Innovations announced that it has signed a contract to provide its Sunflower system for installation in Masdar City. The project, located near Abu Dhabi in the UAE, is touted to be the first carbon neutral, zero waste city powered entirely by renewable energy in the world. It is also the headquarters for the International Renewable Energy Agency (IRENA).

"It is quite appropriate that a forward-looking city like Masdar should choose to install CPV technology," said Joe Budano, Energy Innovations' CEO. "CPV brings great advantages over traditional PV and thin film and represents the future of solar in these high solar resource locations. We are proud to be chosen for this very important project and expect to demonstrate the value and robustness of our HCPV technology in this high radiation and high ambient temperature environment."

Energy Innovation's Sunflower technology is made to withstand high temperature conditions, the likes of which will be found at Masdar City. The Sunflower's highly concentrated PV (HCPV) system uses triple junction cells, which are less affected by high ambient temperatures with a potential to lose only about 5% of their rated power.

Product Briefings

SunPower

SunPower T20 Tracker Evolution delivers maximum energy with 128-cell 400W solar panel

Product Briefing Outline: SunPower has introduced the next generation of its T20 Tracker, which it claims is the most powerful solar tracker on the market today, incorporating SunPower's high-efficiency 128-cell, 400W solar panels for maximum energy output.

Problem: Solar photovoltaic power plants have emerged in recent years as a viable means of large-scale renewable energy power generation. A critical question facing these PV plants at the utility scale remains the competitiveness of their energy generation cost with that of other sources. Emphasis is turning to maximum potential energy production as well as lower installation costs.

Solution: SunPower's newest T20 Tracker is a single-axis, ground-mounted tracker that follows the sun to deliver the highest system performance. It is pre-assembled for a fast, simple and scalable installation and offers customers a choice of design options to meet specific site needs. With fewer moving parts and refined mechanical structure, the T20 Tracker provides increased reliability, durability, less maintenance, and better wind resistance than conventional trackers, according to the company. Each T20 Tracker unit generates up to 3.7 kilowatts of power and, by following the sun, delivers up to 30% more energy than a fixed-tilt system of the same capacity.

Applications: Solar power plants.

Platform: The T20 Tracker also features the new SunPower TMAC Advanced Tracker Controller, which features real-time tracker status updates, remote monitoring and control, proprietary energy production optimization algorithms, and improved reliability including harsh environments. In addition, the TMAC enables power plant operators to wirelessly monitor the status of the T20 Tracker in real-time through the SunPower power plant SCADA control system, giving them the option to control the array from a central operations center.

Availability: SunPower will begin constructing power plant projects using the new T20 Tracker beginning in early 2010.

Advanced Energy Industries

AE's Solaron 250 transformerless inverter targets lowest LCOE for commercial rooftops

Product Briefing Outline: Advanced Energy Industries has expanded its line of high-efficiency, transformerless grid-tie photovoltaic inverters with the introduction of the Solaron 250. With a power level of 250kW, the Solaron 250 is ideal for applications such as commercial rooftop installations. Building on the success of the previously released 333kW and 500kW Solaron inverters, the new Solaron 250 provides customers with another option to achieve the lowest levelized cost of energy (LCOE) available in the industry.

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.

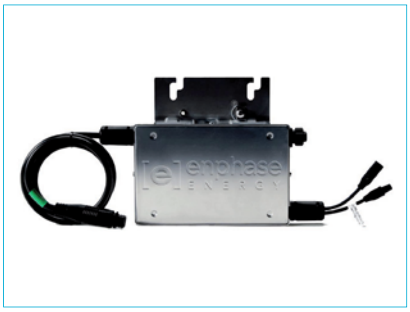
Solution: AE's PV inverter technology converts raw DC power from solar cell arrays to high-quality AC-grid electricity, enabling commercial installations to produce targeted output power levels with fewer solar modules and potentially lower balance-of-system (BoS) costs than was previously possible.

Applications: Commercial rooftop installations. The Solaron inverters are particularly well suited for programs that have buy-American requirements, such as federal building projects and projects supported by the American Recovery and Reinvestment Act.

Platform: The Solaron series from AE uses 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: Currently available.

Enphase Energy



D380 'TwinPack' microinverter from Enphase lowers BoS costs and installation time

Product Briefing Outline: Enphase Energy is introducing the D380 'TwinPack,' a new product optimized for commercial installations. The D380 TwinPack is comprised of two Enphase microinverters in a single enclosure and an innovative cabling system, further reducing Balance-of-System (BoS) costs and installation time.

Problem: Solar power production is affected by various factors such as module mis-match, obstruction shading, inter-row shading, and obstacles such as dust or debris. In addition, non-uniform changes in temperature, irradiance and shading create complex current-voltage curves, further affecting energy harvest. This is due to the fact that in traditional systems the performance of the entire system is dictated by the performance of the weakest module.

Solution: Enphase Microinverter Systems convert the DC output of a single solar module into grid-compliant AC power. The systems offer a number of claimed advantages over traditional central inverters including a 5% to 25% increase in energy harvest, increased system reliability and a simpler – and safer – installation. The D380 maintains the benefits of the per-module Enphase microinverter while reducing installation costs through the two-in-one design. The system also claims reduced BoS costs and reduced installation time, which are realized via a 50% reduction in the number of microinverter units, fewer connections (33%) and junction boxes. The D380 further reduces installation time by introducing an innovative cabling system.

Applications: Commercial installations.

Platform: The Enphase Energy Microinverter System solves solar power challenges by performing Maximum Power Point Tracking (MPPT) at each solar module. The Enphase Microinverter is CSA Listed per UL1741 and can withstand surges of up to 6kV. Enphase Microinverter Systems undergo rigorous testing including HALT and HASS, ensuring reliability.

Availability: The D380 is currently undergoing field testing, with general availability scheduled for Q1 2010.

Product Briefing

Xandex Solar

‘SunMizer’ DC power optimizer from Xandex Solar provides selective module operation

Product Briefing Outline: Xandex Solar is launching the ‘SunMizer’ DC power optimizer for photovoltaic panels. SunMizer is a new DC power optimizer that increases solar energy harvest by recovering power that is lost when shade falls on a solar panel.

Problem: ‘Selective Installation’ gives SunMizer a claimed unique advantage over competing DC/DC power optimizers that require a unit on each panel in a string. Selective installation provides optimized power output at a lower initial cost, which means faster return on investment for the system owner.

Solution: SunMizer is a new per-panel DC-to-DC power optimizer that performs MPP tracking at the panel substring level to increase power harvest. SunMizer achieves maximum power flow from the panel during sub-optimal module operating conditions caused by shade and soiling to recover over 50% of system level power loss.

Applications: SunMizer is compatible with a large list of 156mm cell architecture models from most major panel manufacturers worldwide. Panels with a maximum power rating of 250W (P_{max}), 44V (V_{OC}), and 9A (I_{SC}) can be used with SunMizer, which is also compatible with most 208V and 240V residential-sized inverters.

Platform: SunMizer is lightweight (> 2kg) and its compact dimensions of 6" x 4" x 1.6" (15 x 10 x 4cm) make it easy to install directly to panel racking with standard rack system fasteners and nuts. Each unit has an integral grounding lug that also accepts a ring terminal connection. SunMizer is currently compatible with Uni-Rac Solarmount Standard and Lite, ProSolar Rooftrac, AEE SnapNrack and Unistrut racking systems. Connected in-line with PV panels using standard series wiring schemes, the system does not require specialized wiring or ‘add-on’ equipment. Each SunMizer unit will ship with a limited 20-year warranty that includes a provision for replacement labour.

Availability: Product shipments to the US will begin in Q1 2010.

Product Briefings

Suntech Power

Suntech's Reliathon platform reduces large utility-scale solar system costs by 10%

Product Briefing Outline: Suntech Power has introduce 'Reliathon', an industry-first integrated solar platform combining product and business-term innovations to lower costs and accelerate the path to grid parity with the development of utility-scale solar plants. Reliathon is claimed to reduce total system costs as much as 10%, with 13.8% more power warranted over the lifetime of the system.

Problem: Replacing the industry's current 'patchwork' approach to designing large-scale systems, Reliathon combines Suntech module innovations, a new utility-grade warranty for the Suntech module, as well as pre-agreed preferential pricing and business terms with partner companies.

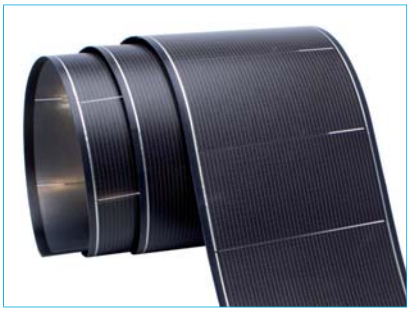
Solution: Key products included in the Reliathon system include the new Suntech Reliathon 270W module, which is self-aligning with integrated grounding, wire management, as well as a new 'Two-in-One' design, that has two 36-cell regions featuring independent circuits that can create better output on fixed-tilt systems in early morning and late afternoon. The Reliathon module includes a 25-year utility-grade warranty offering 12-year limited product warranty (extended from five years) and a 25-year peak power performance warranty now based on annual degradation instead of 12- and 25-year step-downs. The new annual peak power performance warranty provides Reliathon module buyers with 13.8% more warranted power over 25 years with an overall 85% power output level at 25 years.

Applications: Large-scale utility power projects (U.S. region).

Platform: The Reliathon system uses Array Technologies' 'DuraTrack' ground mount system, which was designed specifically for Suntech Reliathon, and makes use of two motors per MW AC versus the typical four motors per MW, further reducing the material costs of the system.

Availability: Reliathon modules and system components will be available in the U.S. for immediate orders with shipment scheduled in Q2 2010.

Ascent Solar Technologies



Ascent Solar's FlexPower Lite modules are designed for area BIPV installations

Product Briefing Outline: Ascent Solar Technologies has unveiled its 'FlexPower' line of products, which includes Light, Mobile and Extreme, and carries an industry-leading power-to-weight ratio, achieves the highest power density of any flexible product currently available in the market and provides a unique form-fit capability, according to the company.

Problem: Ascent Solar has developed proprietary monolithically-integrated processing techniques to take CIGS to production on a high-temperature plastic substrate. These plastics can survive the manufacturing temperatures associated with thin-film CIGS processing while remaining flexible and electrically insulating. The insulating features of the plastics make it possible to connect individual cells into modules during processing. These advances in CIGS processing significantly reduce the weight, cost, and complexity of PV products.

Solution: FlexPower 'Light' modules are manufactured for the BIPV market. The 5-metre long module delivers 123W and is claimed to be the world's largest monolithically interconnected flexible module. Manufacturers of building materials and BIPV systems can now utilize the unique nature of the module for large-area BIPV installations and seamless integration into building surfaces.

Applications: Large area BIPV.

Platform: The flexible CIGS materials are currently produced on Ascent Solar's 1.5MW commercial pilot line in Littleton, CO. The company's internal testing shows active-area peak efficiencies for its full-size monolithically integrated CIGS-on-polyimide modules reaching 11.7%, with median efficiencies on the line averaging between 10.5 and 11%-plus.

Availability: Currently available.

SolarEdge

SolarEdge's power harvesting system targets 25% energy improvements

Product Briefing Outline: SolarEdge Technologies' distributed DC power harvesting systems maximizes power generation of residential and large-scale PV sites by up to 25%, while reducing costs and complexities for panel manufactures, systems integrators, installers and owners.

Problem: Traditional PV installations still suffer from a broad range of limitations. Existing power harvesting systems use centralized or string inverters that perform Maximum Power Point Tracking (MPPT) regulation on the entire serial solar array which leads to unavoidable power losses due to panel mismatch, partial shading sensitivity and sub-optimal MPP tracking, amongst others.

Solution: SolarEdge's distributed DC system is claimed to maximize the power output of each module at the same price as conventional power harvesting systems. Based on a proprietary ASIC chip set, the SolarEdge 'PowerBox' optimizes energy output and enables performance tracking for each panel. Furthermore, each PowerBox automatically maintains a fixed string voltage giving installers greater flexibility to design optimal PV systems. PowerBox is embedded into each module instead of the junction box, or retrofitted by PV installers onto the modules. The SolarEdge Inverter is a centralized inverter. Because MPPT and voltage management are handled separately for each module, the inverter is only responsible for DC to AC inversion. Consequently, the SolarEdge inverter is less complex and is claimed to be more reliable than traditional inverters.

Applications: Residential, commercial and utility-scale PV installations.

Platform: The three-fold SolarEdge architecture consists of module-embedded electronics and custom ASIC which performs module-level MPPT; a centralized DC/AC inverter per array; and a web portal for module-level monitoring and fault detection.

Availability: Currently available.

Performance of single-axis tracking photovoltaic systems in Europe

Thomas Huld, European Commission Joint Research Centre, Ispra, Italy; **Marcel Šúri** and **Tomáš Cebecauer**, GeoModel s.r.o., Bratislava, Slovakia

ABSTRACT

In the past few years, a great deal of interest has developed in the use of sun-tracking mountings for normal flat-plate PV systems. Such systems deliver more energy for the same nominal PV power, but the cost of tracking is also higher than that of normal fixed-rack mountings. Tracking systems that have two axes and follow the sun closely at all times during the day are currently the most popular. However, systems that move the PV modules around a single rotating axis are simpler than two-axis tracking systems and can therefore be manufactured at a lower cost. This article presents research conducted by the authors on the performance of different tracking options. The results show that an optimized single-axis tracking system can deliver almost the same energy as a two-axis tracking system.

PV tracking systems

Photovoltaics has seen huge growth in several European countries recently, from those with hot and sunny conditions like Spain, southern Italy and Greece, to the more moderate conditions in Germany, the Netherlands and the Czech Republic.

In most cases these new PV installations have been constructed with the PV modules mounted in a fixed position, typically inclined at the local optimum slope and facing south, or integrated into buildings at whatever inclination and orientation is needed to fit in with the existing building shape. However, there is a growing interest in mounting the PV modules on moving supports to allow the modules to follow the sun during the day in order to maximise the amount of sunlight that arrives at the module surface. These mountings are known as *sun-tracking* systems.

Tracking systems can be made in a number of different ways. A system that always tracks the position of the sun perfectly is often called a *two-axis tracking* system, since it is not possible to track the position of the sun with a movement around a single axis of rotation. Up to recently, most of the industry interest has been in two-axis tracking systems, since these deliver the maximum energy for a given PV system size. This type of mounting is the only feasible option for concentrating PV (CPV) applications as the lenses or mirrors of the system must point straight at the sun disc at all times.

Figure 1. Photo of the tracking PV system installed by Raytracker, Inc. at the British Telecom US Headquarters, El Segundo, California.

Figure 2. The Solar Wings PV installation. 647kWp of modules are mounted on a single-axis tracking system with the rotation axis aligned about 15° away from north/south towards southwest, and inclined 23° from horizontal.

But this is not the only option available for flat-plate PV systems. A system that follows the sun imperfectly may receive almost as much energy as a true sun-tracking system. Simpler systems featuring one axis of rotation – henceforth known as *one-axis trackers* – may also significantly increase the amount of radiation received compared to the fixed systems. Such systems are less complex to construct and operate, and because the movements are simpler, they can be constructed at lower cost.

> "Up to recently, most of the industry interest has been in two-axis tracking systems, since these deliver the maximum energy for a given PV system size."

The question then becomes whether the reduced cost can justify the reduced energy output. This in turn depends on calculating accurately the energy output from the various tracking options. This article will address a number of different tracking options and compare the estimated energy output between these systems and with the option of a fixed (non-tracking) system. On the other hand, no attempt will be made to assess the costs associated with the various tracking systems. With the industry in such rapid development, any information gleaned in relation to cost will undoubtedly be obsolete almost before this article is published. Nevertheless, the results should help potential investors to compare the different options on the market to find the one that gives the best price/performance ratio.

Examples of single-axis tracking systems

The number of PV systems using single-axis tracking is still rather small but increasing rapidly. The following is a brief selection of the systems that have been installed recently.

Raytracker, Inc. [1] produces and installs PV tracking systems upon which PV modules are rotated around a horizontal axis aligned north/south. Fig. 1 shows an installation of a 400kWp system installed above a parking lot at the British Telecom U.S. Headquarters in El Segundo, California. The trackers rotate the modules from east facing in the morning to west facing in the evening.

Another example is the Solar Wings design [2]. This 647kWp installation is in Waldshut, Germany and features steel cable-mounted modules that track the sun from east to west. The rotation axis is oriented slightly away from true north/south (about 15° towards southwest) and inclined 23° from horizontal. Fig. 2 shows a photo of the installation.

Calculation methods

Mounting types

There are several different options available for mounting flat-plate PV systems, including:

- Fixed mounting on a south-facing rack with the modules mounted at the yearly optimum inclination for the site.
- System with the PV modules rotating around a single axis placed in a north/south direction. The axis may be horizontal or lifted up at the northern end so it forms an angle with the horizontal plane. Modules are placed along the axis in the same plane as the axis, which is then rotated so the modules follow a path facing east in the morning to west in the evening. The examples shown in Figs. 1 and 2 are of this type.
- Single vertical axis system. The modules are mounted at an inclination angle relative to horizontal and moved around the vertical axis from east to west during the day.
- Two-axis tracking system that follows the sun path perfectly at all times.

Calculation methods

The methods used by PVGIS to estimate PV system output have been described in a number of papers [3,4,5,6]; therefore, only a brief description is required here.

The basis for the European part of PVGIS is a dataset with 10 years of data from 566 ground stations in Europe measuring global horizontal radiation and in some cases diffuse radiation. The station data were collected and processed as a part of the European Solar Radiation Atlas [7] and published as monthly averages of daily irradiation sums.

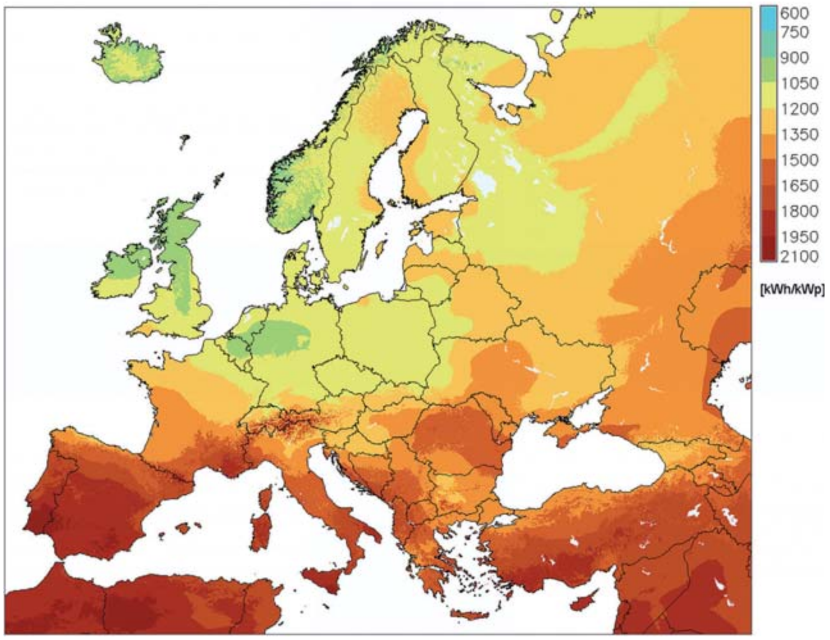


Figure 3. Map of PV performance in Europe showing the energy output of a 1kWp system mounted on a single-axis tracking system with a vertical axis and modules mounted at the local optimum angle.

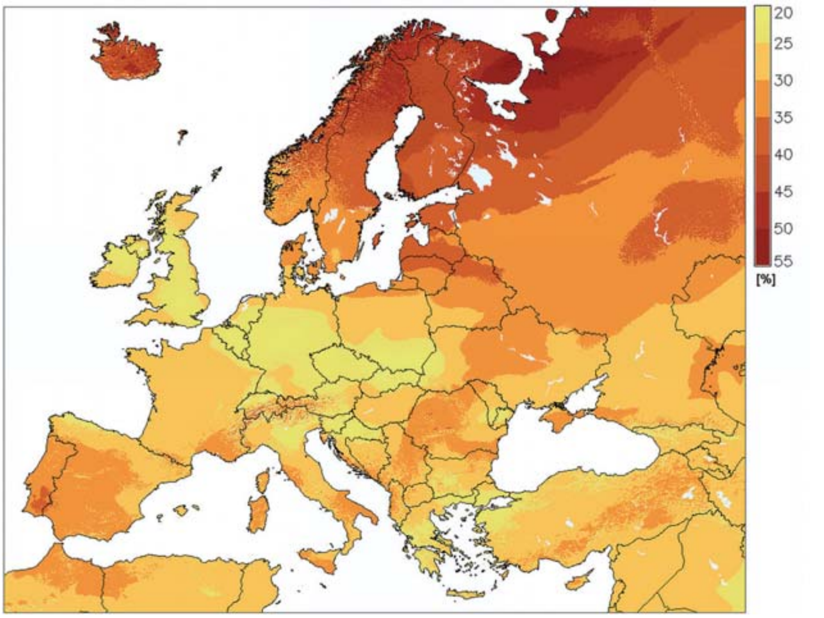


Figure 4. Percentage difference between the global irradiation arriving at the surface of a vertical-axis tracking system and a fixed system. Optimum angle is used both for the fixed and the tracking system.

Spatial interpolation methods were used to estimate the irradiation at geographical locations between the sites where ground station data is available [4].

Using the mathematical models described in Šúri and Hofierka [4] it is possible to reconstruct the average of the solar irradiance at any time during the day for a typical day in each month. This can be done for an arbitrarily placed plane, so it is possible to calculate the way the in-plane irradiance varies during the day also for a sun-tracking system. This method has been described for fixed and two-axis tracking systems [7].

From these daily values we calculate the yearly total irradiation on a given plane (fixed or moving), taking into account shadows from hills and mountains using a digital elevation map with a resolution of 100 x 100m.

The energy output of PV modules depends mostly but not solely on the irradiation level – elements such as the effects of temperature and reflectivity must also be taken into account [8]. Using monthly averaged data, it has been found that if one's interest lies only in the difference between the outputs of fixed and tracking systems, these effects tend to cancel each other out [7]. It follows that the relative difference in the PV output between fixed and two-axis tracking systems is almost the same as the relative difference between the respective in-plane irradiation values, an assumption that may not be fully valid when using real hourly data in the calculation. In addition, there are other losses in PV systems, such as losses in inverters, cables, losses due to dirt and snow and occasional shadows. The results presented in this paper assume that these 'other losses' amount to 14%, a fairly conservative value based on published data on PV systems' performance [9].

For some of the system types, the performance will depend on the chosen module angle. The authors have developed algorithms to find the optimum inclination angle for a given system, which will result in the highest annual output for the chosen location.

Performance comparison of various tracking options

Combining all the calculation methods yields maps of PV performance for Europe, such as that shown in Fig. 3, which shows the estimated PV output for a 1kWp PV system with crystalline silicon modules using a tracking system with a single vertical axis and the modules mounted with the optimum angle for each geographical location. The PV energy production in this map is the energy delivered to the grid, taking into account all losses. The energy output varies from about 1000kWh/year in North West Europe to ~1400kWh/year in Central France, Northern Italy and Hungary, and up to nearly 2000kWh/year in Southern Spain, Portugal and Sicily.

> "The relative difference in the PV output between fixed and two-axis tracking systems is almost the same as the relative difference between the respective in-plane irradiation values."

A comparison of this setup with a fixed system of the same nominal power is shown in Fig. 4, which shows the difference in the yearly in-plane irradiation between the vertical-axis system and the fixed system, in both cases using the optimum angle for the system. The difference is shown as a percentage increase for the tracking system over the fixed system. In this case there is no simple trend from north to south. In Southern

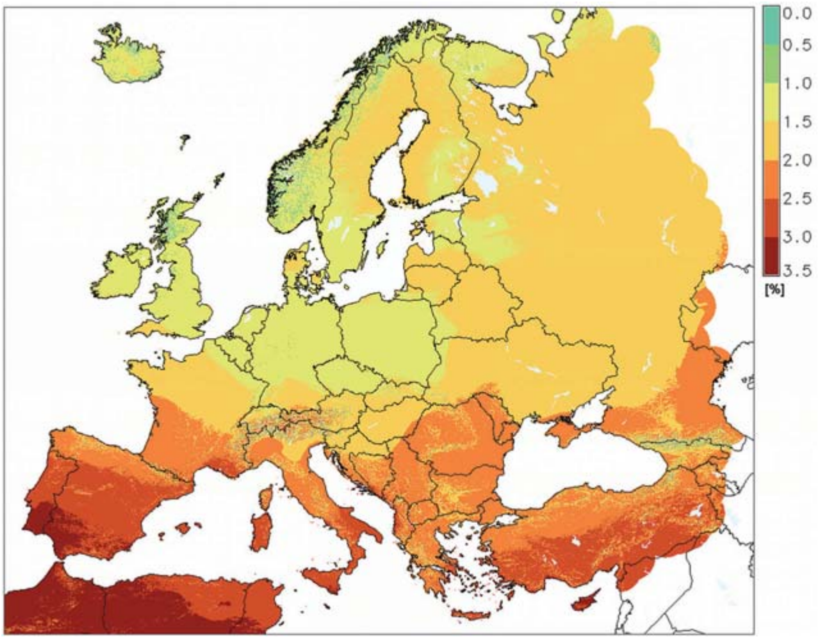


Figure 5. Percentage difference between the global irradiation arriving at the surface of a two-axis tracking system and at a vertical-axis system with optimum angle.

Europe and parts of the Balkans, the gain with tracking is generally around 30%; further north the gain is smaller, with values of 20-25% in much of Central Europe and the British Isles. Going even further north, the difference increases again and reaches more than 50% in Northern Scandinavia.

So far we have been looking only at vertical-axis systems. Repeating the calculation for inclined-axis systems aligned north/south we find that the two tracking options have almost the same performance, provided each of them uses the optimum inclination. The difference in output in most of Europe is less than 1%. Only in the far north will a vertical-axis system perform 2-3% better than the inclined-axis system.

The different single-axis tracking systems will only track the position of the sun imperfectly, so it is to be expected that a true two-axis tracking system would give higher energy output than any of the single-axis systems. But the discrepancy is surprisingly small. Fig. 5 shows the percentage gain in using two-axis tracking rather than the vertical-axis tracking with optimum angle. In Southern Europe the difference is around 3%, while in Central and Northern Europe the difference is smaller, typically around 1.5-2%. All these assumptions apply for areas that are not affected by shadowing of nearby terrain features or other obstacles.

"A north/south-oriented horizontal tracking system performs better everywhere, normally giving 10-20% more energy than a fixed system."

To better illustrate the differences between all the discussed tracking options, we have calculated the PV output

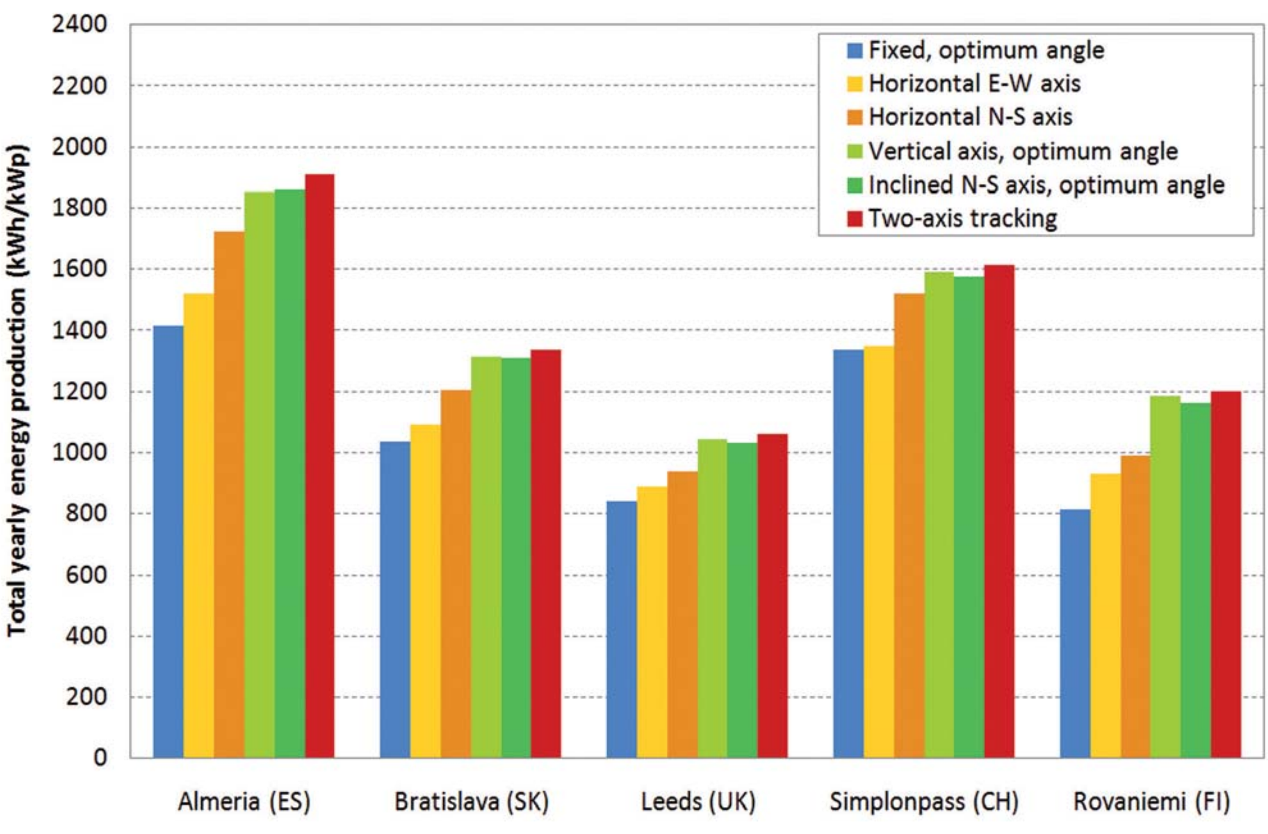


Figure 6. Comparison of the energy output from different system mountings for five locations in Europe. The comparison is made for a fixed system at optimum angle; for horizontal single-axis systems with axis pointing east/west or north/south; for vertical and inclined axis systems with optimum angle; and for a two-axis tracking system.

from a number of different tracking systems for five different locations in Europe representing different climatic zones. The results are shown in Fig. 6. In this case, the fixed system is compared to two different horizontal-axis systems (east/west oriented and north/south oriented), as well as to the inclined and vertical axis and the two-axis system.

The east/west horizontal-axis system has a slight advantage over the fixed system except where there is strong shadowing (Simplonpass), but this rarely reaches 10%. A north/south-oriented horizontal tracking system performs better everywhere, normally giving 10-20% more energy than a fixed system. A significant gain can be seen when moving to optimal angle for a single-axis system. Finally, the two-axis system performs slightly better than the optimized single-axis options.

One interesting feature is that by using tracking systems, the energy output is actually higher in the extreme north than in parts of North-Central Europe. This is only the case for tracking systems because they can follow the sun into the northern part of the sky in summer, unlike the fixed south-facing systems.

Conclusions

It is possible to gain a significant amount of energy when mounting PV systems on trackers. This gain depends on location, but will generally be 20-35% for a two-axis tracking system. Single-axis systems can perform almost as well as two-axis systems when the inclination of the modules is properly optimized. Given that single-axis systems are simpler in construction, this can make these systems attractive from a cost-benefit point of view.

One aspect of tracking systems that has not been discussed in this article is the problem of shadowing. In the morning and evening, the modules cast long shadows that may cover other modules, reducing the power output. For this reason it may sometimes be a better strategy not to let the modules track the sun all the way from sunrise to sunset, but to let them revert to a more south-facing position to avoid shadowing [10]. We are working on refining the calculation methods to take this effect into account.

The results that are based on the simulated average daily profiles of irradiation and temperature do not inherit specific local weather patterns such as convective clouds, thus giving an overview on the larger geographical scale. To calculate local site-specific differences of the tracking systems, data with higher spatial and temporal resolution may provide more realistic results.

Estimation of the energy output from various sun-tracking options is made available as a web application at the PVGIS site [11], where a user can request the calculations shown in this article for any location in Europe. Calculations based on the use of full time series of solar radiation and temperature data can be provided by the GeoModel Company.

References

[1] Raytracker, Inc. [available online at http://www.raytracker.com].

[2] Baumgartner, F., Büchel, A. & Bartholet, R. 2008, "Solar Wings: A new Lightweight PV Tracking System", *Proc. 23rd European Photovoltaic Solar Energy Conference*, Valencia, Spain.

[3] Šúri, M. & Hofierka, J. 2004, "A new GIS-based solar radiation model and its application to photovoltaic assessments", *Transactions in GIS*, Vol. 8, pp. 175-190.

[4] Šúri M. & Hofierka J., 2004, "A New GIS-based Solar Radiation Model and Its Application for Photovoltaic Assessments", *Transactions in GIS*, Vol. 8,2, pp. 175-190

[5] Šúri, M., Huld, T.A., Dunlop, E.D. & Ossenbrink, H.A. 2007, "Potential of solar electricity generation in the European Union member states and candidate countries" *Solar Energy*, Vol. 81, pp. 1295-1305.

[6] Huld, T., Šúri, M. & Dunlop, E.D. 2008, "Comparison of potential solar electricity output from fixed-inclined and two-axis tracking photovoltaic modules in Europe", *Progress in Photovoltaics: Research and Applications*, Vol. 16, pp. 47-59.

[7] *ESRA (European Solar Radiation Atlas)*, 4th edition, including CD-ROM. Eds: Greif, J., et al. published for the Commission of the European Communities by Presses de l'Ecole des Mines de Paris, Paris, France (2000).

[8] Huld, T., Šúri, M. & Dunlop, E.D. 2008, "Geographical variation of the conversion efficiency of crystalline silicon photovoltaic modules in Europe", *Progress in Photovoltaics: Research and Applications*, Vol. 16, pp. 595-607.

[9] Jahn, U., Nasse, W., Nordmann, T., Clavadetscher, L. & Meyer, D. 2004, "Achievements of task 2 of IEA PV power systems programme: final results on PV system performance", *Proc. 19th European Photovoltaic Solar Energy Conference*, pp. 2813-2816.

[10] Navarte, L. & Lorenzo, E. 2008, "Tracking and ground cover ratio", *Progress in Photovoltaics: Research and Applications*, Vol. 16, pp. 703-714.

[11] PVGIS web site [available online at: http://re.jrc.ec.europa.eu/pvgis].

About the Authors

Thomas Huld holds an M.Eng. in electrical engineering and a Ph.D. in plasma physics, both from the Technical University of Denmark. He has worked for the last seven years in the fields of photovoltaics and solar radiation mapping, with particular involvement in mathematical modelling of PV performance and methods for estimating PV performance over large geographical areas. He maintains and develops the PVGIS web application.

Marcel Šúri holds an M.Sc. in physical geography and a Ph.D. in remote sensing and geoinformatics. From 2001 to 2008 he worked in the Joint Research Centre on geographical assessment of solar resources and PV potential mapping and is one of the co-authors of the PVGIS project. In 2008 he joined the GeoModel Company as the executive director. GeoModel develops solar radiation databases, simulation and control tools, maps, and web services to support the PV industry.

Tomáš Cebecauer received an M.Sc. in geography and a Ph.D. in geoinformation science. He worked on the technical development of solar radiation and geographical databases, algorithms, maps and web tools for the project PVGIS in the Joint Research Centre from 2005 to 2008. In 2008 he joined the GeoModel Company as the technical director to manage development of climate databases, tools and geoinformation services for solar energy industry.

Enquiries

Thomas Huld
Email: thomas.huld@jrc.ec.europa.eu

Marcel Šúri
Email: suri@geomodel.eu

Tomáš Cebecauer
Email: cebecauer@geomodel.eu

BIPV News

Dow Chemical unveils new BIPV solution

In the move toward the widespread uptake of building integrated photovoltaics (BIPV), Dow Chemical has unveiled the Dow Powerhouse solar shingle, which incorporates solar panel capability in the form of a building material.

Dow Solar Solutions (DSS) integrates low-cost, thin-film CIGS PV cells into a proprietary roofing shingle design, which represents a multifunctional solar energy generating roofing product. The product design reduces installation costs because the conventional roofing shingles and solar generating shingles are installed simultaneously by roofing contractors.

"This is just one example of how Dow's US$1.5 billion annual R&D investment is allowing us to deliver practical solutions for some of the world's most critical challenges," said Dow chairman/CEO Andrew N. Liveris. "These types of innovative products not only showcase our deep scientific and technical expertise but also demonstrate how our commitment to R&D is fueling Dow's future growth agenda around the world."

Back in 2007, DSS received US$20 million in funding from the U.S. Department of Energy to develop BIPV solar arrays for the residential and commercial markets. The Powerhouse solar shingle is the latest development to come out of this initiative.

The solar shingle systems are expected to be available in limited quantities by mid-2010 and projected to be more widely available in 2011.

Dow Chemical's Solar Shingle technology

systaic purchases business operations of Solarwatt Cells

Integrated solar company, systaic is purchasing the business operations of Solarwatt Cells, wholly owned subsidiary of Solarwatt AG in Dresden. The sale includes 25MW of capacity and a workforce of 54 staff.

This acquisition secures the company substantial cost-reduction potential in the automotive and energy roof system sectors as well as supply and delivery of 'made in Germany' solar cells. The company's integrated PV roof systems are expected to become more widely adopted with the new focus on BIPV in Europe.

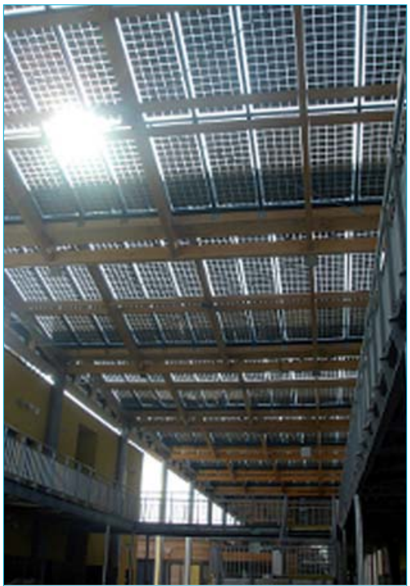
This purchase will also enable systaic to cut its own annual production costs by several million euro.

Scheuten Solar completes school BIPV project

Scheuten Solar's BIPV project at a school of agriculture in the French region of Bourges is now complete. The company delivered 334 PVB glass-glass solar modules to the school in time for completion.

Scheuten also gave technical support to its customer regarding the country-specific building codes, which are due to get more detailed based on the new BIPV regulations brought in with feed-in tariff updates. An official test also took place on the site.

Fifty insulated glass-glass modules and 334 PVB modules with a total power output of approximately 100kWp are now fitted on the roof.



Scheuten Solar school of agriculture project, Bourges, France.

systaic energy roof.

Konarka's Power Plastic integrated into Enviromena shade structure projects

Konarka Technologies, developer of Konarka Power Plastic is collaborating with Enviromena Power Systems to investigate the integration of the Power Plastic into Enviromena shade structure projects. This is the latest PV collaboration in aid of BIPV commercialization.

Enviromena develops projects for utility-scale solutions, commercial solutions and remote power solutions across the Middle East, an area currently shifting towards alternative energy. This move is currently driven forward by Government initiatives as well as an increased demand for solar technology.

BIPV project from Dyesol, Corus enters fifth stage of development

Dyesol and Corus's joint BIPV project to commercially manufacture dye solar cells (DSC) on steel, supported by £5 million from the Welsh Assembly Government (WAG), has entered the next stage. This milestone is the fifth step in achieving the goal of DSC integrated onto strip steel in a coil coating line.

Dyesol BIPV panel.

The two companies have now progressed to the next phase of production development, which is expected to be completed by May 2010. This coincides with the start of the industrialization phase of the WAG project, which will involve production trials, acceptance testing and placement on demonstration sites.

Dyesol is the only supplier of DSC materials to Corus, who will work with the company to commercialize the products on a global scale. Based on the existing coated steel market of over one billion square metres per annum, the annual addressable market is forecast to be over 200 million square metres of PV product.

aleo solar takes advantage of French BIPV tariff; opens business in France

In order to strengthen its presence in Europe, aleo solar is opening a sales office in the Aix-en-Provence, France. This move follows several megawatt deals the company has struck in the country within the last few months.

aleo will take advantage of the high FiT rate for building integrated photovoltaics (€0.60/kWh) in the country, utilizing its BIPV roof system. The company's Kit_3000 provides for an all-in-one 3kW system.

While France is already a key market for the company, it hopes that its sales volumes will increase further in the future. In 2008, installed photovoltaic capacity amounted to around 105MW. Calculations made by the European industry association EPIA predict output to multiply to as much as 4,300MW by 2013. For a country so focused on nuclear power, this marks a significant shift to renewable sources of energy.

All business in France will now be managed by the new office in Aix-en-Provence.

China aims to install 2GW, PV installations by 2011

China's capital city, Beijing, is to see significant developments in the photovoltaic sector over the coming years. The capital's government has developed a solar promotion program that aims for 70MW of installed PV capacity, including BIPV technology by 2011.

Although the number of installations is not yet known, the government has said that each power station or rooftop BIPV project will be 5MW or above. Initially these installations will be used as demonstration projects.

Although China has been slower than expected in its number of PV installations, with only 40MW in 2008, the country aims for a more optimistic 2GW by 2011.

The Beijing municipal government also intends to develop other 'new energy' demonstration projects in five other areas of the country by the same year. These will include 3,000 new energy vehicles, an increase of 1.2 million square metres of solar heaters, 20 million square metres of heat pump floor panel, and 50MW of biomass power generation.

Solarmer breaks plastic cell efficiency record for second consecutive year

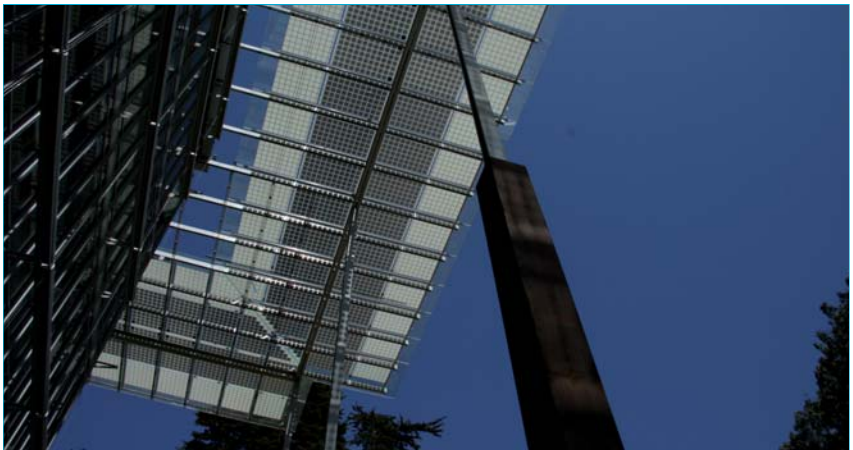
Developer of plastic solar cells, Solarmer Energy, has again broken the world record for the efficiency of plastic solar cells. The company's latest efficiency of 7.6% has been independently certified by Newport Corp.'s Technology and Applications Center's Photovoltaic (TAC-PV) Lab.

Solarmer BIPV solutions.

Quercus Trust acquires Applied Solar assets

Applied Solar has closed the previously announced sale of its assets and operations to Quercus APSO LLC, the wholly owned subsidiary of The Quercus Trust. Quercus APSO LLC, intends to change its name and conduct business as Applied Solar, LLC. With the consummation of the transaction, Applied Solar will have the benefit of a much stronger balance sheet and little or no long-term debt.

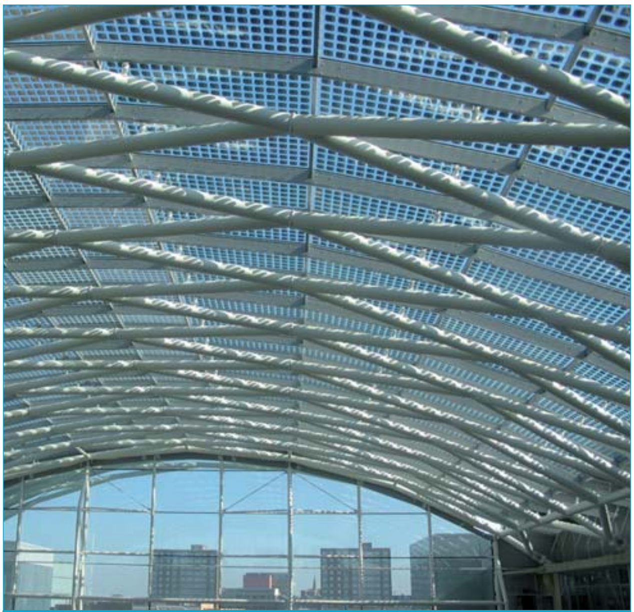
David Field, Quercus' president and CEO, commented, "We are pleased to announce the completion of this transaction, and look forward to continuing our efforts to develop new BIPV products, including an anticipated 2010 introduction of a product that will integrate with asphalt shingle roofing tiles, which represent approximately 80% of the U.S. residential roofing market. At the same time, we intend to further build upon our key strategic industry relationships that have enabled us to significantly penetrate the residential BIPV market and will soon lead our products into the European marketplace." Field will continue in the same role at Applied Solar.



Applied Solar PV glass.

Case Studies

Hackney, London, UK



London Borough of Hackney's 'Customer First' Centre.

PowerGlaz at Hackney puts the 'Customer First'

Project History: Since its introduction in 2004, PowerGlaz, manufactured by Romag, has led the field in building integrated photovoltaic (BIPV) solutions for architects and those involved in the design of PV systems for buildings.

Some notable Romag buildings include The City Hall in London, BP's HQ in Middlesex, and 'The Solar Sail' in Guangdong in China, but the most recent project to benefit from PowerGlaz BIPV is in the London Borough of Hackney where PowerGlaz covers the glazed roof of the Council's 'Customer First Centre.'

Concept & Design: This project presented many challenges but, because of Romag's 'in-house' glass processing capabilities, these challenges were easily met.

With a total of almost 600 panels, 96 are PowerGlaz double-glazed BIPV modules providing a total output of 65kWp. Romag has also supplied screen-printed double-glazed units and SGP 'high-performance' laminated glass, all meeting stringent performance specifications for 'solar shading' and insulation. Combinations of the following features were included:

- Argon-filled insulated glass units combining low-E glass to reduce the U-value and heat loss.
- Structural bonding of carrier frames for subsequent structural glazing, using Dow Corning 993 silicone.
- SGP interlayer for enhanced structural performance.
- A combination of heat-strengthened, toughened and heat-soak tested laminated glass to provide maximum safety.

Romag processed all the glass 'in-house,' enabling phased deliveries to comply with the construction programme and demonstrating that Romag and PowerGlaz always puts the 'Customer First'!

Design Specification:

PV System Power: 65kWp
Type of Integration: Roof-Integrated
Size of Integration: 600 panels

Madrid, Spain

Source: HOK International

Telefónica Headquarters master plan.

Telefónica Headquarters, City of Communications, Madrid

Project History: The City of Communications business park project was born at the concept design stage back in 2002. Global Architectural Firm, HOK International was responsible for the master plan and urban design of the development site. Once this stage was complete, local architect Rafael de La-Hoz Castanys took over for the architectural delivery of this project. At the time of completion in 2008, the building had the largest horizontal surface for collecting solar energy in Europe. The complete structure has over 16,600 photovoltaic solar panels that run the length of the entire office complex on the building rooftops.

At over a kilometre in length, the rooftop has an area of 390,000m^2, of which 26,000m^2 is occupied by solar photovoltaic panels. The installed power reaches an approximate 4MW peak, generating over 3.6GWh of power per year.

This design enables the building to save 15% energy costs on climate conditioning in winter, and 34% in summer, as well as saving on lighting. The façade of the office blocks is a double skin, where the external glass is hung out from staggered glass fins. The project involved an investment of approximately €21.8 million.

Concept & Design: Although this building has both a glass façade and a canopy, neither of these things generates the PV power. Fundamentally, the entire roof of this building is photovoltaic, constituting one of the largest horizontal surface for collecting solar energy in Europe. The solar panels that cover 26,000m^2 of the roof of the canopy transform solar thermal energy into electricity, at the rate of 4,389,000kw/h/year. This represents a reduction of 2000 tons of CO_2 emitted into the atmosphere. The roof shades the facades, generating cloisters, protecting entrances and creating a refreshing environment.

Design Specification:

PV System Power: Approximately 4.3MW annually
Type of Integration: Roof-Integrated
Size of Integration: 26,000m^2 solar PV
Cost of Project: Approximately €21.8 million

Fab & Facilities

Materials

Cell Processing

Thin Film

PV Modules

Power Generation

Market Watch

The rise of building-integrated photovoltaics: policy construction begins

Emma Hughes, News & Features Editor, *Photovoltaics International*

ABSTRACT

Building-integrated photovoltaics, or BIPV, is one form of solar electricity that looks set to dominate the solar market in the coming years. The increase in BIPV installations is already evident in some European countries as governments begin to tweak their policies in order to provide a platform for this technology. The past few months have seen countries such as France and Italy make efforts to up the installation rate of this integrated form of solar, increasing the feed-in tariff (FiT) rate quite substantially for BIPV and lowering it for the more common installations such as roof and ground-mounted systems in order to increase the uptake. This BIPV-dedicated section will focus on the new policies implemented in France and Italy, concentrating on France's policies as a blueprint for others. It will provide a focus on why governments are so keen to increase incentives in favour of BIPV and what the future implications of this market shift will be.

France: BIPV foundations are laid

France was one of the first European countries to place a new focus on BIPV, setting the pace for other nations to implement changes and learn from the practices implemented there. Due to its highly favourable BIPV FiT, the French PV market is dominated today by BIPV applications for residential and commercial applications. The country's incentive for this form of PV is set higher than any in the world at €0.60/kWh, leading to a significant increase in BIPV installations.

The French government chose to place an emphasis on BIPV for several reasons. Firstly, France has a rich architectural heritage that it is keen to preserve, and, at many levels of government, it is considered necessary to conserve the architectural integrity of France's urban, village and country landscapes. Unlike some forms of building-applied photovoltaics (BAPV), which can often be viewed as unsightly additions simply placed on top of an existing structure, BIPV is seen as an acceptable compromise as it replaces certain elements of a building's structure; the PV elements become its 'skin,' whilst also providing renewable energy. Secondly, when the FiT was last revised in early 2006, France had a small domestic PV industry that worked largely for export markets (namely northern Africa and Germany). An emphasis on BIPV products, of which few existed on the world market, was considered to be a convenient way of increasing the possibilities for the French PV industry to dominate in at least one market segment, and the high BIPV tariffs were to help finance product development and expansion in the local industry. Thus, the French BIPV market was born.

Source: Solarcentury

Figure 1. Energy roof from Solarcentury, Rotignon, France.

Although the French government is keen to significantly increase the amount of BIPV installations in the country, it cannot be said that the process is a straightforward one. In order to keep in line with its architecturally aesthetic impetus, the government has implemented some restrictions on what type of BIPV application is acceptable. One of the ways the government has come up with to enhance the quality of implementation is to oblige the installer to submit a certificate attesting that the works were designed and constructed in compliance with regulations and rules of art. If the installation complies with the guidelines it will receive the full BIPV FiT bonus.

Source: Solarcentury

Figure 2. C21e solar electric roof slates in Languedoc-Roussulon, France.

The French market is therefore segmented into those products eligible for the current FiT bonus and those that are not. These eligible systems must be either PV roofs, tiles or slates that have been industrially designed with or without support; sun shades (brise-soleils), windows, balcony and terrace balustrades, railings and vertical protection, PV glass roofs without back protection, façades or curtain walls. Any of these eligible forms of technology applied for in 2009 will receive the full €0.60/kWh tariff.

However, a draft text that is expected to be applied by January 1st 2010 is anticipated to be far more restrictive. The new policy will state that in order to be eligible for the full BIPV bonus, the system must not only fulfil one of the above criteria, but, in the case of PV roofs, the module itself must provide the waterproofing for the roof. Integration systems that rely on a plastic or metal waterproofing under-sheet will no longer be eligible for the bonus. To compensate for this tightening of eligibility criteria, an intermediate tariff will be created that will allow systems installed parallel to the roof to be eligible for a smaller bonus. This will call for a total tariff of €0.45/kWh.

The BIPV tariff in France is therefore attractive, yet not altogether simple. However, the return on investment (ROI) is also fairly positive, as if the BIPV tariff is

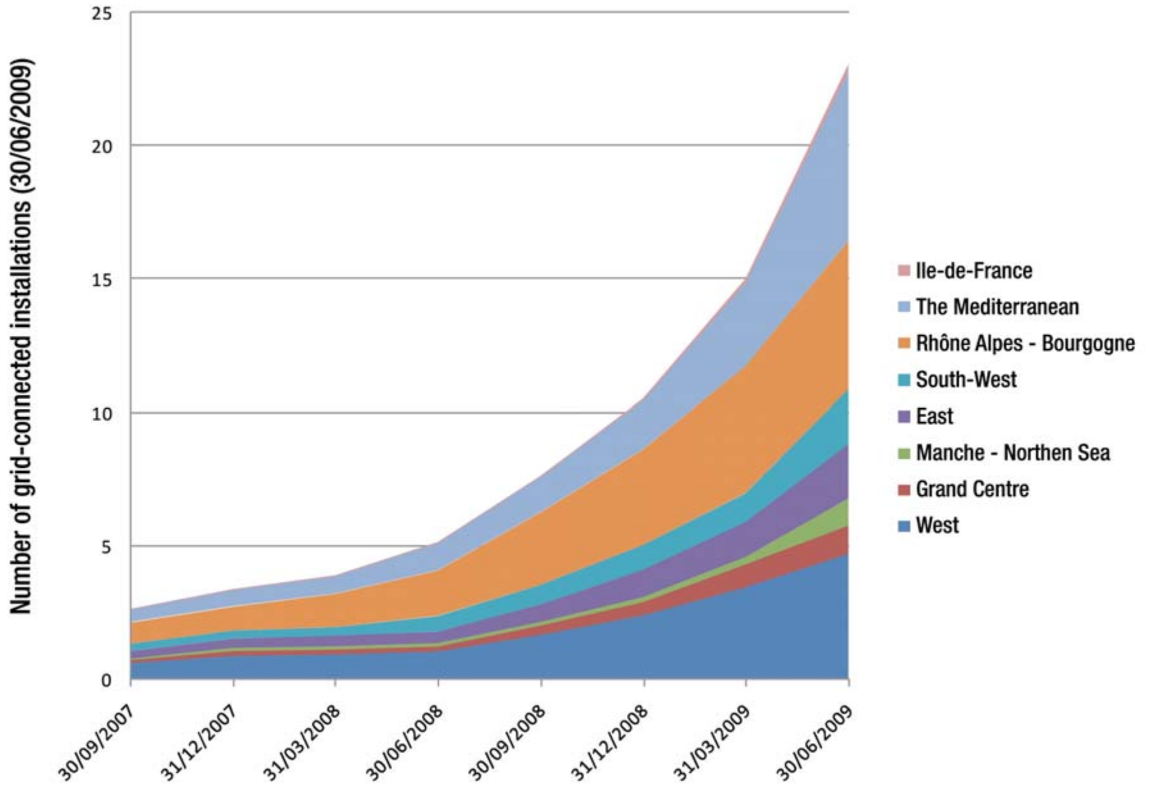


Figure 3. Number of grid-connected installations (by region) [1].

combined with tax breaks and incentives for private homeowners installing systems on their own houses, the economic payback could be achieved in five years (this figure is based on the insolation levels in southern France). It can be considered reasonable to expect that with the new, more complex BIPV regulations coming into force by early 2010, the amount of installations by the end of 2009 should significantly increase.

That is not to say that France has seen a limited interest in this form of PV. Figures as of June 2009 show that approximately 23,000 systems have already been connected to the mainland grid since the introduction of the tariff in 2006, only a handful of which were not BIPV. The tightening of the eligibility

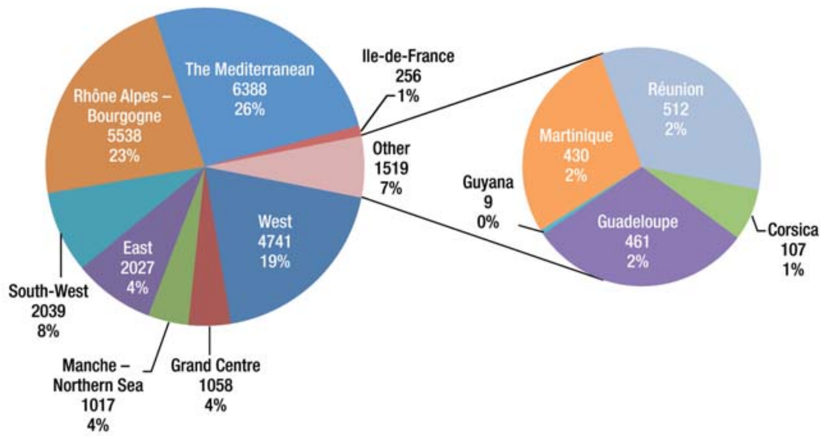
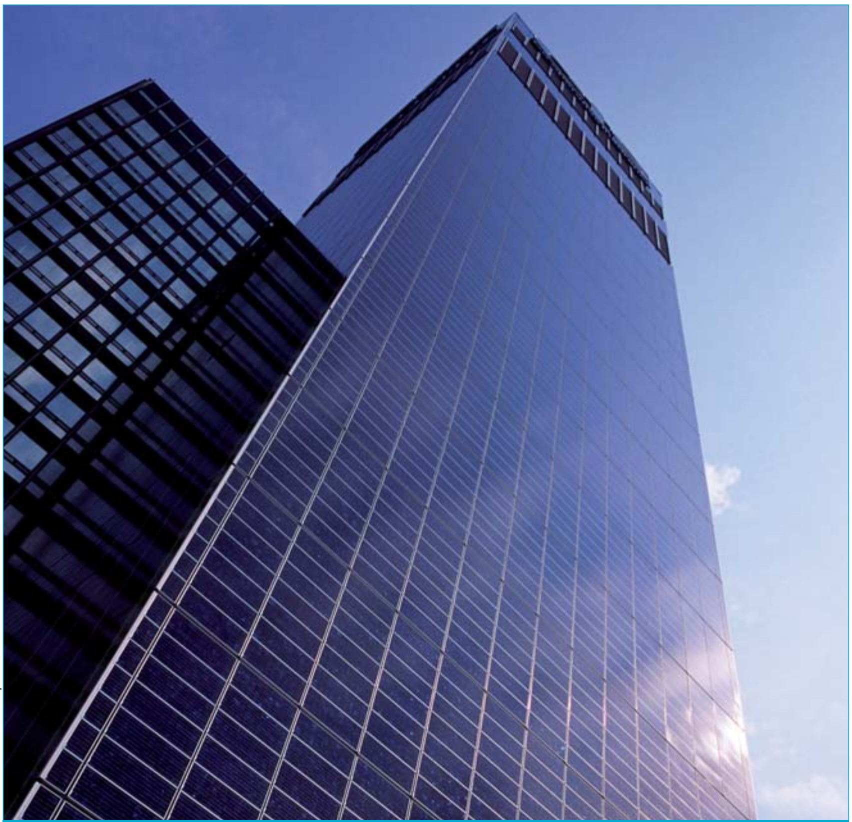


Figure 4. Number of grid-connected installations (as of June 30th 2009) [1].

Country	Roof/ground tariff (€/kWh)	BIPV tariff	BAPV tariff	Term (Years)
France	0.32-0.43	0.60		20
Germany	0.32	0.33-0.43		20
Italy	0.35-0.39	0.43-0.48	0.39-0.43	20
Switzerland	0.30-0.40	0.38-0.56	0.37-0.46	25
Austria		0.30-0.46	0.30-0.46	10+1+1
Czech Republic	0.48-0.49			20
Greece	0.40-0.60			20
Luxembourg	0.36-0.39			15
Netherlands	0.29-0.38			15
Portugal	0.62			5+10
Slovenia	0.33-0.37			5+5+10
Spain	0.32-0.34			25

Table 1. BIPV tariff comparisons in Europe (correct as of October 13th, 2009).

Data courtesy of EPIA.



Source: Solarcentury

Figure 5. Europe's largest solar façade, the CIS Tower, Manchester, UK.

criteria for the BIPV bonus in France is also expected to encourage more sophisticated BIPV products such as roof tiles and waterproofing joints for standard modules. Without this advancement, there is limited room for growth progression in this technology, as the new regulations will restrict the amount of conventional solutions eligible.

Italy: forging ahead with its own BIPV policies

Paving the way for other countries to enter the BIPV fray, France's work in promoting the use of solar energy and a new FiT rate have encouraged the adoption of similar strategies in Italy. The tariff that ranges from €0.43-0.48/kWh for BIPV installations has promoted a total installed PV capacity of approximately 600MWp to date. This tariff weighed against the non-integrated rate, set at €0.39/kWh for systems of 1-3kWh, is less appealing in comparison. Of the 600MWp installed so far in the country, 462MWp is either BAPV or BIPV. At 77% of the installed capacity, this figure alone shows the strong drive for the integrated form of PV technology in the country.

Although the Italian incentive is not as high for BIPV as in France, the rules surrounding this type of installation are equally as strict. The Italian electricity services operator GSE [2] has recently updated and published its Guideline for BIPV applications. This list of guidelines has been developed to help PV manufacturers, designers and installers develop BIPV systems in Italy. The GSE guide outlines the specifics of BIPV acceptability, listing many forms of restrictions on this type of installation. The guide also defines minimum requirements of both a functional and architectural nature that each installation will have to fulfil in order to obtain the full incentives for partial or total building integration. Some examples of eligible BIPV solutions include:

- PV modules that substitute the covering material of the roof and have the same architectural functionality of the surface;
- Mounting structures with fully operating shelters, canopies, arbors or sheds;
- Modules partly substituting the transparent or semi-transparent covering material, thus allowing the natural lighting of the rooms below, such as PV glass/c-Si glass.

This is just a handful of the 10 eligible examples listed on the GSE website. Again, we can expect these regulations to complicate things from a PV perspective unless significant advancements are made in terms of the inventiveness of integrated PV solutions. The technology surrounding this is therefore expected to advance quite significantly in the next few years if BIPV is to become successful while complying with the regulations in place.

The future of BIPV

As BIPV installations become more creative and inventive with the advancements in technology from leading BIPV companies, so the need for architectural input grows in the industry. Products and technologies such as Suntech Power's BIPV solutions, Dow Chemical's latest 'Solar Shingle' technology and Solarcentury's applications have been demonstrated throughout Europe. In order to achieve a better standardization of PV materials and components, a strong technical collaboration between the building and the photovoltaic sectors is needed. We can therefore expect to see a strong relationship develop between those in the photovoltaics industry and those in the architectural industry as the BIPV sector grows. Many architects are already getting involved by collaborating with those in the PV manufacturing and installation industry.

All the technical aspects aside, the BIPV industry is also likely to grow quite significantly for another more obvious reason. As the technology advances in the ways described in this focus, the more these new-build, aesthetic constructions will become a popular focus for the average citizen. One of the issues with PV's growth so far has been the question of who to approach if one requires an installation, who are the manufacturers, who are the installers and how much will it cost; will it be complicated to complete, and so on. However, if the technology is already integrated into a building, then all of these issues are erased, increasing the amount of interest on the part of the potential customer.

The integrated form of PV is certainly set for expansion as we move into 2010. Achieving this goal will require fine-tuning of incentive policies, reliance on aesthetic preference and strengthening of the relationship between the PV and construction industries. The PV sector can expect to be placed quite prominently in the spotlight as new-build BIPV technology begins to crop up across the globe and residential and commercial PV installation becomes commonplace in the construction industry.

Acknowledgements

The author acknowledges the contribution of **Melodie de l'Epine**, European Programmes & PV Consultant, **Hespul** for all graphs and the information on France's BIPV policies.

References

[1] SOLER 2009, "Etat du parc solaire photovoltaïque" [available online at http://www.enr.fr/docs/2009151922_05ParcPVjuin2009SOLERv200909.pdf].

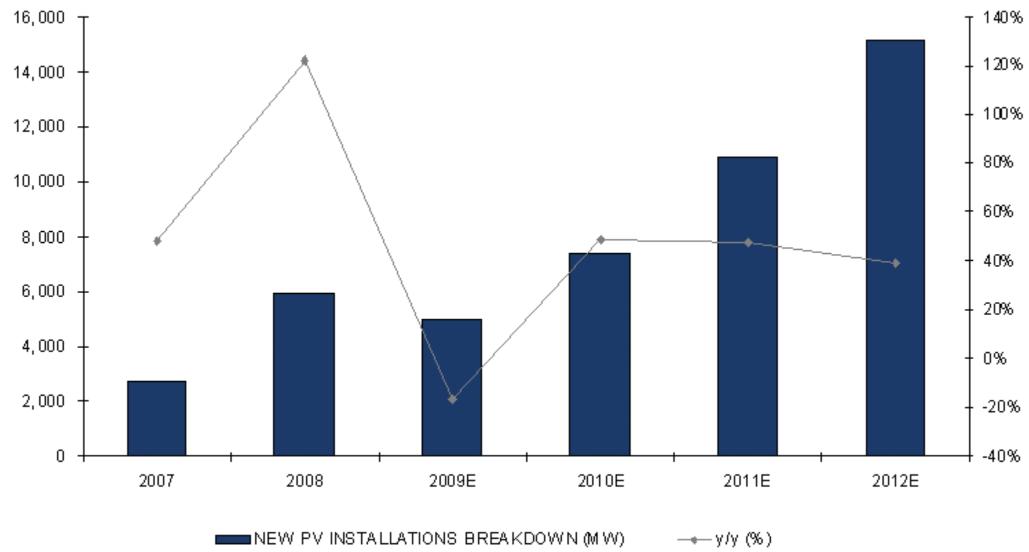
[2] Information available online at www.gse.it

About the Author

Emma Hughes is News & Features Editor for *Photovoltaics International* and Editorial Manager for the Design-BuildSolar project, due to launch in February 2010.

Market Watch

172



169

News

SolarCity, U.S. Bancorp unit double size of solar project fund to US$100M

SolarCity and U.S. Bancorp Community Development Corp. have doubled the size of their solar fund to US$100 milllion, which will finance projects in California, Nevada, and Oregon in 2009. The partnership backs SolarCity's SolarLease and power purchase agreements, financing options that permit homeowners and businesses to put no money down on solar systems. SolarCity, which was founded in July 2006, says it recently passed the 4000 customer mark, including more than 2000 SolarLease customers since it introduced the leasing option in April 2008. The solar systems integrator has hired 112 new workers in the past four months and says it plans to add 50 more employees before year's end to continue to increase installation capacity.


Source: SolarCity

SolarCity eBay project, San Jose, CA, USA.

U.S. News Focus

SunPower and SunLink settle patent infringement case

SunPower and SunLink have settled a patent infringement case brought by SunPower before the U.S. District Court for the Northern District of California. SunPower called the lawsuit against SunLink back in February 2008 asserting infringement of SunPower's patent rights covering its lightweight rooftop mounting products, SunPower PowerGuard and the SunPower T10 Solar Roof Tile.


SunPower'S T5 Solar Roof Tile.

The specifics of the settlement remain confidential, yet SunLink has acknowledged the infringement of SunLink's MMS rooftop solar product as well as the validity and enforceability of SunPower's patent rights. SunLink has also received a license to SunPower's infringed patents for confidential consideration provided under the settlement. SunPower holds over 120 patents for its solar technology, including the world's most efficient solar cell and the SunPower T5 Solar Roof Tile.

Vast majority of Americans believe in development and use of solar energy

According to a new poll, Americans overwhelmingly believe that the nation should develop and use solar energy and that the federal government should make solar power a national priority. The Schott Solar Barometer survey finds almost half of all Americans are thinking about solar power as an option for their homes or businesses and cite solar as their top choice among energy sources.

The national poll, conducted for Schott (and cosponsor the Solar Energy Industries Assn.) by an independent firm for Kelton Research, found 92% of those surveyed think it is important for the nation to develop and use solar energy, a result that was consistent across all political party affiliations. A large proportion of those Americans polled – 77% – believe the federal government should make solar power development a national priority, including providing the financial support needed.

In addition to the 49% of respondents considering solar for their home or business, 43% rate solar as their top choice for energy, far outpacing wind (17%), natural gas (12%), nuclear (10%), and other sources. Among those who would like to have solar installed, 70% want to make the change within the next five years. The poll was conducted between Aug. 31 and Sept. 8 using an email invitation and an online survey, and showed a 3.1% sampling variation.

DOE provides US$750 million to accelerate renewable energy development

U.S. Energy Secretary Steven Chu has said that the Department of Energy (DOE) will provide up to US$750 million in funding from the American Recovery and Reinvestment Act to help accelerate development of renewable energy projects, such as solar installations. Funding will go towards the cost of loan guarantees that could support as much as US$8 billion in lending to eligible projects. The DOE will invite private sector participation to help with the financing of these projects. The DOE has also announced the Financial Institution Partnership Program (FIPP), a set of standards designed to expedite the DOE's loan guarantee underwriting process and leverage private sector expertise and capital for the efficient and prudent funding of eligible projects.

The Recovery Act created a new Section 1705 under Title XVII of the Energy Policy Act of 2005 for the rapid deployment of renewable energy projects and related manufacturing facilities, electric power transmission projects and leading-edge biofuels projects that commenced construction before September 30, 2011. The goal of FIPP is to leverage the human and financial capital of private sector financial institutions by accelerating the loan application process while balancing risk between DOE and private sector partners participating in the program.


U.S. Energy Secretary Steven Chu.

News

Chu opens Solar Decathlon, announces US$87M more in solar-targeted DOE awards

Using the opening of the U.S. Department of Energy's Solar Decathlon competition on the National Mall in Washington, DC as a backdrop, DOE Secretary Steven Chu announced the latest round of monies that have been awarded to "support the development of new solar energy technologies and the rapid deployment of available carbon-free solar energy systems." Of the US$87 million allocated, US$50 million comes from the American Recovery and Reinvestment Act, bringing the total invested to US$800million.

Meanwhile, the Solar Decathlon kicked off, an international event in which DOE "challenges university teams to design and build homes that run entirely on solar energy." This year's competition (the fourth since 2002) featured 20 teams – hailing from the U.S., Germany, Spain, Canada, and Puerto Rico – which have shipped their partially constructed homes to the National Mall and are assembling the structures there. Each home features a PV system or systems as a key part of its design.

Trailing leader Illinois going into the final day of the Solar Decathlon, Team Germany from the Technical University of Darmstadt scored a perfect 150 in the tenth and final leg of the competition – net metering – passing the Illini and holding Team California at bay, to secure the overall title. The win marks the Darmstadt team's second straight victory (having taken top honours in 2007) in the U.S. Department of Energy event, which featured the university teams "designing, building, and operating the most attractive and efficient solar-powered home" on the National Mall in Washington, DC.

Gov. Schwarzenegger signs executive order raising California RPS to 33% – highest in U.S.

California Governor Arnold Schwarzenegger signed an executive order that will increase the state's Renewable Portfolio Standard to 33% by 2020 – the most aggressive RPS in the United States. The move came after the Governor threatened to veto bills passed by the state's legislature that would have also pushed the standard to 33%, but would have limited the amount of energy that could be imported from outside of California and were seen by Schwarzenegger and his allies as "unnecessarily complex."

The governor's office says the order puts the "highest priority on renewable resources that will provide the greatest environmental benefits that can be developed quickly and support reliable, efficient and cost-effective electricity system operations including resources and facilities located throughout the Western Interconnection. Working with the Public Utilities Commission (PUC), the Independent System Operator (ISO) and the California Energy Commission (CEC), CARB must adopt these regulations by July 31, 2010."

California Governor Arnold Schwarzenegger.

IRENA pushes for faster adoption of renewable energy; nuclear not among the options

Educating the masses on renewable energies is one thing, but governments also need assistance in understanding that nuclear energy is not one of them. At Climate Week in New York, IRENA condemned the decision of the IEA to include nuclear and CCS projects in developing markets into the mechanisms under the Kyoto Protocol. IRENA has also called for faster and better mechanisms for countries to access the financing required to shift energy needs to renewable formats.

European News Focus

Centrosolar posts record quarterly results: almost sold out for 2009

Solar systems firm Centrosolar Group has posted record results for its third quarter financial results, which the company attributed to its focus on integrated PV installations and shift away from the large-scale low margin ground-mounted market. Centrosolar posted €7.4 million (EBIT) in the quarter, 45% above its best quarterly results in the same quarter a year ago, which was then driven by the Spanish market demand. Centrosolar expects consolidated revenue of €280 – €290 million for the year, down from €330 million generated in 2008. However, the company has returned to profitability and margins have increased. Module sales are expected to be in the region of 85MW, up from 70MW in 2008.

The company also noted that it expects further declines in solar cell prices, which will translate to better margins on its modules, especially since it is not locked in to long-term supply contracts. Although Centrosolar said production at its highly-automated module plant in Wismar, Germany was almost sold out for the rest of the year, it would not be adding capacity or buying in modules for its distribution base.

Massive PV production capacity increase underway, says EU's Joint Research Centre

In the eighth 'Annual Photovoltaics Status Report', the European Commission's Joint Research Centre (JRC) has reported a 'massive' increase in PV production capacity is underway and that worldwide production capacity for solar cells would exceed 38GW by the end of 2010. The report also notes that production volumes in 2008 increased by 80% compared to 2007, reaching 7.3GW of potential output with China, Taiwan and Europe all adding significant capacity.

The key problem is that market demand will be significantly below production capacity levels. The report noted that market forecasts for 2010 vary considerably ranging from 6.8GW (Navigant conservative scenario); 7–10GW (EPIA policy-driven scenario, EuPD, Bank Sarasin, LBBW); and Photon Consulting's high projection of 17GW. The report noted that Europe's solar cell production rose from 1.1GW to 1.9GW in 2008. China increased solar cell manufacturing output to 2.4GW in 2008, while Japan had 1.2GW and Taiwan with 0.8GW.

Source: Centrosolar

Centrosolar integrated PV.

PV sector outlook: an analyst's perspective

Vishal Shah, Barclays Capital, New York, USA

ABSTRACT

Solar currently represents less than 0.5% of global electricity generation. However, as renewable electricity gains importance in the US$1 trillion global electricity market, we forecast solar photovoltaic shipments to rise at a compound annual growth rate of 50% for the next four years. We expect an increasing number of countries to promote solar energy as the cost gap between solar and fossil fuel-generated electricity closes. This paper provides an overview of what to expect from the PV market in 2010.

Growth overview

After a challenging 2009, we expect potential resolution of financing/permitting bottlenecks to mark the beginning of the second growth phase of the solar era as we believe new incentives in multiple markets and greater supply of lower-priced panels should lead to accelerated shipment growth from 2010. The solar industry is currently transitioning from the first growth phase – where demand was driven by two to three major markets such as Germany, Japan and Spain – to the second growth phase. We expect grid parity to be achieved in several key markets by 2010–12, which could potentially mark the beginning of the third growth phase for the solar sector.

Solar industry growth over the past five years has always exceeded expectations. German market subsidies were the main driver for better-than-expected demand until 2007; Spain was the source of better-than-expected demand in 2008. Industry demand in 2009 is once again exceeding subdued expectations that were set at the beginning of the year as a result of the Spanish market's decline and financial crisis. Demand elasticity in the solar market has been historically quite significant. Small declines in prices have led to substantial pick-ups in demand, historically speaking.

This year was different for a number of reasons. First, access to cheap financing is the primary requirement for demand elasticity. Financing dried completely in a number of major markets including Germany. Second, the weakening economic and job outlook increased the liquidity risk premium – solar investments being highly illiquid caused a sharp decline along with several other illiquid investment classes. Third, panel prices had increased sharply during the 2007-08 timeframe and as prices started declining, primarily led by aggressive pricing strategies of Chinese companies, several installers decided to wait for price stabilization. We believe prices have now approached a level where the rate of price declines is much slower and as such that the waiting game may be over for a large number of installers.

As the global macroeconomic outlook continues to improve and credit conditions continue to ease, we expect more evidence of demand elasticity in markets with relatively low permitting constraints. After an approximately 15% annual decline in 2009, we estimate that solar industry shipments are poised to increase 50% annually in 2010 to reach 7.4GW. Germany is expected to lead industry demand this year and next with demand from other emerging solar markets excluding Spain, Germany and the U.S. likely to grow at the fastest pace this year and next. We estimate that demand in these emerging markets, such as Italy, Belgium, France, and the Czech Republic, accounted for 1GW and represented 18% of global market share in 2008. Demand is likely to increase 35% annually in 2009 and reach 1.4GW, and an increase of 100% annually in 2010 to reach 2.8GW. We expect the main demand drivers to be strong incentives, highly attractive investment rates of return (IRRs) and gradually easing financing/permitting constraints.

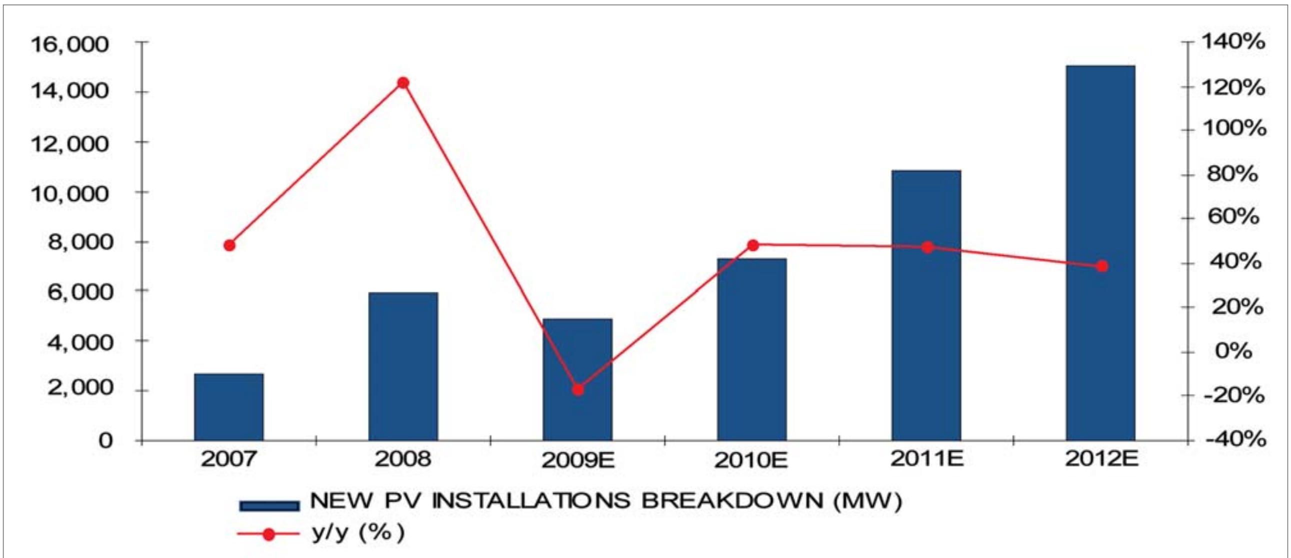


Figure 1. Forecast of new PV installations (MW).

Uncertainty with respect to 2010 demand in Germany remains high. The German government is considering a new subsidy program that is expected to be less generous than the existing subsidy program. Timing of implementation of this subsidy program is likely to define German market growth prospects. Implementation of a new subsidy program in July 2010 is likely to accelerate demand in the seasonally slower first half of 2010 and, although second half growth could likely slow down in a new subsidy scenario, we expect overall German market growth to still increase by 10% annually in 2010. In a scenario where the government introduces a new subsidy program in 2011, we expect the German market to show substantially stronger growth than in 2009, approaching 4GW, based on the current monthly installation run-rate.

Demand in the U.S. market is expected to improve from 2009 levels as some of the utility-scale projects are constructed, commercial segment demand recovers as a result of the DOE loan guarantee program, and the treasury cash grants program and solar project financing conditions continue to improve. An improving economic outlook is also expected to result in somewhat stronger residential demand. We expect U.S. solar industry shipments to increase from 360MW in 2009 to 750MW in 2010.

"Demand in the U.S. market is expected to improve from 2009 levels as some of the utility-scale projects are constructed."

Spain and Japan are also expected to show strong demand recovery in 2010. Spanish solar shipments look set to increase from 300MW in 2009 to 550MW in 2010, in line with the current subsidy program cap. We expect Japanese solar shipments to increase from 275MW in 2009 to 375MW in 2010 as new solar subsidies drive stronger-than-expected shipments growth in the residential segment.

We expect the solar industry shipments to accelerate beyond 2010 as several markets approach grid parity thanks to low panel prices. Our current forecasts call for overall industry shipments to increase from 7.4GW in 2010 to 15.1GW in 2012. We forecast German market shipments to increase from 2.8GW in 2010 to 4.1GW in 2012; U.S. market shipments to increase from 750MW in 2010 to 3.5GW in 2012; and Chinese market shipments to increase from 460MW in 2010 to 1.2GW in 2012. Development of the Chinese and German markets is contingent upon implementation or continuation of favourable solar subsidies. Most of the growth beyond 2010 is expected to come from the utility-scale/ground-based market segment. Both the U.S. and Chinese market policies support utility-scale solar generation over rooftop generation and we expect these two markets to lead industry shipments growth beyond 2010.

Several other markets such as India, Canada and Japan have the potential to emerge as strong growth markets over the next few years. Spain was a 200-300MW market until 2007 and the introduction of an attractive subsidy program in this market resulted in a tenfold increase in demand in just one year.

This second growth phase of the solar era and demand upside led by resolution of permitting/financing constraints is likely to continue over the next few years.

Forecasting demand during second growth phase

Past experience shows that predicting growth in emerging technology sectors is very difficult. Several historical forecasts with respect to adoption of personal computers and telecommunications have proven to be very conservative. Predicting solar industry growth is even more difficult because demand is influenced by several factors, such as oil price movements, subsidy development and exchange rates.

So how do we forecast demand? Our demand forecasting framework is based on two primary growth drivers for solar: development of government subsidies and development of financing. We believe that as long as these two growth drivers are intact, the solar market (the entire value chain) in dollar terms should grow at a robust pace.

In our view, as long as solar is not at grid parity – i.e., as long as solar demand is driven by government subsidies – investors should focus on volume times price, not just on volumes or on price. The upper limit to market growth is likely to be defined by government subsidies: as long as government subsidies grow, solar market size should grow. If volumes increase rapidly, prices should decrease in a similar proportion, in our view, such that the overall market size is the same. Once solar achieves grid parity, the solar market is likely to be driven by the pure economics of supply/demand and is likely to have one less growth driver (no government subsidies).

We expect solar market growth to be determined by how quickly or slowly the solar value chain takes advantage of government subsidies. Growth would be faster if the subsidies are spent over fewer years and conversely, growth would be slower if the subsidies are spent in more years.

For instance, if a 1W solar system costs US$9 and the government incentives are approximately US$13/W, the net profit to the customer is approximately US$4/W. Although the US$13 government incentive is provided over a period of 20 or 25 years, the solar ecosystem receives US$7–9/W up front. Solar market growth is likely to depend on how quickly these solar incentives provided by the government are transferred to the solar value chain through the customer.

"Our demand forecasting framework is based on two primary growth drivers for solar: development of government subsidies and development of financing."

In general, during the next five years, we expect the following factors to affect solar industry shipments:

1. Supply of silicon and solar cells. The supply of solar cells will likely increase rapidly as a result of an increase in production from new and existing silicon players, as well as successful commercialization by new thin-film solar manufacturers.
2. Government support in the form of improved levels of subsidies in existing and new markets. Although we believe Germany will remain an important market for solar energy demand, we expect increased support from new governments in the form of more attractive solar subsidies to drive demand.
3. Favourable solar system ASP trends. We expect solar ASPs to decline by approximately 50% in 2009 and another 30% in 2010, which should improve the economics of promoting solar for several prospective new governments. Moreover, we expect the development of a solar ecosystem in the form of better customer awareness, greater availability of solar modules, and the reduction of installation costs to drive additional solar demand.
4. Development of local fossil fuel-generated electricity rates. As the cost of oil, natural gas, and coal-based electricity increases from 2010, the gap between the solar electricity price and fossil-fuel-generated electricity price will narrow.
5. Development of interest rates and other financial instruments driving solar demand. The low interest rate environment should result in favourable economics for project developers, leading to strong demand.

Courtesy of First Solar.

Figure 2. Large-scale installations such as Sempra Generation's 10MW plant in El Dorado, Nevada (using First Solar modules) look set to achieve superior growth.

How large is the potential solar opportunity in the second growth phase?

We estimate US$200 billion of government spending on gross subsidies in the second growth phase. These calculations are based on a what we believe is a conservative scenario, assuming that governments take note of the increasing subsidy burden and enforce an annual cap on installations. This scenario is used to calculate the minimum growth of installations during phase two of solar industry growth. Our scenario analysis does not take into consideration potential upside from solar programs in new markets and the possibility of no annual caps in several solar markets.

Recalling our demand-forecasting framework: subsidy equals customer profit plus solar industry revenue. We assume that US$50 billion of the US$200 billion incentives constitute profits for end customers and US$150 billion constitute solar industry revenue. In addition to the subsidized markets, we see at least 5GW of utility-scale market opportunity during the second growth phase. Most of this demand will come from U.S. utilities with some initial traction from European utilities. Although the subsidy number seems very large, we believe a more appropriate number for the government to consider should be "net subsidy burden" which takes into consideration factors such as local fossil fuel-generated electricity costs among other things. We estimate the net cost burden of solar subsidies assuming US$0.10/kWh of traditional fuel costs to be US$125 billion during the second growth phase.

"The net solar subsidies as percentage of GDP are significantly less than health care and education spending in all of the countries supporting subsidies."

In our opinion, a $125 billion cost burden is not that large especially after taking into consideration that it would be shared by more than 12 different countries. We believe the net solar subsidies as percentage of GDP are significantly less than health care and education spending in all of the countries supporting subsidies. The bottom line is that we believe the net subsidy burden is insignificant for governments to potentially scale back solar programs. In our view, solar's job creation potential and the promise of producing electricity at lower prices than natural gas once grid parity is achieved should lead to continued government support during the second growth phase.

Thin film versus silicon

In our opinion, silicon technology will continue to lead the growth wave for the following reasons: 1) capital intensity of thin-film players (US$2/W) is higher than that of silicon players (US$0.50–US$1/W). We expect relatively low levels of vertical integration in the silicon space especially since upstream/midstream segments have more than adequate capacity to support near- to medium-term growth; and 2) new thin-film technologies could find it difficult to scale and achieve bankability status. Companies such as Sharp that have strong balance sheets and have made significant technology advancements stand to potentially lead the thin-film growth wave along with First Solar. For other start-ups, particularly funded by equipment suppliers such as Applied Materials, we believe success would depend to a large extent on subsidy programs and manufacturing incentives of local governments.

Where will growth come from: rooftop or utility-scale?

During the first growth phase, markets such as Japan and Germany led most of the installation growth. Growth was largely within the small/medium-size rooftop segment. Over the next three to five years, we see the potential for large commercial rooftops and ground-mounted systems to achieve superior growth as the U.S. utilities become more aggressive with solar PV programs. In the near term, until financing conditions improve, we expect growth to be limited to the small/medium-size rooftop segment. In addition to the traditional markets such as Germany, Italy, and Spain, we expect Japan, China, U.S., Canada, and India to be the key swing markets with potential upside surprise in the 2010-12 timeframe.

Growth strategies

During the first growth phase, the focus of most companies was to procure as much polysilicon supply as possible. During the second growth phase, we expect the focus of most companies to be on identifying end markets for product deployment. To that extent, we expect execution strategies of companies to be defined by downstream acquisitions. Companies with larger contract wins should be able to scale their operations and increase market share. We expect more downstream M&A activity over the next three to five years as companies look to diversify geographically and establish new downstream channels.

There also seems to be potential for strategic alliances to emerge between large-scale solar power developers with strong financial backing and upstream polysilicon players with relatively strong balance sheets. Downstream players will most likely lead the industry transformation as the power development market is localized as inherently more complex industry constraints have shifted from upstream to downstream.

As cell/module players reach efficiency development limits, we expect scale to be the primary cost differentiator, resulting in the emergence of EMS-type business models in the mid-stream segment. Although it is early days yet to identify obvious winners in the race toward market leadership, we expect a combination of business models to dominate the sector over the next three to five years as: 1) midstream players aggressively diversify downstream through power developer M&A; and 2) large-scale downstream companies (there are only a handful at present) strike alliances with upstream players.

About the Author

Vishal Shah joined Barclays Capital in September 2008 as the head of the Cleantech equity research team. Formerly, he was the lead Cleantech equity analyst at Lehman Brothers, covering U.S. and China-based solar stocks. Vishal has been an equity analyst covering solar and semiconductor equipment sectors since 2002 at firms such as Lehman Brothers, Needham & Company, and Morgan Stanley. In 2009, his team received top recognition in the Institutional Investor All America Research Survey. Before joining Wall Street, Vishal worked in the semiconductor equipment industry at Applied Materials. He earned a B.Tech. degree in chemical engineering from the Indian Institute of Technology, Bombay and an M.B.A. from INSEAD, France.

Enquiries

Barclays Capital
745 Seventh Avenue
New York
NY 10019
USA

The cell and module equipment market 2009: a sobering year with a brighter future

John West, VLSI Research, Bedford, UK

ABSTRACT

As 2009 comes to a close, many equipment suppliers are reflecting on the fact that the photovoltaic industry, despite its huge growth potential, can be a brutal place to do business. In the first half of the year many equipment suppliers had the unnerving experience of falling off a cliff, going from record order levels to no orders at all in the space of a few months. This sobering moment served as a reminder that the PV industry needs both access to finance and government support to continue growing. Indeed, it should be remembered that photovoltaics would still only be an interesting technology serving niche markets were it not for government subsidies. Despite orders for equipment declining by over 70% this year, the market for PV cell and module manufacturing equipment is set to grow by 5% to a value of $5.0 billion in 2009.

The one good thing about this year has been the accelerated drop in cell and panel prices. This is bringing ever closer the day when the price of PV generated electricity reaches parity with electricity generated from non-renewable sources and subsidies are no longer required. It is also driving a new round of investment in more efficient manufacturing equipment.

Utilization rates on the way up

Explosive growth in demand for PV cells and panels in the past few years has resulted in a scramble to add capacity. In 2008 the nominal production capacity of the industry almost doubled to 15GWp, yet sales of PV cells and panels only reached 6GWp. Looking at these two figures would give one the impression that the capacity utilization rate for the industry in 2008 was only 40%. However, the 15GWp number represents the nominal production capacity as measured at the end of the year and should not be taken as a true reflection of the actual capacity that was available. A better estimate of the actual capacity for the year as a whole is to take the average of the capacities at the beginning and end of the year. This method gives an average capacity of 11GWp and a utilization rate approaching 55%.

In a rapidly growing industry, however, it is necessary to take the process one step further and calculate the utilization rate on a quarterly basis. By doing this and factoring in ramp-up times, the effective quarterly utilization rates during 2007 and 2008 were in the range of 60% to 80%. These high utilization rates explain why the industry was so desperate to add capacity during this period, as with cell demand growing so fast and capacity utilization so high, manufacturers had

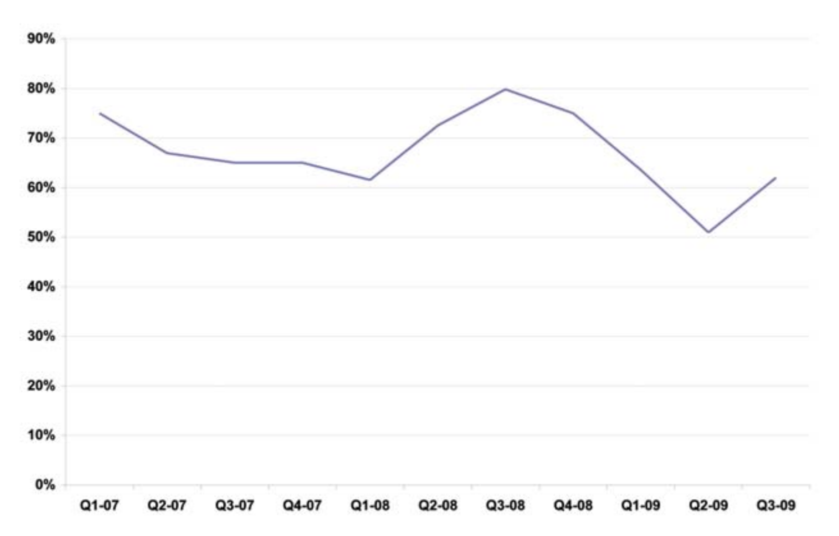


Figure 1. Capacity utilization rates from Q107 to Q309.

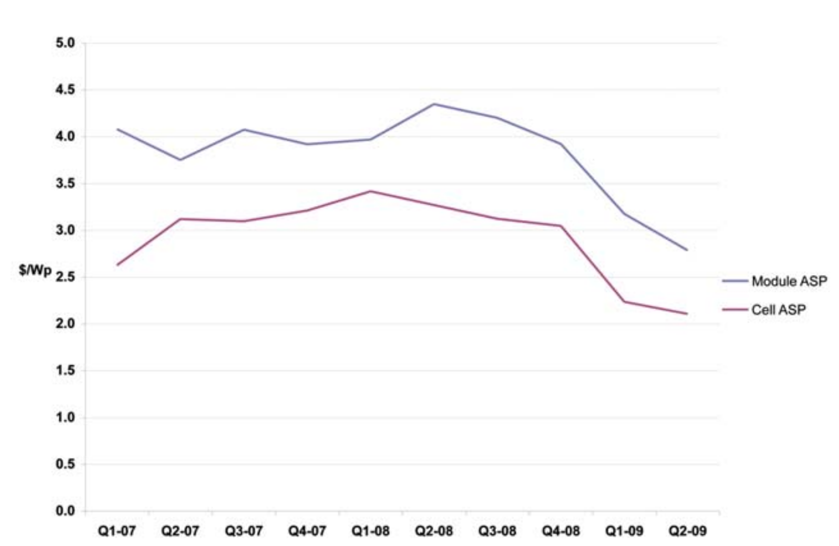
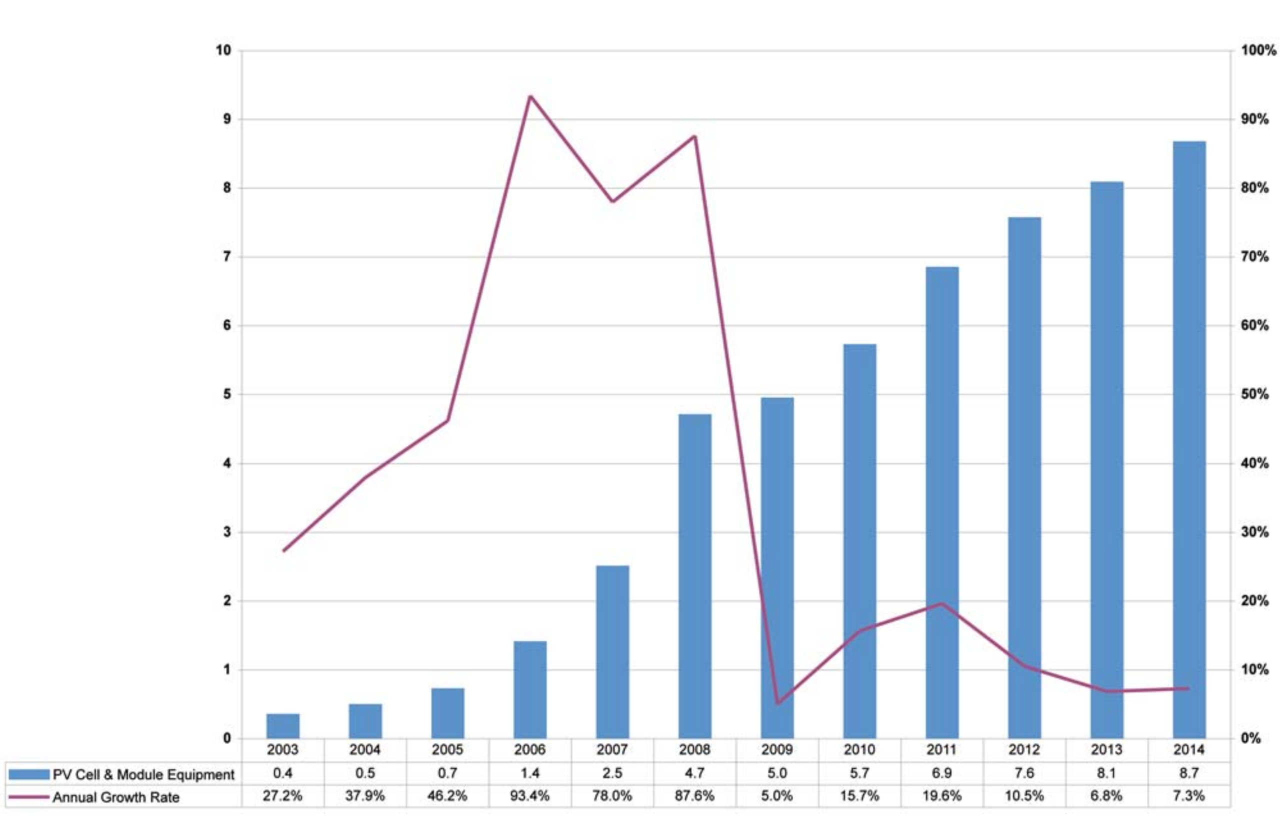


Figure 2. Cell and module prices (data gathered from average prices of publicly listed companies).



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
PV Cell & Module Equipment	0.4	0.5	0.7	1.4	2.5	4.7	5.0	5.7	6.9	7.6	8.1	8.7
Annual Growth Rate	27.2%	37.9%	46.2%	93.4%	78.0%	87.6%	5.0%	15.7%	19.6%	10.5%	6.8%	7.3%

Figure 3. PV cell and module manufacturing equipment market sales (in $Bn) and projected annual growth rates.

to add capacity as quickly as possible or risk hitting 100% utilization within a few months.

"Demand for PV cells and modules has surged in the third quarter of 2009 and utilization rates are now above 60% and rising."

However, the situation in 2009 has clearly changed. Demand for PV cells and modules softened and utilization rates plummeted. In the second quarter, utilization rates fell back to 50% which resulted in an immediate and dramatic cut in capital expenditures causing major problems for the equipment industry. However, demand for PV cells and modules has surged in the third quarter of 2009 and utilization rates are now above 60% and rising. Interestingly, this situation has not yet triggered another round of increased capital expenditures as cell and module manufacturers wait to see whether this is just a seasonal spike in demand or the start of a sustainable recovery.

Prices on the way down

While 2009 looks like being a reasonably good year in terms of MWp shipped, falling prices are causing problems for cell and module manufacturers. Prices have declined by around 35% in the past 12 months and many manufacturers are now selling at prices below production costs.

This state of affairs is unsustainable. Cell and module manufacturers will have to invest in new, more efficient production capacity if they wish to remain competitive. Such a scenario is not new, however. We have already seen this happening as several manufacturers, most notably Q-Cells, have retired older, less efficient capacity. Our initial estimates show that around 4% of the installed base will be replaced or upgraded in 2009, and this percentage is set to rise further in 2010.

Equipment market outlook

Despite orders for equipment declining by over 70% this year, the market for PV cell and module manufacturing equipment is set to grow by 5% to a value of $5.0 billion in 2009. This is a direct result of most companies working through the backlog of orders that were placed in 2008 and getting paid for them in 2009. A further contributing factor is the receipt of revenue for tools that were shipped in 2008 but the revenue only being recognised on the company books in 2009.

This year will be remembered as a period of transition for the PV equipment industry. From 2000 to 2008, the high double-digit growth rates meant that the primary concern was in relation to delivery of equipment. In contrast, falling cell and module prices in 2009 has focused the cell and module manufacturers' minds on new production technology to get manufacturing costs down and cell efficiencies up. This is benefiting those equipment companies that have the research and development resources to develop the next generation of production equipment. It is these companies that have fared best during this difficult period.

"In contrast, falling cell and module prices in 2009 has focused the cell and module manufacturers' minds on new production technology to get manufacturing costs down and cell efficiencies up."

Beyond 2010, it is difficult to predict the trajectory of the equipment industry because demand depends on shipments of cells and modules, which for the time being depend on government subsidies. However, based on cell and module demand growth of 25 to 30%, in terms of MWp shipped, this should drive long-term growth in demand for equipment of around 10-12% resulting in a market value of $8.7 billion in 2014.

About the Author

John West is the managing director of VLSI Research Europe and has been analysing the PV equipment market since 2006. He was awarded an M.B.A. from Cranfield University and has a degree in medical physics from the University of London.

Enquiries
Email: johnwest@vlsiresearch.com
Tel: +44 1234 834666

Photovoltaics International

In our next issue:

Solibro
Trends in CIGS manufacturing

University of Konstanz
UMG a-Si material analysis

GIFI
Italian BIPV market focus

I would like to purchase a subscription.

Price:	1 x Issue	**$59.00 USD**	(includes international delivery)	❑
	4 x Issue	**$199.00 USD**	(includes international delivery)	❑ Please start my subscription with edition ....

Method of payment: ❑ Credit Card ❑ Bank Transfer

Name: ....
Job Title: .... Job Function: ....
Company: .... Div/Dept: ....
Street Address: ....
City: .... Post Code/Zip: ....
Country: ....
Telephone Number: .... Web URL: ....
E-mail: ....
For the purposes of our circulation audit, please indicate the last digit of your birth year (YYYY): ....

Company Activity (tick where appropriate):

❑ PV Manufacturer (inc. Thin Film & Module) ❑ Materials Supplier ❑ Equipment Supplier
If you ticked any of the above three options, please indicate the company technology type by ticking one or more of the boxes below:
❑ Si Cell ❑ Thin Film ❑ Module ❑ Concentrator ❑ Emerging ❑ Polysilicon ❑ Ingot/Wafer
❑ University ❑ Energy Utility Supplier ❑ Government Agency
❑ R&D Facility ❑ Financial Community ❑ Other (please specify..................)

In order to continually improve Photovoltaics International we require your feedback. We would be very grateful if you would answer the following questions:

(Q) Which section(s) of the publication are of interest to you? (please tick)
Fab + Facilities ❑ Materials ❑ Cell Processing ❑ Thin Film ❑ PV Modules ❑ Power Generation ❑ Market Watch ❑
(Q) What technical subjects do you wish to see in future editions? ....
....

Signature: .... Date ....

Payment Details:
Fax on +44 (0) 20 7871 0101 or email info@pv-tech.org:

Type of credit card:
Card Number:
Expiry Date: 3 Digit CVV Code (back of card):
Cardholder's name: ....

Post: Make cheques payable to "**Semiconductor Media Ltd.**"
Photovoltaics International, Trans-World House,
100 City Road, London EC1Y 2BP, UK
Online: PayPal - visit **www.pv-tech.org/shop**

To request an invoice please call on 020 7871 0148
or email: cnorthon@pv-tech.org

Bank Transfer Details:

Account Name:	Semiconductor Media Limited
Account Number:	80686832
Sort Code:	20-39-53
Swift Code:	BARC GB 22
IBAN Number:	GB 42 BARC 203953 80 68 68 32
Bank:	Barclays Bank Plc, 10 Hart Street, Henley-on-Thames, Oxon, RG9 2AX.

All invoices are calculated in Pounds Sterling.
Any payments made in US$ must be made according to the appropriate exchange rate at the time of payment.

Advertisers & Web Index

ADVERTISER	WEB ADDRESS	PAGE No.
24th European Photovoltaic Solar Energy Cooperation EPIA	www.epia.org	47
2BG Srl	www.2bg.it	141
Air Products and Chemicals, Inc.	www.airproducts.com/sunsource2	3
Alconox	www.alconox.com	35
Angstrom Sciences, Inc.	www.angstromsciences.com	91
Atlumin Energy, Inc.	www.atlumin.com	107
ATMvision AG	www.atmgroup.com	17
Bekaert	www.bekaert.com	111
BTU International	www.btu.com	23
Camstar	www.camstar.com	65
Coveme S.p.A.	www.coveme.com	121
CRS Reprocessing Services	www.crs-reprocessing.com	37
DEK Solar	www.deksolar.com	57
Despatch Industries	www.despatch.com	75
ECI Technology, Inc.	www.ecitechnology.com	55
Edwards Vacuum, Inc.	www.edwardsvacuum.com	67
Etimex Solar GmbH	www.etimex-solar.com	125
Eyelit, Inc.	www.eyelit.com	OBC
Festo	www.festo.com	77
GreenPower Conferences	www.greenpowerconferences.com	50, 171
Grenzebach Maschinenbau GmbH	www.grenzebach.com	97
GT Solar, Inc.	www.gtsolar.com	39
Hong Kong Science & Technology Parks	www.hkstp.org	11
J.A. Woollam Co., Inc.	www.jawoollam.com	89
J. Schmalz GmbH	www.schmalz.com	79
Jinko Solar Co., Ltd	www.jinkosolar.com	119
Kipp + Zonen B.V.	www.kippzonen.com	153
Komax Solar	www.komaxsolar.com	93
KUKA Systems GmbH	www.kuka-systems.com	8, 9
Leybold Optics Dresden GmbH	www.leyboldoptics.com	103
Linde Group	www.linde.com/electronics	31, 33
M+W Zander FE GmbH	www.mw-zander.com	19
Manz Automation AG	www.manz-automation.com	IFC
Meco Equipment Engineers B.V.	www.meco.nl	61
Messe Dusseldorf GmbH	www.messe-dusseldorf.de	45
Mettler Toledo	www.mt.com/thermalexcellence	139
MRL Industries	www.mrlind.com	69
Neptun Srl	www.neptunglass.com	123
Noppen (Shanghai) Co., Ltd.	www.noppen.com.cn	175
P.Energy S.p.A.	www.penergy.it	143
PCO Imaging AG	www.pco.de	137
Prediktor	www.prediktorsolar.com	135
Regional Growth Partnership	www.rgp.org	13
Rena GmbH	www.rena.de	73
Robert Bürkle GmbH	www.burkle-gmbh.de	145
Romag Ltd.	www.romag.co.uk	165
Satcon Technology Corporation	www.satcon.com/solstice	149
SEMI	www.semi.org	124
Sensovation AG	www.sensovation.com	133
SENTECH Instruments GmbH	www.sentech.de	105
Sindlhauser Materials GmbH	www.sindlhauser.de	101
SNEC PV Power Expo	www.snec.org.cn	81
Solutia, Inc.	www.saflex.com	131
Spire Solar Corporation	www.spiresolar.com	25
System Photonics S.p.A.	www.system-photonics.com	163
Targray Technology International, Inc.	www.targray.com	109
Technic, Inc.	www.technic.com	59
Testbourne Ltd.	www.testbourne.com	106
Umicore Thin Film Products	www.thinfilmproducts.umicore.com	105
VAT	www.vatvalve.com	99
Von Ardenne	www.vonardenne.biz	113

To advertise within Photovoltaics International, please contact the sales department: Tel: +44 (0)20 7871 0123

PV cell handling that avoids turning wafers into pieces of bacon

Photo courtesy of Applied Materials

Charles Gay, President, Applied Solar.

Charlie Gay has been thinking about the thinness of solar wafers since his days as a Ph.D. researcher at Spectrolab. When he was offered the job to run the research group at Arco Solar nearly 30 years ago, Gay told Bill Yerkes that he needed a few months to finish a job involving a particular kind of thin silicon cell for the space program before he could join the new company. At least that's how Yerkes remembers it in an archival video interview I have a copy of, a small part of many hours of conversations with PV pioneers compiled by the late Mark Fitzgerald, the founding editor of the original *Photovoltaics International* journal.

Gay has come a long way from his days as that "young, unknown guy," including stints as head of Arco and then when it became Siemens Solar, director of NREL, and now as president of the Applied Solar branch of Applied Materials. But as one of his comments at a recent briefing revealed, he has not stopped pondering that thin solar stuff.

I asked Charlie about the extendibility of mechanical wafer handling, especially during screen printing, and at what point the advent of ultrathin wafers might prompt a different automation approach to be taken.

"There's a couple of creative ways that you can work with very thin wafers," he started. "One of the things that's probably most important to keep in mind here that we lose sight of is that a thin wafer being moved at a high speed flaps, it moves. What takes time is for the wafer to stop moving, not so much to be able to put the wafer in a particular location or how to hold it in a particular location.

"So much of the handling capability first is how to move that 4000 wafer-per-hour target, how to do that with breakage rates that are less than one in 10,000…that 0.01% that we've been able to demonstrate, (such as) doing it without contacting the wafer using Bernoulli chucks in positioning the wafer.

"The process applied to that wafer is one in which… the nature of silicon is such that it is a relatively low temperature coefficient of expansion material, and when you put a metal on that wafer that has a very different expansion coefficient, you can turn that wafer into something that looks like a piece of bacon," he quipped.

Photo: Lauri Patterson/iStockphoto

"So we want to try and keep the wafers flat, we want to be able to keep them from flapping around while they're moving.

"What's very exciting here is that with the advanced platforms, we're basically integrating the lithography aspects of this business with the automation, so that the tolerances that are really desired for maximizing efficiency, those are in the order of 10 microns or so. For us, we tend on the IC side to say let's get down to 22 nanometers or 18 nanometers – 10 microns is where that sort of plateau of performance exists with the various forms of crystalline silicon. And that platform which can handle thicknesses ranging anywhere from 80 microns to 180 microns, hitting that tolerance, and then bringing a tool platform that doesn't leave residual stress in the wafer, so it can continue on to the next station.

"Those are the elements that are now coming to the foreground of planning…the factory of the future – it's almost here today," he concluded.

The research community is hard at work investigating subsystems that will help make Gay's future-factory vision a reality. A team from Fraunhofer IPA in Stuttgart has begun analyzing different thin-wafer handling methods, with a focus on the various types of grippers. A paper presented at the recent EU PVSEC discusses the elements of the group's "thin-wafer gripper test bed" and offers some initial results from the testing platform.

The early test results noted "a high throughput achieved with high velocity and high acceleration results in less optimal performance," yet for most of the grippers, especially those using the Bernoulli principle, "a higher cycle time results in better positioning accuracies."

As for the air consumption during pick/place/transport moves, the paper states that "in general, the analyzed grippers with the bigger contact spot achieve equal results with obvious lower pressure. But then, during the place operation, the bigger area of the gripper often leads into a higher unregulated dynamic vacuum. Caused by this vacuum, the just-placed wafer gets sometimes sucked by the gripper and moves again slightly away from the planned end-position. The dimension of the dynamic vacuum depends on the scheduled stop time (<200ms) for the placement, the design and finally the material of the gripper surface."

The team believes that one way to deal with this problem is "a special blowoff functionality during set-down which is provided by one test gripper."

Evaluations of small-area grippers revealed that they had difficulty handling the wafers with a soft touch, according to the paper. A high-speed camera caught "a mechanical vibration with an enormous bow" in the wafer. (And we know that a bowing, flapping wafer is not always a happy wafer.) But the team has yet to determine the "consequences of these vibrations," needing further analysis to get to the root cause(s) of the phenomena.

Ultra-thin-wafer handling may not be the sexiest topic in the advanced solar-cell process pantheon, but for crystalline silicon to continue to progress down the PV tech roadmap, it's one that demands concerted efforts in the institutional and corporate research communities. Someone needs to bring home the bacon.

This column is a revised version of a blog that originally appeared on PV-Tech.org.

Tom Cheyney is Senior Contributing Editor (U.S.) for the Photovoltaics International journal and writes blogs for PV-Tech.org.

Scalable manufacturing software for the Solar Industry

Lower your manufacturing costs with scalable manufacturing software from Eyelit.

Eyelit continues to work with many solar manufacturers by providing scalable manufacturing execution system (MES), automation and quality management solutions that can be quickly implemented at manageable costs and lower total cost of ownership. Eyelit's product suite provides the features required to cost effectively ramp to high-volume production. Eyelit is the one vendor that can supply factory automation, data collection, traceability, lean manufacturing, executive dashboards, quality management (APC, CAPA, SPC, non-conformance, RMA) , equipment maintenance and material management to enable solar companies in identifying, maintaining and continually improving product, processes and equipment utilization while driving down overall manufacturing costs.

eyelit

www.eyelit.com