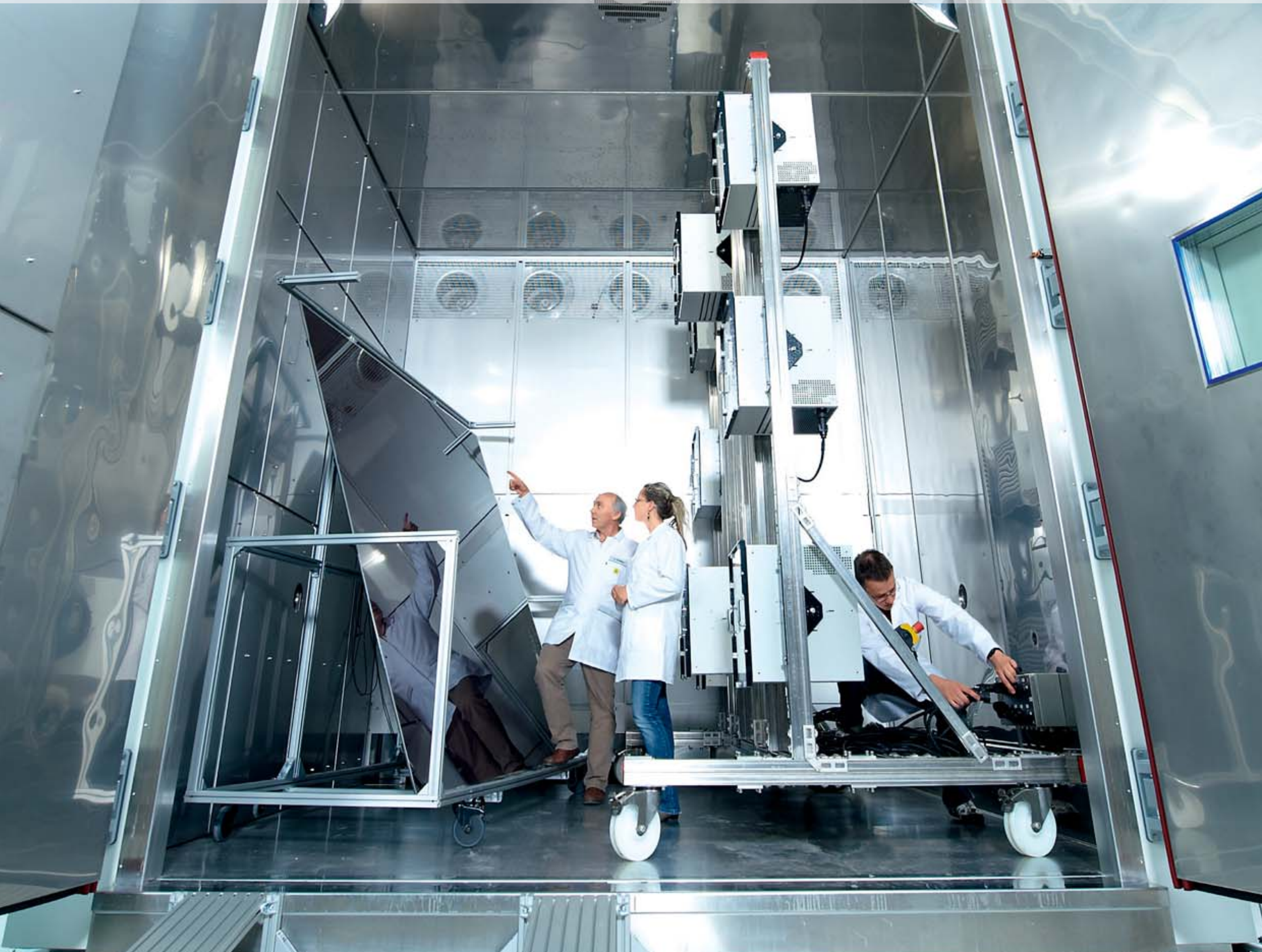
Eleventh Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS

TU Freiberg: challenges of the wire sawing process
China Sunergy: study of dark lines on mc-Si solar cells
UNSW: mass-produced LDSE cells to reach 22% efficiency
Module focus: Fraunhofer CSP, SunPower & Heriot-Watt University
Jacobs University: light trapping in nanotextured thin-film silicon cells



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Cover image shows large climate chamber meeting specifications of IEC 61215. Image courtesy of Fraunhofer CSP; copyright Juergen Jeibmann Photographik.

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Publisher's foreword

As another year of planned record PV deployments (c.20GW) gets underway, several European countries have implemented steps to prevent the industry running away with itself entirely. With the governing bodies behind industry behemoths Germany and Spain planning on revising downwards their incentives schemes for solar power installation, it appears that the massive uptake in PV-related energy sources has resulted in some countries identifying potential revenue pitfalls further along the line.

However this potential downside is so far being offset by the clearly apparent good news: so effective are the technology developments in this industry that lowering of module and BOS component prices are maintaining margins throughout the supply chain. Once again rapid technology deployment is maintaining strong cost competitiveness in the PV industry.

We're featuring a special focus on all things PV modules in this edition of *Photovoltaics International*. SCHOTT Solar's lifetime and reliability group carries out an investigation into the effects of environmental ammonia on the lifetimes of PV modules (p.112), while Fraunhofer CSP performs a study of the effects of encapsulation polymers on module reliability (p. 118). Continuing on the encapsulation theme, Heriot-Watt University presents findings of its studies into the feasibility of decreasing the short-wavelength EQE via luminescent down-shifting in mc-Si PV modules (p.104). SunPower Corp. closes the loop and applies failure models and effects analysis to the manufacturing process, while our regular module spot market piece provides data on the markets for the whole of 2010.

A contribution that is sure to generate interest among our readership is the requirements of grid-connected PV inverters (p.149). A special 10-page study by TU Bergakademie Freiberg (p.36) on the challenges associated with the wire-sawing process provides a comprehensive overview of this vital manufacturing step, while China Sunergy's study of dark lines (p. 64) and UNSW's study of LDSE solar cells (p.56) deliver some must-read material for those involved in cell production.

We have gathered together some of the more pressing news in regard to global FiT developments on page 158, as well as our regular feature from the Blog pages of PV-Tech.org. If you haven't already seen our newly designed website, be sure to check it out and send us your comments on the look and feel of the site.

At the SNEC show in China, we launched the latest in our range of technical annuals, *Manufacturing the Solar Future: The 2011 Production Annual*, which at a hefty 456 pages compiles over 50 technical papers from the pages of the *Photovoltaics International* journals over the years, as well as product reviews, company profiles and a comprehensive glossary of terms. You can get your copy from our website.

As usual, the *Photovoltaics International* team will be attending several PV industry events worldwide this year, and we hope to see you there. We would like to thank all of our contributors, advertisers and advisory board members for their support, and look forward to a prosperous year for the industry.

Enjoy the read!

Síle Mc Mahon
Managing Editor
Photovoltaics International

Photovoltaics International

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

Editorial Advisory Board

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

Gerhard Rauter, Chief Operating Officer, Q-Cells SE

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

Takashi Tomita, Senior Executive Fellow, Sharp Solar

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

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

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

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

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

Dr. Zhengrong Shi, Chief Executive Officer, Suntech

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

Dr. John Iannelli, Chief Technology Officer, Emcore Corp

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

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

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

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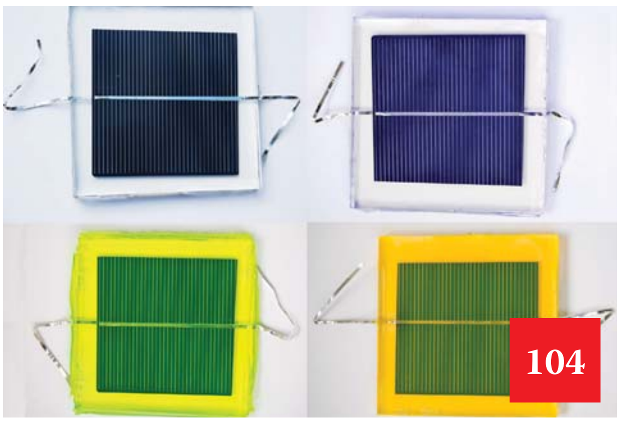
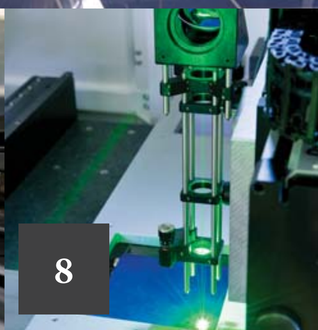
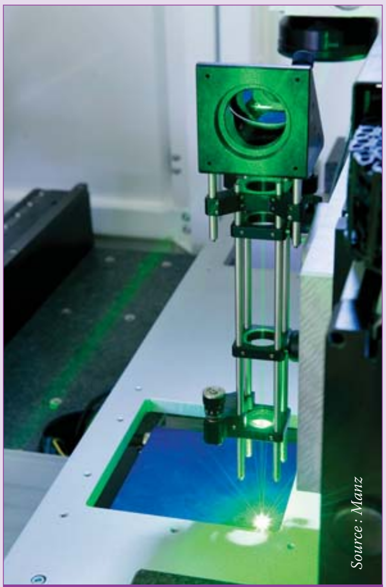


Fab & Facilities



News

Manz Automation to build new Chinese factory



Manz's laser multitool.

Manz Automation has broken ground on a new production, technology, and training facility in Suzhou, China. The factory will manufacture equipment for the photovoltaics, FPD and PCB industries, with 50% devoted to solar tools. The building will be finished by the end of this year, with production machinery installed early next year and the initial production ramp planned for February 2012.

The first phase of the facility, which will be located in the Suzhou New Area Science and Technology Industrial Park, will feature about 20,000m^2 of cleanroom and other manufacturing space, with another 7,000m^2 devoted to offices. Manz purchased nearly 67,000m^2 of property at the site and said it has enough room for future expansion.

The company said it plans to hire 600-700 staff for the new factory. With most of its customers now in Asia, Manz has existing facilities in Suzhou and Taoyuan, Taiwan, which employ 800 of its 1,750 global workforce.

In a press conference at the SNEC Exhibition in Shanghai, CEO Dieter Manz said that the initial PV tools to be produced at the Suzhou site will be automation and other more mature equipment, but not any of the company's latest technology, which will continue to be manufactured in Germany. He cited intellectual property concerns, noting the importance of protecting key company trade secrets.

During the press conference, Manz officials also discussed recent developments in both the crystalline-silicon and thin-film sectors. The company offers a selective-emitter solution for c-Si cells developed at and exclusively licensed from the University of Stuttgart, which incorporates its high-precision laser process technology.

CEO Dieter Manz said that based on multiple tests with customers, it would increase absolute conversion efficiency by 0.5%. He also claimed the approach offered the lowest cost of ownership on the market, largely because it was a single-step process that used no consumable materials such as pastes. The company's studies show that by deploying the laser-based SE technology in conjunction with its high-speed, high-accuracy screen printer, a 60MW cell line would bring in an additional €2 million in revenues based on the efficiency enhancement.

Capacity News Focus

CIGS PV firm SoloPower lands conditional DOE loan guarantee of US$197 million to fund production ramp

CIGS thin-film photovoltaics manufacturer SoloPower has received a conditional commitment for a US$197 million loan guarantee from the U.S. Department of Energy Loan Programs office. The company said the funds will support construction of a flexible thin-film module manufacturing facility in Wilsonville, Oregon, that, when completed and at full capacity, is expected to have an annual capacity of approximately 400MW.

The San Jose-based company, which has also received a generous package of local and state incentives, recently announced plans to build its first large-scale factory in the Portland suburb. Retrofit of the existing building is scheduled to begin in the second quarter of this year.

The thin-firm said the initial 75MW production line should be in operation by the end of 2011.

Once up and running at full capacity, the facility is expected to provide direct employment to approximately 500 people, and represent a total investment of about US$340 million. About 270 construction jobs will be created to build the plant, in addition to other jobs likely to be generated in the local supply chain.

SoloPower's lightweight, flexible copper-indium-gallium-(di)selenide modules have been UL and IEC certified and are rated at up to 260Wp per panel, with 12.1% peak conversion efficiency verified by NREL. Small-volume sales are in progress to customers in five countries, according to the company.

The DOE loan guarantee program has issued nearly US$18 billion in conditional or final commitments for 19 (corrected amount) clean energy projects. SoloPower becomes the third PV company to receive a conditional or final loan commitment from DOE for the purpose of building a volume production facility, the other two being tubular CIGS company Solyndra (US$535 million) and CdTe module manufacturer Abound Solar (US$400 million).

MEMC and Samsung Fine Chemicals to build polysilicon plant

MEMC is to establish a new joint-venture firm with Samsung Fine Chemicals to produce polysilicon for the PV industry. The agreement between SFC and MEMC's affiliate, MEMC Singapore, includes building a 10,000MT plant in Ulsan, South Korea, close to an SFC chemical plant. Production ramp is targeted for 2013.

In a research note discussing the move by MEMC to partner with SFC on polysilicon production, Jeffries financial analyst Jesse Pichel estimated the total investment for the new plant would be approximately US$1 billion. MEMC's equity contribution was estimated to be 25%, while 25% would be allocated to Samsung and 50% would be bank debt to the JV. MEMC's direct contribution will only be around US$250 million.

Volume production starts at world's largest CIS thin-film module plant

Showa Shell Sekiyu subsidiary Solar Frontier has begun the commercial ramp of its new advanced, fully-automated CIS (copper, indium and selenium) thin-film solar module production plant, located in Miyazaki, Japan. Initial production capacity is claimed to be 600MW and it expects to reach a nameplate capacity of 1GW in 2012.

Solar Frontier is one of the few thin-film manufacturers to have the capacity to match thin-film leader, First Solar. Although not housed in a single manufacturing plant, the complex is the first to be built and operated with a 1GW capability. The plant broke ground in September 2009 and cost approximately US$1.2 billion.

All the products manufactured at the plant have obtained the relevant certifications for performance and safety by Japanese and European standards organizations; U.S. certifications are expected shortly.

Hanwha SolarOne to build 2GW solar cell and module complex

Hanwha SolarOne is set to build a 2GW cell and module complex in Jiangsu Province, China with the help of Nantong Economic and Technological Development Zone. Phase one of the project will see a 1GW complex built at a cost of US$500 million.

The complex will be located just north of Hanwha's Shanghai headquarters, and in close proximity to its manufacturing base in Qidong, which is also one of the 10 largest sea ports in China. This location will enable management and manufacturing resources to be shared, thus lowering production costs and providing a competitive cost edge over the company's major competitors.

Previously outlined production capacity expansion plans for 2001 included increasing ingot capacity from 360MW to 510MW and wire saw capacity from 400MW to 572MW. Solar cell capacity will also be increased from 550MW to 820MW.

Recently, Hanwha SolarOne signed a new long-term wafer and polysilicon supply contract with GCL-Poly, which will provide 2,500MW of wafer and polysilicon products from January 2011 until December 2015.

Source: Hanwha/Solarfun

Hanwha cells during the manufacturing process.

Schott Solar increases module production capacity to 800MW, sets up joint venture with Hareon Solar

After examining its results for the past fiscal year, Schott Solar has decided to increase its global PV module production capacity to 800MW in 2011. To help facilitate its wafer capacity expansion, Schott has formed a joint venture with China-based Hareon Solar Technology. The first phase of the JV will add 300MW to Schott's module manufacturing capacity at its existing New Mexico and Czech Republic facilities.

Fab and Facilities Order Focus

3S Modultec sells production line to Lithuanian firm

3S Modultec has increased its presence in the Eastern European solar market by selling one of its integrated production lines to Lithuanian firm MG AB Precizika. The 38MW facility will manufacture crystalline panels for projects in Eastern and Southeastern Europe, and will be the first of its kind in Lithuania.

The TÜV Rheinland-certified manufacturing line will be installed in the Baltic state this spring, with production beginning a few months later.

Flextronics to provide electromechanical design services to CSP developer eSolar

Flextronics and eSolar have signed a deal that calls for the former to provide electromechanical design capabilities to the concentrating solar thermal power plant developer. Flextronics will focus its design services efforts relating to eSolar's next-generation heliostats and solar collector systems at its Plano, Texas location.

Flextronics works with a growing number of customers across the various segments of solar manufacturing value chain, including Q-Cells, SunPower, Enphase, Amonix and Petra Solar.

ZBB Energy lands order for energy storage unit from Chinese solar manufacturer

ZBB Energy has acquired a contract with a China-based solar manufacturer for its ZESS V3 energy storage technology. Furthermore, ZBB will also be supplying its ZESS POWR PECC and ZESS V3 to an unnamed petrochemical producer.

The sizes of the orders and customer names have been withheld until all commercial agreements are finalized.

Poly Plant Project to offer technology, tools for Shansheng New Energy plant

Poly Plant Project (PPP) will be working with Baotou City Shansheng New Energy for the delivery of a basic engineering package (BEP) and key equipment packages for the polysilicon production plant. Once work on the polysilicon plant has been completed, Shansheng New Energy will have its own coal and quartz mines, a coal-fired power generation plant, MGSi production, polysilicon production, ingot pulling, cell and module production lines and PV power generating installations.

Over the next few years, Shansheng New Energy will be expanding its polysilicon production from its current 3,000MTY to 18,000MTY as well as ramping up their module production from its current 200MW to 1GW.

The BEP provided by PPP will include a cold conversion hydrogeneration process for TCS production, TCS purification, polysilicon deposition and chlorosilanes recovery and neutralization. PPP will also supply Shansheng New Energy with a complete package of key specialty equipment for TCS production, polysilicon deposition and other heat recovery and transfer equipment.

Additionally, PPP's field services team will offer project management, construction and installation support, commission and startup support, ramp-up to reach nameplate capacity as well as ensuring the plant is in working order and at its prime service level. Finally, PPP will be offering a set of guarantees, which include the plant's polysilicon output and the purity of the polysilicon material produced by PPP's process technology and equipment.

Both companies will be equally represented in the JV. Schott will oversee the management positions necessary to upkeep its quality and reliability at the manufacturing site and is developing a special center on quality assurance to be located in China.

Schott also plans to double its wafer production capacity at its German facility to 500MW during 2011. The number of employees at the plant will be increased to help support the expansion.

AUO Optronics to build 300MW wafering plant in Taiwan

A subsidiary of AUO Optronics has broken ground on its first multicrystalline ingot and wafer production plant in Taiwan's Chungkang Export Processing Zone. The first-phase expansion plan by AUO Crystal Corp (ACC) is to build wafering capacity of 300MW. Financial expenditure details were not provided.

Though AUO Optronics has a JV manufacturing agreement with SunPower, the plan is to offer wafers for external sale. SunPower uses monocrystalline wafers for its high-efficiency cells. ACC expects approximately 1,000 jobs will be generated at the facility over the next three years.

The facility is expected to be operational this year. The equipment move-in is scheduled to take place in August 2011 with mass production planned in the fourth quarter of this year.

Gestamp Renewables to construct steel factory in Surprise, Arizona

Gestamp Renewables has unveiled plans to build a 27-acre Solar Steel factory at the Skyway Business Park in Surprise, Arizona. The new facility will include a steel fabrication factory and the U.S. headquarters for Gestamp Solar Steel.

The factory's first phase will cover 75,000 square feet, with the possibility of a phased expansion over time that would include added manufacturing capacity. The Arizona plant will fabricate steel structures for customers, which includes BrightSource Energy and its 392MW Ivanpah Solar project. The Solar Steel factory intends to manufacture steel structures for both CSP and PV solar projects.

Schmid to build manufacturing plants alongside Xinjiang Puxing Chengda

Schmid Silicon Technology has agreed to build two solar manufacturing facilities with Chinese firm Xinjiang Puxing Chengda. Contracts for the 3,000-tonne polysilicon factory and the integrated cell and module factory were signed by the two firms shortly before the start of the SNEC exhibition in Shanghai.

The Chinese company will reportedly invest a total of RMB10 million (US$1.5 billion) in building a PV industrial park and solar production base, which will include a total silicon capacity of 15,000 tonnes, 2.5GW of solar cell and module production, and a 500MW thin-film line.

Kyocera taking module capacity to 1GW as new plants in Europe and China get go-ahead

Kyocera is building new PV module assembly plants in the Czech Republic and China, which, when combined with existing facilities, will see Kyocera's capacity reach 1GW in early 2013. The expansions at the two new plants will add another 620MW to nameplate capacity.

Kyocera has recently started construction of its second solar module assembly plant in the Czech Republic, which is being built close to its existing facility and is set to be completed in late 2011. The addition of another 360MW of capacity will push annual production capacity to 560MW.

At the company's Chinese site in Tianjin, existing production is being shifted to a new, larger facility, which is scheduled to be completed this spring. When the new plant is fully ramped, it is expected to have a nameplate capacity of 360MW.

First Solar completes 238MW German manufacturing facility

First Solar has moved a step closer to doubling its production capacity in Germany by completing work on its new factory in Frankfurt, Brandenburg. Construction work on the manufacturing facility cost €173 million, took just 12 months to complete and has boosted First Solar's overall annual module capacity to 477MW.

The factory itself, which is partially powered by a PV roof installation, will manufacture 238MW of modules each year and create 500 jobs in the region. Production is scheduled to begin in June 2011.

The Frankfurt plant expansion is the latest stage in First Solar's plan to increase global production capacity to 2.7GW by 2012.

Source : First Solar

The new manufacturing facility will be situated close to First Solar's Frankfurt offices.

Lanco Infratech to build new manufacturing facility in India

Lanco Infratech has unveiled plans to build a manufacturing facility in Rajnandgaon, India to produce purified silicon, cells, modules and polysilicon. The first phase of the project will cost around INR13.7 billion (US$300 million) and production is scheduled to begin in 2012; annual capacity of the plant is 250MW.

The plant will be located within a special economic zone in the state of Chhattisgarh, which has been established to promote trade and investment through a mixture of tax incentives, tailored infrastructure and other government support.

The company's Lanco Solar Holdings unit also builds projects and provides construction and contracting services. Over the next two years, the holding company plans to add 300MW to its own solar thermal and PV portfolio and provide contract work totalling around 500MW for plants in India, Europe, the U.S. and Canada.

Lanco Solar has also signed power purchase agreements for a 5MW PV plant and a 100MW solar thermal plant in Rajasthan, and a 35MW PV plant in Gujarat state.

Aide Solar breaks ground on second phase of Chinese production facility expansion

Aide Solar is to add 2GW of module capacity to its Xuzhou facility in China, with a 947,228 square foot expansion of the site. The second phase of expansion at the company's existing 1 million square foot poly- and monocrystalline solar cell and PV module production factory begun in late January and is expected to be completed in Q4.

Once construction is completed, Aide Solar plans to convert the present Xuzhou facility into a dedicated cell manufacturing facility,

Source : Aide Solar

The expansion of Aide Solar's Xuzhou facility will be completed in Q4 2011.

which will pave the way for the company to expand cell production when the need arises.

Power-One opens 1GW facility inverter production facility in Phoenix

Power-One's opening celebration for its Phoenix-based wind inverter manufacturing facility brought out not only the company's CEO, but State and city officials as well, who came together to sign the front panel of the first 100kW central inverter. The 122,000 square foot plant, which will have a 1GW production capacity by the end of this year, actually began its operations in October 2010 with 40 employees. In time, the new facility will not only expand its employee base to 350 people, but also its site capacity, which is capable of holding 4GW.

Sharp's Wrexham factory expansion creates 300 jobs

Sharp UK is to double annual capacity at its manufacturing plant in Wrexham, UK, creating 300 jobs in the process. The expansion will increase capacity to 500MW and has been described as excellent by Chris Huhne, the U.K.'s energy and climate change secretary.

Sharp's £20 million expansion was unveiled during the summer and will be completed in March; daily panel production is set to rise to 8,000. With a total workforce of 1,100, the company is now the UK's biggest employer in the renewable energy sector.

Princeton Power Systems opens new inverter, energy storage production facility

Princeton Power Systems (PPS) has opened its new Princeton, New Jersey facility, which will manufacture inverters and energy storage systems for the alternative energy divisions. In addition to housing PPS's military-qualified variable speed drive product, the 10,000-square foot facility contains floors that are qualified for assembling 90" inverter cabinets. The new facility boasts various labs, including an inverter test lab, a printed circuit board lab and a variable speed drive test and assembly lab.

Among the high-power distribution room, machine shop and offices that the New Jersey facility accommodates is a compliance test lab, which is set to give PPS the ability to certify compliances through TÜV, CSA and other agencies. The lab will incorporate value-stream mapping, leveraging technology and a corrective action process to augment the efficiency and improve test and manufacturing capabilities.

CIGS thin-film company SoloPower chooses Oregon as site for first volume production facility

SoloPower has become the fourth CIGS thin-film photovoltaics manufacturer since the beginning of the year to select a site for its volume production facility. The San Jose-based company has chosen Wilsonville, Oregon, where it plans to build a 75MW plant and create 170 new jobs as part of its initial phase of expansion. SoloPower made its decision in part because of a package of local and state incentives that includes at least US$40 million in potential loan and tax credit monies.

Once the flexible CIGS module facility is completed, it will have four production lines with a cumulative nameplate capacity of 300MW and eventually will employ around 500 people, the company says. The planned total investment will be approximately US$340 million.

The incentives offered to SoloPower include a US$20 million loan from the Oregon Department of Energy, which was recommended for approval by the Small Scale Energy Loan Program advisory committee. The company has also applied for a Business Energy Tax Credit of another US$20 million from the state.

Source : Sharp

Sharp Solar's Wrexham manufacturing plant

Suntech doubles Arizona plant's operating hours

Suntech Power's new solar panel manufacturing facility in Goodyear, Arizona will now run for twice as long every day as it attempts to ramp up its annual production capacity to 50MW. The 117,000-square foot site, which produces Suntech's 280W panels, will now run for up to 16 hours a day and employ 78 staff.

When it opened last October, the Arizona facility had just 40 employees and operated for eight hours a day. However, thanks to the ever-increasing demand for panels across North America, Suntech is already planning for further expansions, and it hopes the site will eventually have a workforce of more than 150 and an annual production capacity of 100MW.

Ceradyne opens new crucible plant in China to meet solar wafer demand

Just three years after starting production of its high-purity ceramic crucibles, Ceradyne has opened its second factory in Tianjin, China. The 218,000-square-foot site cost an estimated US$34 million and will help meet increased wafer demand from China and Asia-based PV manufacturers.

Steed Technology plans to expand gas abatement solutions selection with acquisition of ATSI

Steed Technology recently completed the full acquisition of outstanding stock for Applied Technology Specialists (ATSI). Steed has confirmed that manufacturing of all products will remain in Northern California, while research and development will continue in Oklahoma. Both companies will now operate under the Steed name.

The acquisition of ATSI allows for Steed to increase its offering of gas abatement solutions with the ATSI EcoGuard line


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

of "Point of Use" product. Furthermore, as environmental regulations are forcing companies to pinpoint ways that increase the effectiveness and efficiency of their abatement systems, Steed will rely on the ATSI team in consulting and solutions for companies looking to meet the environmental requirements.

centrosolar to expand c-Si module production under TSMC agreement

The world's largest semiconductor foundry, TSMC, has entered into a five-year c-Si module subcontract agreement with centrosolar. Financial terms were not disclosed. The deal marks TSMC's entry into c-Si cell production beginning in the third quarter of 2011, when centrosolar will produce modules for TSMC at a new manufacturing plant extension to be built at its existing plant in Wismar, Germany. The modules will be marketed by TSMC within Europe. The exclusive supply contract is worth 100MW per annum.

To meet the needs of TSMC, centrosolar will expand module production to as much as 500MW annually, up from its current level of 200MW. A new production hall and warehouse will be constructed at its existing production site in Wismar, Germany.

The first phase, which is expected to be completed by the third quarter, will add an additional 150MW of module capacity and provide an additional 300 jobs at centrosolar at a cost of approximately €20 million. It will be financed from the company's own cash flow as well as through subsidies and bank loans.

Source : Centrosolar

A centrosolar module during the manufacturing process.

Demand for PVA material in Europe forces resin production expansion at Kuraray

Kuraray is to increase resin production of PVA (polyvinyl alcohol) at its European subsidiary Kuraray Europe to meet demand across Europe. An investment of €58 million will see production expanded by 24,000 tonnes per annum, up from existing production of 70,000 tonnes per annum at its plant in Frankfurt, Germany.

The capital investment includes measures for an energy optimization project. Expansion will come on-stream in the second quarter of 2013.

3S Modultec helps to build Senegalese production factory

3S Modultec has agreed to help the Senegalese solar power company SPEC build West Africa's first solar panel factory. The Dakar facility is scheduled to be operational by the middle of 2011 and will produce TÜV-certified panels for the African market.

3S Modultec is not only providing SPEC with a 15MW production line – with the potential to expand to 25 MW – but also training and maintenance services for the factory; the Swiss firm will also supervise the SPEC team during the planning, ramp-up, launch and certification phases.

CIGS cell maker AQT Solar picks South Carolina as site for second production facility

Lured by a package of lucrative state incentives as well as what it saw as favourable workforce, educational, infrastructure, and business climate factors, CIGS thin-film photovoltaic cell manufacturer AQT Solar has chosen Richland County, South Carolina, as the location for its second manufacturing facility after a year-long site selection process. The company expects to begin production in its new factory by the beginning of 2012, with phased expansion continuing through 2014 that will eventually account for the creation of some 1000 jobs.

The AQT news marks the third announcement of production site selections by CIGS companies in the past week, following those of W Solar (Wisconsin) and Stion (Mississippi). Located in the Carolina Pines development zone in Blythewood outside Columbia, the 184,0000-square-foot building that will house AQT's copper-indium-gallium-(di) selenide PV cell manufacturing facility is LEED Silver certified and has been unoccupied since its completion in 2009.

Stion to build CIGSSe thin-film solar module production facility in Mississippi

CIGSSe photovoltaic module manufacturer Stion said it will build a new production facility in Mississippi as part of an incentive agreement with the state that includes a US$75 million loan and other tax and training incentives. The project, which will be the first thin-film solar panel factory in Mississippi, will deliver more than 1,000 jobs and US$500 million of investment over the next six years.

The first phase of the project features a 100MW line planned for Hattiesburg, which will include more than US$100 million of investment and 200 direct jobs in 2011 and 2012, according to Stion.

In June 2010, Stion closed a US$70 million Series D financing to help scale production, which included a partnership with leading semiconductor foundry, TSMC. The company's initial manufacturing and R&D facilities are located at its headquarters in San Jose.

The company's current product line features monolithically integrated, 65cm × 165cm glass-glass, copper-indium-gallium-sulfide-(di)selenide modules, with 11%+ conversion efficiencies and power ratings of 110-120W.

Southwest Solar Technologies completes first stage of Phoenix solar park

Southwest Solar Technologies (SST) has completed the first stage of its solar park in Phoenix, Arizona. The focal point of the 18-acre facility is a 75-foot-wide solar dish, which plays a key role in SST's solar dish turbine technology. SST is also looking for assistance for further development of the park and has also opened discussions with several potential partners, according to CEO Brad Forst, including Arizona's government, universities and private businesses.

Source : SST

SST's 75-foot wide dish forms the focal point of its Phoenix solar park.

Tonsan opens world's largest PV sealant factory

Tonsan, one of Asia's leading PV sealant and potting compound manufacturers, has officially opened the world's largest sealant factory in Suzhou County, China. The opening ceremony, which was held on December 17th, was attended by industry luminaries, including Zhao Yu Wen, chairman of the Chinese Renewable Energy Society, and Guang Chun Zhang, senior vice president of Suntech.

The 1 million-square-foot plant is equipped with the latest research tools and sealant technology and features a full-scale applications laboratory and long-term reliability test centre.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Other News Focus

Schmid expands automation offerings with new acquisition

The Schmid Group has bought montratec, a spin-off from Swiss firm Montech, as it looks to improve its technology and services within the automated transportation systems (ATS) sector. montratec specialises in the manufacture, development and marketing of ATS and the acquisition will facilitate Schmid's proposed move into the optical, medical and automobile industries.

The manufacturing, development and marketing arm of montrec will remain independent, while installation and after-sales service will be handled by the Schmid Group's service stations.

Pfeiffer Vacuum increases sales to €220.5 million in 2010

Preliminary financial results for Pfeiffer Vacuum show the company has increased its year-on-year sales revenues by 21.1% to €220.5 million in 2010. A strong fourth quarter in sales led to higher than expected overall business, the company noted.

The orders received for the 2010 financial year total €223.7 million, a 38.8% increase from the previous year of €161.2 million. The Book to Bill Ratio was 1.01 compared with 0.89 in 2009. New orders received were €58.4 million compared with €43.9 million the previous year, up 33%.

Schiller Automation creates international subsidiary

Germany's PV manufacturing solutions provider Schiller Automation has created a U.S.-based subsidiary, Schiller LLC, to help it service its expanding portfolio of international clients. Schiller LLC's Boston headquarters will include marketing, sales, business development and field service divisions, and initially focus its attention on the North American and Asian markets.

Camstar Systems records record revenue figure for 2010

Camstar Systems has revealed that its final 2010 financial results saw record revenue growth of 38%. Software license revenue more than doubled year-on-year and further gains in maintenance and services revenue growth resulted in Camstar significantly exceeding all of its pre-2010 targets.

Camstar's investments and acquisitions also made a significant contribution to its record-breaking figures, with its SigmaSure and Camstar Quality products being the major benefactors.

H.B. Fuller to build new innovation centre at St. Paul headquarters

H.B. Fuller is to build an innovation centre of excellence for the solar panel and window industries at its world headquarters in St. Paul, Minnesota. The centre will centralize application and product development with the aim of providing manufacturing solutions to the company's customers more quickly and efficiently. Teams of product and industry specialists around the world will support the centre in St. Paul.

Location Briefings

Italy

Image credit: Thinkstock/GettyImages

Location: Italy ranks among the best solar markets in world, thanks to its high irradiation levels and strategic location close to the emerging South Europe and Middle East markets.

Infrastructure: Having set itself the target of reaching 8,000MW of installed solar capacity by 2020, the Italian market has gone from strength to strength, reporting over 7,000MW of total capacity at the beginning of 2011. With such great strides being taken in the country, Italy has proven itself as one of the most active solar markets – and certainly one to watch for the next few years.

Italy offers strong manufacturing activities notably in high technology sectors such as mechatronics, nanotechnology and industrial design. The country is also extremely open to foreign investments. Academic spin-offs and public research centres are focusing their efforts on cutting-edge PV technologies such as third-generation PV and Pulsed Plasma Deposition technology for CdTe-based thin film.

Key features/incentives: A demand-pull strategy, based on a strong incentive scheme and a number of legislative measures, has been introduced in the recent years by the Italian Government. The new Conto Energia 2011–2013 provides premium feed-in tariffs for 20 years, depending on capacity and installation typology. Relevant tariff upgrades are provided for substitution of asbestos rooftops,CPV and innovative BIPV solutions.

The new National Guidelines for RES power plant authorization have introduced a unified procedure throughout the country, for power plants with total capacity < 1MW.

Italy offers relevant investment opportunities, with particular emphasis on the following sectors:

- Power generation in commercial, logistic and residential segments, which are expected to become the most important segments in the future thanks to Italy's high building density
- PV technology manufacturing such as third-generation PV, BIPV and Smart Grid or innovative industrial automation applications in partnership with Italian mechatronic firms.

Invitalia, the government agency for inward investment promotion and enterprise development, directly manages incentive programs for manufacturing plants and has a strategic agreement with the public authority promoting RES development in Italy (GSE), the National Research Council and the Industrial Association in order to provide the best investments conditions in the RES sector.

Key Tenants: Aleo Solar, Applied Materials, Sharp, MT Microelectronics.

What they say: "Italy offers good conditions due to government promotion of photovoltaics and we have seen here a promising future market for our premium modules. A market for roof-mounted equipment is developing in Italy and is now comparable to that in Germany". *Giovanni Buogo – Aleo Solar Sales Manager, Italy*

Product Review

Edwards

Edwards improves performance and longevity of integrated etch tool pumps

Product Outline: Edwards has expanded its iXA family of magnetically-levitated turbomolecular pumps with the introduction of the STP-iXA2206 and STP-iXA3306 pumps. Developed for solar, glass coating, semiconductor and LCD etch applications, the iXA2206/iXA3306 pumps offer performance superior to that offered by earlier iXA family pumps.

Problem: The STP-iXA2206 offers the same pumping speed of the earlier STP-A2203, yet the maximum throughput capability has been increased. The integration of the onboard controller eliminates the need for control unit rack mounting and a connection cable between the pump and the control unit, saving installation time, space and cost. Its compact design and size compatibility with previous models simplifies upgrades from existing pumps.

Solution: The new STP-iXA2206/iXA3306 models are fully-integrated vacuum pumps that are claimed to be easy to install and offer a small footprint. The pumps feature the latest-generation small power supply, which has been incorporated into the onboard controller first introduced with the STP-iXA2205 pump. They also include a temperature management system option to minimize the formation of process-generated byproducts. The pumps' five-axis magnetic bearing systems and new motor and drive systems ensure long life and low operating costs with maintenance intervals as long as five years.

Applications: Fully-integrated vacuum pumps for etch requirements.

Platform: The STP-iXA3306 offers industry-leading pumping performance. It has a maximum pumping speed of 3200 litres per second and improved throughput performance at high gas flows.

Availability: Currently available.

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Waste water treatment for crystalline silicon solar cell production

Martin Schleef, **Detlef Worf**, **Rolf Bartels** & **Mila Kostieva**, M+W Germany GmbH, Germany; **Mariska de Wild-Scholten**, ECN Solar Energy, The Netherlands

ABSTRACT

This article provides an overview of the typical waste water treatment methods for crystalline silicon solar cell production. Firstly, a short description is provided of the main process steps of photovoltaic production and the types of waste water generated during these steps. Secondly, the typical waste water treatment methods of hydrogen fluoride (HF) precipitation and neutralization are presented. Furthermore, some options for the reuse of rinse water are discussed and several guidelines for the design of waste water treatment systems are given. Finally, the relative environmental impact of the waste water treatment compared to the emissions of the whole fab is presented using the life-cycle assessment (LCA) methodology.

Process steps and waste water treatment

The production of crystalline silicon solar cells typically includes the following process steps:

a) Saw damage removal/texturing
b) Emitter formation (doping with phosphorus)
c) Phosphorus silicate glass (PSG) etching
d) Silicon nitride (Si_3N_4) deposition
e) Screen printing of metallization
f) Edge isolation

Some of these processes generate few or non-concentrated waste water streams, whereas some processes produce significant volumes of rinse water and concentrated acids, which have to be treated in the waste water treatment system. The process steps that generate the largest and most concentrated waste water streams are, in order of extent of effect, the following: a) saw damage removal/texturing; c) PSG etching; and b) emitter formation.

Depending on the type of silicon wafers, several different methods are used for the saw damage removal/texturing process. Poly- or multicrystalline silicon wafers require a mixture of diluted hydrofluoric and nitric acid (HF/HNO_3) to remove defects in the crystal structure brought about by the wafering process on the surface of each wafer. During the process, the chemical baths are spiked in order to keep the quality of the etch solution constant. Nevertheless, the bath has to be changed completely at regular intervals, depending on the throughput. This requirement leads to a constant flow of highly concentrated HF/HNO_3 solutions, which in turn need further treatment.

For monocrystalline silicon wafers, this process is typically performed using a hot caustic solution with isopropanol (IPA). As with polycrystalline wafers, the baths used in this process must also be changed completely at regular intervals and for the same reasons. Concentrated IPA streams pose a problem, however, in that they are hot and need to be cooled down before they are collected for final discharge.

During the process of emitter formation (doping with phosphorus), phosphor is used to diffuse into the substrate doped with boron in order to create a p/n-junction in the silicon wafer. The phosphorus diffusion process forms PSG on the wafer's surface, requiring removal by application of diluted HF acid, which in turn needs to be treated in the waste water treatment installation.

The silicon nitride deposition process is carried out with the aim of reducing light reflection on the wafer's surface. The process chamber has to be cleaned regularly, for example with a fluoride-containing source, which generates a fluoride-containing exhaust. The treatment of this exhaust, usually performed by local abatement systems, can generate some waste water, but the level is relatively low compared to the first three processes.

The remainder of the production processes typically generate little or no waste water.

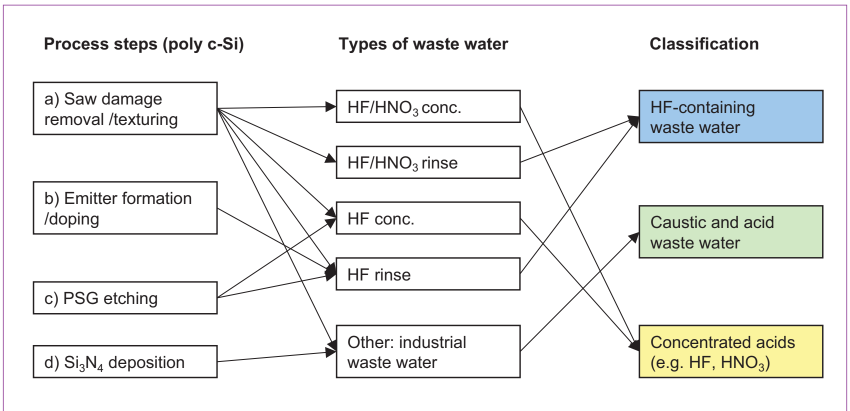

Figure 1. Process steps (poly c-Si) and types of waste water.

Types of waste water in c-Si PV production

There are many different types of waste water involved in the production of crystalline silicon photovoltaics, which can be distinguished according to their source (bath, chamber clean), concentration (diluted, concentrated), chemical characteristics (acidic, alkaline) or according to their composition (F-containing, non-F containing).

In practice, the different waste water types are classified according to their concentration, chemical characteristics and composition. Waste water generated during the production of PV products is usually divided into two groups: rinse water and concentrated acids. Rinse water, which has a much lower concentration of chemicals, is treated in the onsite waste water treatment plant, while the concentrated acids are usually collected for external discharge. From the point of view of composition, the fluoride content level is one of the most important parameters because of its relatively strict discharge limits.

Fig. 1 shows the process steps and the types of waste water streams generated during the production of a typical

polycrystalline silicon product. The only difference between this schematic and that of monocrystalline PV production would be the process step a) saw damage removal/texturing as explained earlier. This scenario would feature a waste water stream (commonly referred to as 'caustic IPA'), which is collected for external discharge instead of the HF/HNO_3 concentrate and rinse.

Types of waste water treatment methods

The usual approach to the treatment of waste water from the PV production process involve the following steps:

- HF treatment
- Neutralization
- Collection of isopropanol-containing waste (applicable only to monocrystalline manufacturing)

These methods are described in the following sections.

HF treatment

Waste water that is contaminated with HF is collected and sent to the HF treatment system, where the following three steps are carried out: precipitation, sedimentation and filtration. The insoluble solids generated in the treatment system are dewatered and discharged for external disposal, as depicted by the representation in Fig. 2.

Precipitation is a method of removing dissolved substances from the waste water stream. This is carried out by the addition of chemicals to react with the target substance to form an insoluble compound. These reactions usually have a specific optimal pH range, and thus pH adjustment may be necessary to optimize the process.

Calcium, either as lime water $Ca(OH)_2$ or calcium chloride $CaCl_2$, is commonly used to precipitate fluorides, sulphates and phosphates. The basic chemical reactions can be seen in Table 1.

Calcium hydroxide

$2\,HF + Ca(OH)_2 \rightarrow CaF_2 + 2\,H_2O$

Calcium chloride

$2\,HF + CaCl_2 \rightarrow CaF_2 + 2\,HCl$

Table 1. Basic chemical reactions within the HF treatment process.

Sedimentation, also called settling, is the physical separation of suspended solids from the liquid stream using gravity. Equipment that makes use of this process includes grit chambers, sedimentation tanks, inclined plate clarifiers and thickeners.

Some variations in sedimentation units are inclined-plate clarifiers and upflow sludge blanket clarifiers. Retention time, surface loading rates, scour velocity and the tank maintenance requirements are some factors to consider when choosing a sedimentation unit.

Filtration is a separation process in which the mixture of liquid and solids is passed through a filter medium down a pressure gradient. The liquid passes through the medium as a filtrate while substances impermeable to the medium are retained as residues. Various extents of filtration are possible by changing the filter medium characteristics, such as pore size and filter thickness. In decreasing pore sizes, filtration media can range from sand beds to paper and from textile filters to membranes.

Filtration can also be classified into dead-end and cross-flow filtration. In dead-end filtration, the filter medium is inline and the whole waste water stream passes through it. In contrast, the waste water stream passes through tubes made of the filter medium in cross-flow filtration. As such, the effluent is thickened but not completely filtered.

In the photovoltaics industry, dead-end filtration as a filter press is the most common approach for separation of liquids and solids.

Solids are collected as a filter cake in a container for shipping and subsequent external disposal. In most cases, the filter cake (CaF_2) is a non-hazardous material but local requirements can demand a special treatment.

Following HF treatment, the water is sent to the neutralization system for pH adjustment.

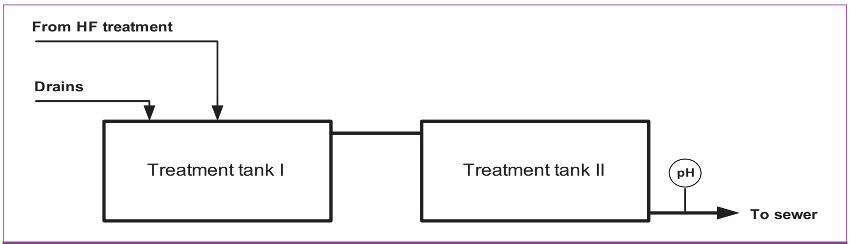

Figure 3. Diagram of a neutralization system.

Neutralization

Fig. 3 shows a simplified diagram of a typical neutralization system, which treats waste water contaminated with acids and/or bases. This treatment consists of the adjustment of waste water pH to a neutral range between approximately 6 and 9, or as determined by the specific discharge regulations, which can require the addition of acids and bases in order to meet the requirements. Sulphuric acid (H_2SO_4) and hydrochloric acid (HCl) are the most commonly used acids in this process – the former (H_2SO_4) is the least expensive and the easiest and safest to use. Due to the fact that HCl generates corrosive vapours, it is not recommended for this process. Sodium hydroxide (NaOH) is the most commonly used alkaline chemical because it is both easy to handle and inexpensive. The choice of chemicals used is dependent on the cost and operation of the plant.

Sodium hydroxide

$NaOH + H^+ \rightarrow Na^+ + H_2O$

Table 2. Basic chemical reaction for neutralization of acidic waste.

Sulphuric acid

$H_2SO_4 + 2\,OH^- \rightarrow SO_4^{2-} + 2\,H_2O$

Hydrochloric acid

$HCl + OH^- \rightarrow Cl^- + H_2O$

Table 3. Basic chemical reactions for neutralization of alkaline waste.

Tables 2 and 3 show some of the basic chemical reactions that occur during the neutralization of acidic and alkaline waste, respectively. The process consists of acid and base dosing, processes that usually require two mixing tanks in order to fine-tune the pH to the required range. pH control instrumentation must be provided

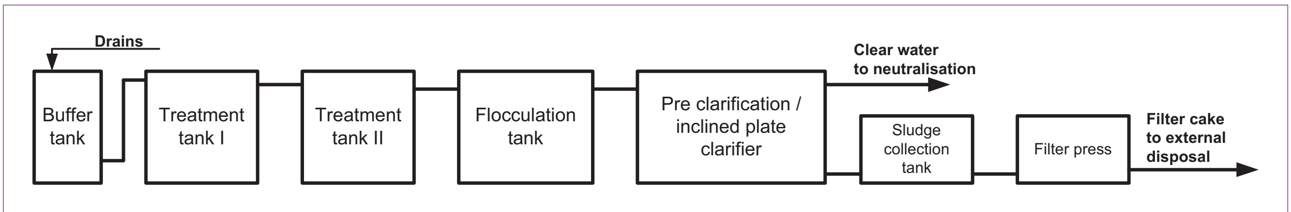

Figure 2. Diagram of a HF treatment system.

to control the dosing of the chemicals.

Important design parameters for the neutralization process are required mixing time and dosing, factors that determine the tank size and dosing valve size. Careful attention must be paid to the process control, as very precise dosing is required.

Collection of isopropanol (IPA)

Fabs that run a monocrystalline silicon process segregate their isopropanol-containing waste streams, which are collected in intermediate bulk containers (IBC) for external discharge. As described earlier, other waste streams can be treated in a common treatment system.

Design guidelines for waste water treatment

Fig. 4 shows a standard design of a waste water treatment facility, in this case, prior to the performance of the neutralization HF treatment. The concentrated acids are usually collected onsite in IBC containers and then transported for external treatment.

A more detailed overview is given in Fig. 5, which includes the various sources of waste water, the ultrapure water (UPW) plant and the reverse osmosis (RO) plant. The thickness of the arrows corresponds to the relative contribution of each source of water and waste water.

A variation of the standard design for waste water treatment does not include this HF treatment step. In this case, neutralization alone is used to treat the waste water, including the concentrated acids. This type of treatment system has been designed and installed in practice. However, due to some local authority requirements, it may be the case that this is not in fact an acceptable solution, even if it is technically feasible and found to comply with the environmental regulations.

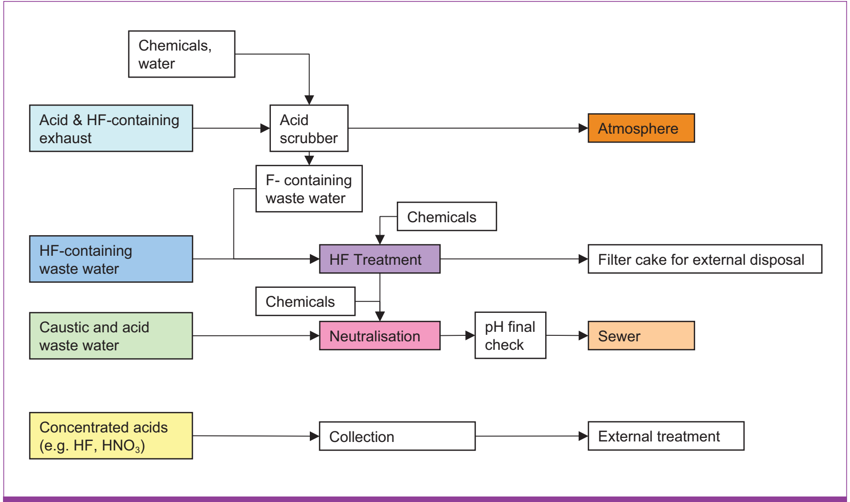

Figure 4. Standard design option for waste water treatment: HF treatment and neutralization.

Waste water coming from the scrubbers should not be neglected when designing the waste water treatment system in terms of HF mass flow. Even if the amount of water is relatively low compared to that coming from the various production processes, it is possible that it accounts for a significant amount of the total HF effluent of the fab. This is due to the fact that scrubber waste water is dependent on the type of etching processes used.

In terms of effluent limits, the design of the waste water treatment system strictly depends on the location of the PV fab. For example, the fluoride emission limit at discharge point is very different for different countries or regions. Germany does not have a general value; the fluoride limit depends on the requirements of the local authorities, ranging from lower than 20 up to 50mg/l. In France the fluoride limit is in the order of 15mg/l, but may be slightly different for some regions, whereas in Italy the fluoride limit can be even lower than 6mg/l.

Local infrastructure is another highly important parameter for the design of the waste water treatment plant. The concentrated acids are usually collected for external discharge – if this is not possible, they have to be treated onsite, a factor that must be considered at an early enough stage in order to be implemented into the design of the waste water treatment plant.

Possibilities of rinse water reuse

Rinse water from the etching process baths that has not been contaminated with nitric acid (HNO_3) is collected separately in a receiver tank. Therefore, a separate drain line is required to handle only rinse water for the recycling plant.

In the first step, this rinse water is filtered to prevent damage of the reverse osmosis (RO) membranes by silicon particles from broken wafers, for example. The filtered water's pH value is adjusted before being sent to the reverse osmosis unit, where most of the dissolved fluoride salts are held back

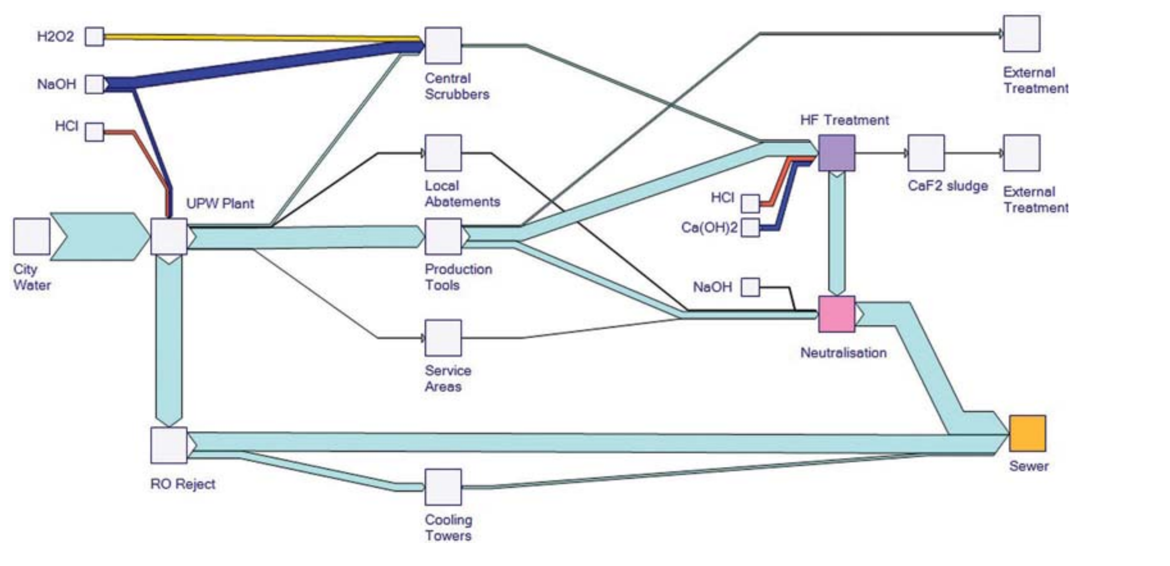

Figure 5. Schematic overview of a crystalline silicon solar cell line and its waste water treatment system.

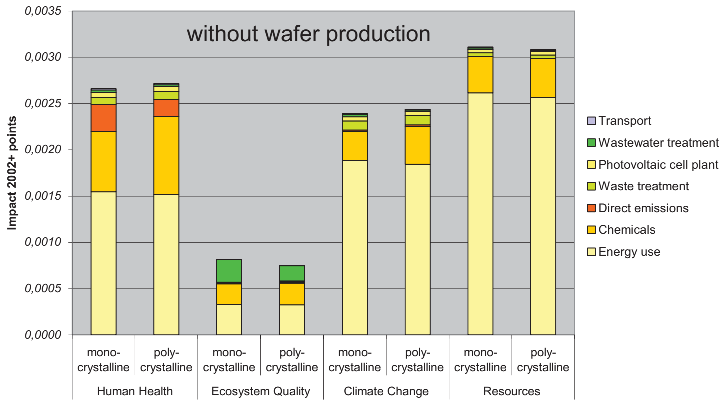

Figure 6. Environmental impact of PV cell fabrication per m² of Si solar cell and for small-scale productions (60MW).

in the concentrate stream. This concentrate will need a further treatment in fluoride precipitation in order to adhere to the specific impurity level requirements.

The permeate of the reverse osmosis could be reclaimed and used for several purposes, such as feed water for the local abatement systems, central scrubbers and cooling towers, among others.

Life cycle assessment

Life cycle assessment (LCA) considers all environmental impacts for a certain system, both direct and indirect. This assessment includes all processes, starting from the production of raw materials and primary energies, through the resource consumption, transport and finally treatment, be it onsite or offsite. The European Integrated Pollution Prevention Guideline [1] requires such considerations for relevant installations.

The overall impact of PV cell fabrication has been published [2] based on the IMPACT 2002+ scale [3], the main results of which are shown in Fig. 6. The graph in Fig. 6 presents PV production with the exclusion of the contribution of silicon as a raw material. All data on indirect emissions, silicon production included, are taken from Ecoinvent [4].

Fig. 6 clearly displays the fact that indirect emissions (energy use, use of chemicals, PV cell plant) are in all categories that bear more importance than the direct emissions themselves (emissions from the solar cell manufacturing facility). Only by including indirect emissions in the equation can a representative judgement of the environmental impact of photovoltaic manufacturing be obtained.

Waste water treatment and the related emissions have a minor environmental impact in categories such as human health, climate change and use of resources. It has, however, a significant effect on the quality of the ecosystem, primarily as a result of the chemicals being used during the various waste water treatment steps.

Conclusion

Waste water treatment systems for crystalline silicon solar cell production are mainly comprised of the HF treatment and neutralization steps. The composition and the amount of waste water depend in the first instance on the processes used in the fab as well as on the city's/region's water parameters.

It is not likely that we will see wet etching processes substituted by dry etch processes in the near future. While this replacement has been partially performed in other industries, it remains too expensive a process for the crystalline silicon solar cell manufacturing industry.

City water parameters depend on the local conditions and each individual fab's waste water treatment system must be examined and designed according to these parameters. Furthermore, the design process must also take into consideration the local conditions, such as special requirements from the local authorities, as well as infrastructure for external treatment. In terms of LCA, waste water treatment has a relatively low environmental impact.

Disclaimer

The information contained within this article has been given in order to show the status of today's solar cell production and waste water treatment technology. Nevertheless, none of the authors accepts liability for any damage arising from using the given information for design, construction or operation. Waste water treatment systems differing from those described herein may not necessarily be inferior.

Acknowledgements

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References

[1] Guideline 2008/1/EG of the European Parliament and Commission concerning integrated pollution prevention [available online at http://ec.europa.eu/environment/air/pollutants/stationary/index.htm].

[2] Hottenroth, H. et al. 2009, *14th UMBERTO user forum*, St. Goar, Germany.

[3] Jolliet, O. et al. 2003, *The International Journal of Life Cycle Assessment 2003*, Vol. 8, pp. 324–330.

[4] ecoinvent Centre, ecoinvent data v2.0. ecoinvent reports, Swiss Centre for Life Cycle Inventories, Dübendorf [available online at http://www.ecoinvent.ch/].

About the Authors

Martin Schleef has worked as a senior engineer at M+W Germany GmbH – A Company of the M+W Group – since November 1999. As a leader of the Process Systems group he is responsible for design, construction and project management of UPW and waste water systems.

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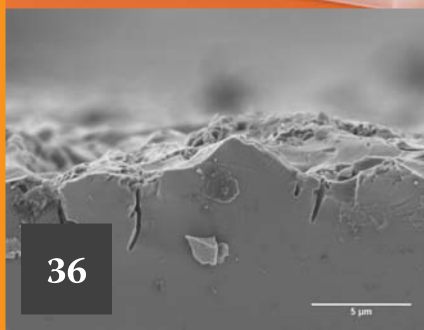
Materials



News

Linde sees customer capacity treble

Last year saw the gases division of the Linde Group capitalize on the solar industry's growth by securing supply contracts with over 25 new and pre-existing customers in the thin-film and crystalline silicon manufacturing sectors. Among these clients were major names such as Bosch, GCL, Suntech, Trina and Motech.

This influx of clients has seen Linde's worldwide PV customer capacity treble to 17.4GW – a growth primarily fuelled by Chinese firms creating new production capacity of nearly 13.5GW. On the back of this success, Linde is now positioning itself to take advantage of renewed investment in amorphous silicon in 2011 by increasing production of its award-winning fluorine generation technology to meet escalating demand.

Linde has also revealed that 2011 will see it focus much of its attention on the manufacturing growth region of Asia by continuing to heavily invest in its Chinese silane and ammonia infrastructure.

Source: Linde

Linde tanks for liquids, liquid gases and bulk material.

Polysilicon News Focus

OCI secures US$950 million polysilicon supply deal with Yingli

A polysilicon supply contract has been signed between OCI and Yingli Green Energy to the tune of US$950 million. The contract will commence in January 2012 and is expected to continue through to the end of 2018. In a separate statement, OCI reported a US$108.8 million polysilicon supply deal with specialist products firm, Ferrotec, which makes quartz-based products for various industries. The contract lasts from January 2012 through to the end of 2018.

GCL-Poly signs huge polysilicon, wafer supply deal with Solarfun

GCL-Poly Energy Holdings and Solarfun Power Holdings have mutually entered into a long-term wafer and polysilicon supply contract where GCL-Poly will provide Solarfun with 2,500MW of wafer and polysilicon products from January 2011 until December 2015. Included in the contract signed between the two companies is a price adjustment mechanism.

Source: GCL Poly

GCL Poly wafer inspection.

MEMC plans significant capacity expansion: wafer prices to fall in 2011

Polysilicon supply remains tight, according to MEMC management, though they didn't know whether the situation would last. However, in a conference call to discuss financial results management mentioned that they would soon announce significant capacity additions where the demand is centered, suggesting expansions at its Malaysian plant or new facilities in Asia.

Significant polysilicon and wafer capacity expansions have been announced by the likes of GLC-Poly, LDK Solar and others, while MEMC, once of the largest wafer producers has remained on the sidelines.

MEMC noted in the call that capital expenditures were US$115.1 million in the quarter, driven by investments in 300mm wafer production for the semiconductor industry and its continued expansion of in-house solar wafering manufacturing as well as projects for productivity improvement.

Solar materials net sales for the fourth quarter were reported as US$279.9 million, an increase of 27% from the third quarter of 2010 and an increase of 93% from the fourth quarter of 2009. Overall net sales for the quarter were US$850.1 million, an increase of 69% from US$503.1 million in the third quarter of 2010.

Solar materials segment operating profit was US$38.1 million in the fourth quarter, compared to US$17.6 million in the third quarter. Management noted that although polysilicon was in tight supply at the moment it expected wafer prices to decline 15-20% this year.

GT Solar releases new STC converter

GT Solar International has unveiled its next generation silicon tetrachloride (STC) converter for polysilicon production plants that use direct chlorination for hydrogenating STC. The new STC converter is primarily aimed at companies utilizing older, direct chlorination polysilicon plants. GT Solar claims that the new converter is an upgrade that will increase production capacity and lower annual operating costs. Each STC converter has the potential to support 2,500 tonnes of annual polysilicon production.

Business News Focus

SiC Processing raising €100 million for slurry recycling expansion

With significant ingot and wafer capacity expansions, notably underway in Asia, the demand for slurry recycling is working in tandem. With a claimed 40% market share, SiC Processing is raising €100 million via a bond issue to further expand operations in Asia and other regions.

SiC Processing saw sales increase 54% in 2010 to €160 million, compared to the previous year. Nordic Capital Fund VII acquired a majority stake in SiC Processing in June 2010.

Q-Cells switches major wafer suppliers

Q-Cells has changed its primary wafer supplier in an attempt to stave off the threat posed by the fluctuating supply and price of wafers. Previous supplier, LDK Solar, has been replaced by GCL Poly.

In the past, restrictive long-term supply contracts has seen Q-Cells hit hard financially by market fluctuations, resulting in disputes arising with LDK over contract pricing and pre-payment amounts. Q-Cells CEO Nedim Cen said the new major supply deal with GCL Poly will involve very low levels of pre-payment clauses.

Having expanded into module production, GCL Poly is competing with many of the major suppliers. Although the company will not disclose plans for module expansions in 2011 until the full year results in late March are released, GCL may also become a key supplier to Q-Cells in more downstream activities in the future.

Belgian PV encapsulant developer NovoPolymers gets €4.2 million in new funding

NovoPolymers has announced that in addition to expanding its Belgian production plant, the company has also received €4.2 million from its shareholders Gimy and Capricorn Cleantech Fund during the company's second financing round.

Source: NovoPolymers

NovoPolymers' technology production.

With the expansion of the company's manufacturing facility, the Belgian plant will have a production capacity of 1GWp. NovoPolymers' technology is based off thermally curable ethylene vinyl acetate (EVA) sheets. They are known for their line of thermoplastic-based encapsulant sheets used in c-Si cell-based PV modules. The company is also developing a cured EVA system to expand its portfolio further.

GT Solar sales increase as customer wafer production expansions continue

Sales of DSS crystalline growth systems dominated sales in GT Solar's most recent quarterly earnings. DSS furnace shipments were at record levels, with more than 480 units shipped in the quarter. Significant expansion of wafer capacity, primarily in Asia, fuelled revenue 15% higher than its second financial quarter. Revenue reached US$262.9 million, compared to US$229.3 million in the previous quarter – a new record for the company.

Order backlog was US$1.23 billion, with US$601.2 million in the polysilicon segment, US$529.1 million in the PV segment and US$96.2 million in the sapphire segment. Included in the total backlog was US$388.1 million of deferred revenue.

New orders for the quarter were reported to be US$330.7 million, which included US$73.9 million in polysilicon, US$167.9 million in PV and US$88.9 million for sapphire. GT Solar noted that it expected US$794 million to roll off the backlog over the next 12 months. The company raised its fiscal year 2011 guidance for revenue to within the range of US$835 million to US$860 million, up from the previously provided range of US$775 million to US$850 million.

GT Solar provided a preliminary outlook for its fiscal year 2012, which ends on March 31, 2012. For FY 2012, the company expects revenue in the range of US$850 million to US$1 billion, and gross margins of 40 to 42%.

REC signs wafer sales contract with Asian firm

REC has signed a three-year multicrystalline wafer sales contract with an unnamed Asian cell producer. The take-or-pay agreement will see REC deliver NOK1.1 billion (US$188 million) worth of wafers between 2011 and 2013, with prices based on prevailing market prices. Total prepayment and other security related to the contract represent approximately 10% of the estimated contract value.

Source: REC Solar

REC's wafer manufacturing facility in Singapore.

Other News Focus

Yissum, Vaxan sign nanoparticle ink research and licensing agreement with Israeli university

Yissum Research Development, the Technology Transfer Company of the Hebrew University of Jerusalem and Vaxan Steel have signed a licensing and research agreement to develop silver nanoparticles and silver-coated copper nanoparticles for conductive inks. The contract stipulates that Yissum provides Vaxan with an exclusive sales license for Asia – excluding Israel and former Soviet states – in return for research fees and royalties from future sales.

The inks, created by scientists at the Institute of Chemistry at the Hebrew University, can be used in unison with a variety of printing technologies, including inkjet printing of electronic circuits on silicon wafers in the thin-film photovoltaic industry.

Corning touts R&D efforts to bring photovoltaic glass to market

The PV industry may use glass as a key component within rigid modules but for many glass manufacturers, the PV industry is one of its smallest market sectors. With demand dominated by the construction and automotive industries, PV is just a speck on the TAM (total available market) charts, often too minor for most glass manufacturers to bother with.

However, the growth in the industry has not gone unnoticed by glass manufacturers, though few glass products are as yet specifically made for PV requirements. That could change, at least at Corning, which is touting a major investment in research and development for photovoltaics, and the company's Harrodsburg, Kentucky plant is in the process of expanding its manufacturing capabilities with the intention of beginning production of PV glass early in 2012.

ReneSola claims new multicrystalline wafer comparable in performance to mono

ReneSola said it has developed a multicrystalline wafer process that achieves an average cell conversion efficiency rate of 17.5%, more than 1% above standard cell conversion efficiency rates and comparable in performance to monocrystalline wafers but at lower cost. ReneSola intends to start pilot production of the 'Virtus Wafer' in the first half of 2011.

The results were said to have been endorsed by several leading global solar cell manufacturers, though the company did not say the results had been independently verified by a research organization such as Fraunhofer or NREL.

Heraeus to build metallization paste factory in Singapore

The Heraeus Photovoltaic Business Unit has started building work on a new factory in Singapore to manufacture silver metallization paste for crystalline solar

Materials Order Focus

Praxair secures silane contracts with Trina Solar, ShanXi LuAn and Realforce

Several new bulk gas contracts have been signed by Praxair Electronics with three China-based PV manufacturers. Key contracts, primarily for silane, were signed with Trina Solar, ShanXi LuAn Solar Energy and Realforce Solar, a subsidiary of Realforce Group. Praxair Electronics currently serves more than 50 solar fabs worldwide, with a combined capacity of over 6GW, and claims to be the largest industrial gas supplier to the polysilicon market. No financial details were disclosed.

Praxair is supplying unidentified quantities of silane, ammonia and bulk atmospheric gases to ShanXi LuAn Solar Energy in Changzhi, Shanxi Province, while Trina Solar in Jiangsu Province is receiving just silane. Realforce Solar in Jining, Shandon Province will be supplied with silane and ammonia.

GCL-Poly to supply 4.4GW of wafers to China Sunergy

In one of the largest-ever signed single wafer supply agreements, GCL-Poly will supply approximately 4,400MW (4.4GW) of multicrystalline wafers to China Sunergy over the next six years. Under the conditions of the long-term agreement, wafer shipments will commence in February for completion in December 2016, and include a price adjustment mechanism based on wafer market price.

The massive wafer supply deal would seem to underline China Sunergy's push to become a major PV manufacturer in the year to come. In the company's third quarter financial results, China Sunergy only shipped approximately 87.8MW. No further financial details were disclosed.

Meyer Burger secures new US$169 million wire saw deal

An existing customer in Asia has placed orders worth approximately US$169 million with Meyer Burger for wire-saw equipment used in solar wafering operations. The company said that the wire saws were scheduled to be delivered during 2011. The company's MB Wafertec subsidiary secured the deal.

GCL-Poly signs supply contract for AEG's Thyrobox M system

GCL-Poly Energy Holdings has signed a €36 million supply contract with AEG Power Solutions for its Thyrobox M power supply system. GCL hopes the Thyrobox will help consolidate its position as one of the world's leading polysilicon and wafer suppliers.

After experiencing fluctuating demand in recent years, the polysilicon market is showing signs of renewed growth – illustrated by the growing number of new projects and capacity expansions. Thyrobox is a compact power solution for the polycrystalline silicon deposition process and, depending on the type of reactor, has a footprint up to 70% smaller than its rivals in the market.

Meyer Burger bags another new customer in Asia

Meyer Berger has signed a further equipment order with an unidentified customer based in Asia. The CHF 45 million wire saw deal highlights the continued capital spending to increase wafer capacity in the solar industry. Meyer Burger said that its subsidiary, MB Wafertec secured the deal for slurry based wire saws, used for wafering processes. The wire saws are scheduled to be delivered during 2011.

TechPrecision receives US$1.2 million order for monocrystalline chambers

TechPrecision has received an order worth US$1.2 million for its monocrystalline chambers from a major wafer producer and OEM. This is the third new strategic tier-one customer TechPrecision has acquired during the current fiscal year.

The unnamed customer has also indicated that it will require 100 additional units in 2012 and a further 200 in 2013; a significant amount of this production will be carried out by TechPrecision's subsidiaries, Wuxi Critical Mechanical Components and Ranor.

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cells. The site, which will also house some of the company's R&D, sales and technical service divisions, is scheduled to begin production in the second half of 2011. The Singapore facility will further expand Heraeus's global reach – it already has plants in the U.S. Germany and China – and add to its burgeoning workforce.

PV materials market worth US$6.5 billion in 2010, says SEMI and Linx-AEI report

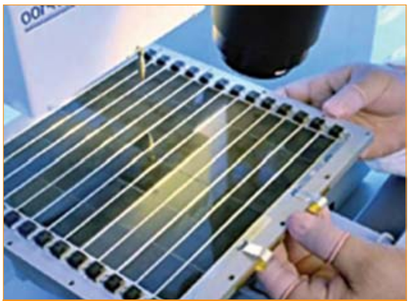
A joint report issued by SEMI and Linx-AEI Consulting reveals that the market for advanced chemicals and materials used in PV solar cell and module manufacturing grew by 114% in 2010 to US$6.5 billion. Continued capacity expansions and more advanced cell designs could see the PV materials market reach US$16.9 billion in 2015, according to the report, which includes silicon, slurries, gases, wet chemicals, precursors, dopants, and other critical materials for both crystalline and thin-film technologies.

However, the outlook for materials sales in 2011 is expected to slow from the significant rise seen last year. The report cites PV module demand in Germany slowing as it adjusts to new incentive policies and module prices decline. Growth is expected to return next year as new markets emerge, according to the industry report.

BioSolar reveals that its BioBacksheet is almost complete with the UL certification process

BioSolar has advised that the production samples of its BioBacksheet technology have finished most of the Underwriter's Laboratories (UL) material property tests and is on its way to receiving full UL certification. Tests on the product have included: material identification, partial discharge test and resistance to catching fire among other UL led testing. The last test, a measurement of relative thermal index (RTI) will soon be conducted.

The RTI test will assign BioSolar's BioBacksheet a value 90 days into the RTI testing. Once assigned, commercial solar panels using the BioBacksheet will be submitted for final panel certification or recertification under UL 1703 before they can be sold on the general market.



Source: BioSolar

The BioBacksheet by BioSolar.

Crystalline supply chain prices falling on lower feed-in tariffs, says IMS Research

The introduction of lower feed-in tariffs in some of the key PV markets at the beginning of the year is causing prices to fall throughout the crystalline supply chain, according to the latest quarterly report from IMS Research. Polysilicon, wafer, cell and module prices are expected to fall 7% on average in Q1 and should continue to decline in Q2.

The market research firm noted that the average polysilicon contract price fell by just 2% in Q4 2010. However, polysilicon spot prices fell by 10%, reversing the increases seen in the previous quarter, when Tier 2 and 3 suppliers had been able to sell silicon at inflated prices because of high demand and a shortage in supply.

IMS Research believe both contract and spot prices will continue to drop in Q1 2011, falling by 4% on average over the previous quarter.

AMG acquires solar silicon casting IP from BP Solar

AMG Advanced Metallurgical Group has bought the intellectual property and manufacturing assets for BP Solar International's Mono2 solar casting technology. Furthermore, AMG has also secured a team of scientists and engineers with a background in silicon casting who will be able to continue the research and development with manufacturing operations at BP Solar's Maryland facility.

Developed by BP Solar and the U.S. Department of Energy, the Mono2 technology will be incorporated into AMG's engineering systems division, ALD SCU400plus and SCU600plus solar melting and crystallization vacuum furnaces.

Ceradyne secures acquisition of VIOX

Ceradyne has completed its acquisition of VIOX, a specialty glass company based in Seattle, Washington. Over the past few years VIOX has seen around 70% of its sales come from solar glass products, which have been specifically formulated for polycrystalline silicon solar PV applications. Ceradyne bought VIOX with a US$27 million cash payment at closing, which also includes a post-closing adjustment in two months. Additionally, conditional payment of up to US$22 million may be paid if VIOX reaches certain sales diversification and earnings targets over a 30-month period after the closing.

VIOX will become a wholly-owned subsidiary of Ceradyne under the company's Advanced Ceramic Operations segment and managed by Ceradyne's VP David Reed. At this time, all current VIOX employees will remain in their positions, including VIOX's president, Reynold Hagel. As VIOX continues to expand, Ceradyne plans to provide financial, technical and any other necessary resources to assist the subsidiary's development.

Jean-Marc Gilson appointed CEO at Avantor Performance Materials

Jean-Marc Gilson has been appointed as Avantor Performance Materials' new chief executive officer. Gilson will work alongside the company's executive chairman, Raj Gupta, and core leadership team, and be responsible for managing the company's strategic development and future global direction.

After being awarded a Master's degree in chemical engineering from the University of Liege in 1988, Gilson started his career as a process engineer with Dow Corning in 1989. Gilson rose rapidly through the ranks at Dow Corning, serving in a number of engineering, financial, manufacturing and management roles in Europe, Asia, and the U.S.; in 2005 he relocated to Japan to take on the position of vice president and general manager, where he oversaw the company's Specialty Chemicals sector, and in 2009 he was appointed the company's executive vice president.

Avantor manufactures and markets high-performance chemicals and materials for microelectronics and photovoltaic manufacturing under the brand names, J.T. Baker and Macron Chemicals.

Product Reviews

Entegris

Multifunction wafer and cell shipper from Entegris reduces breakage

Product Outline: Entegris has launched a new multifunction shipper designed to provide photovoltaic wafer, cell and module manufacturers with decreased cell breakage, improved transportation efficiencies, lower warehouse and labour costs, and reduced waste. The Multifunction 3 shipper is constructed with cleanable polypropylene materials.

Problem: Safe but efficient transportation of wafers and cells is a key cost driver for PV manufacturers. Poor packaging can lead to wafer and cell breakage, increasing wastage.

Solution: Constructed with cleanable polypropylene materials, the Entegris multifunction shipper can be used multiple times and recycled efficiently, thus allowing wafer and cell manufacturers a green alternative to reduce packaging waste and disposal costs. Furthermore, the shipping system maximizes the number of cells or wafers on a pallet, improving transportation efficiencies and reducing warehousing costs. Another feature of the Entegris shipper is its ability to serve as both a sorting bin and a shipper, eliminating the need for an operator to manually transfer the wafers or cells thereby endangering the substrate. This improvement helps manufacturers improve their processes in a way that provides increased yields and reduces labour costs.

Applications: Wafer and cell shipping.

Platform: Constructed with cleanable polypropylene materials, the shipper can be used multiple times and efficiently recycled.

Availability: Currently available.

Cyberstar

Cyberstar uses patented Gradient Freeze process to boost mass yield of silicon ingots

Product Outline: Cyberstar has introduced its new 650/800kg Crystallization Furnace System for multicrystalline silicon ingot production.

Problem: Polysilicon and wafer production are key cost contributors to overall module manufacturing costs. Improving the mass-yield of the grown ingot reduces costs and improves product quality. However, these benefits need to be provided in an environment of faster growth and reduced cycle times to maximize cost reduction goals.

Solution: Cyberstar's patented 'Gradient Freeze' process technology is claimed to provide advantages that other traditional casting systems are not capable of providing, the most significant being better mass-yield of the grown ingot, faster growth and cycle times and a small footprint.

Applications: Multicrystalline silicon ingot production.

Platform: The 650kg furnace produces ingots comprised of 6" × 6" bricks using a GEN6 crucible or 5" × 5" bricks using a GEN5 crucible. Furnace output: >13MW with GEN6 crucibles and >10MW with GEN5 crucibles. Material yield: 79%; Cycle time: 50h; dimensions (W × L × H): 2.6m × 4.5m × 4.5m; ceiling height: 5.5m; weight: 7000kg total system. System is available in 60kg & 250kg sizes. The 60kg multicrystalline furnace can also accept the Cyberstar Czochralski growth components, allowing the growth of both multi- and monocrystalline silicon in the same furnace. Dedicated Czochralski systems are also available.

Availability: These systems are available in Cyberstar's new Crystal Growth Development Center in Grenoble, France.

GT Solar

GT Solar's DSS650 multicrystalline ingot growth system has 25% more output

Product Outline: GT Solar International has announced the commercial release of the DSS650 multicrystalline ingot growth systems. The DSS650 can grow significantly larger silicon ingots averaging 625kg, resulting in 25% more output. It is also designed to provide the same quality performance and reliability as its 2,200-plus DSS systems in the field.

Problem: The DSS650 furnace produces the industry's largest high-volume production ingots comprised of 25 bricks. PV manufacturers may also be able to lower the cost of wafer operations because the taller bricks help to optimize and improve the utilization of the wafer saw beam to minimize waste and improve the amount of good wafers produced.

Solution: The DSS650 incorporates new changes to its proprietary hot zone technology, which improve system performance and control during the ingot growth process, and optimize the new process recipe required to produce larger ingots. Customers can upgrade their current DSS furnaces to take advantage of the higher throughput and performance of the new DSS650.

Applications: Directional Solidification System (DSS) furnaces for casting multicrystalline ingots.

Platform: The DSS650 has a furnace output > 9MW per year (assuming 16.5% efficiency from 156mm cell lines). Ingot size: 84 × 84cm2; ingot weight: typical 625kg (590kg to 650kg); mass ingot yield (MIY) ≥70%; cycle time ≤74 hours. Features a bottom-load process chamber for added operating convenience; dimensions: (W × L × H) 3823mm × 4774mm × 5105mm (151" × 188" × 201"). Ceiling height: 6000mm (236"); power for entire system: 200kVA, 380–480V, 3 Ph, 50/60Hz. Power factor: Ave 0.9.

Availability: Currently available.

Silicon and wafer materials 2011 overview

Mark Thirsk, Linx Consulting LLC, Mendon, Massachusetts, USA

ABSTRACT
With more than 80% of PV module demand being satisfied by crystalline-based modules, the health of the silicon and wafer supply chain is of vital importance to the overall PV industry. This paper reviews the overall materials value chain from the manufacture of PV silicon to the wafer, prepared for manufacture of the cell. A glimpse is provided of the various market dynamics that exist in the supply chain, as well as the technology trends that influence or threaten the supply of wafers. Although the manufacturing routes are mature and well established, we also take a look at the possibility of novel and disruptive technologies altering the overall supply landscape.

Silicon supply

The PV industry today relies on various forms of silicon as a key raw material. More than 80% of installed modules use monolithic silicon wafers as the building block for the cell. Thin-film silicon modules may have reached a cost level that will allow them to compete on cost with the other leading TF module technology, CdTe. The supply chain for silane, the deposition precursor for TF silicon modules, is directly linked with that of polysilicon.

"Vertically integrated suppliers do have the ability to tune their cell production to make the best use of their captive silicon capacity."

There is an ever-increasing group of companies producing polysilicon. The production route starts with a common industrial raw material, metallurgical-grade Si, which needs purification and refinement to become electronic-grade polysilicon. This refinement is carried out by gasification of the solid material, followed by gas phase distillation, and the subsequent transition back to the solid phase by chemical vapour deposition.

The two most common routes for conversion to the gas phase both start by reacting metallurgical-grade silicon with HCl to produce trichlorosilane (TCS). The next step is the purification of the TCS through distillation, after which it is used as the precursor for deposition in the Siemens process. An alternative is to catalytically decompose the TCS to monosilane (often called just silane) which is then used for the deposition precursor after purification.

The advantages of the TCS process lie in its simplicity and cost, whereas the extra step required for silane manufacture adds cost and complexity, but results in a higher quality product with fewer recycling concerns due to the absence of chlorinated molecules. The manufacture of TCS – or silane – and its subsequent conversion by CVD in the Siemens process is a large industrial enterprise which benefits from scale and a high standard of chemical engineering.

Polysilicon manufacturing plants are generally custom-built by specialist chemical plant constructors, and a high degree of expertise in running the process is required to successfully start and operate these large plants. Furthermore, the intermediates and byproducts of the gaseous route are both pyrophoric and toxic, driving the location of greenfield factories well away from areas of high population. The plants are also extremely power-hungry, requiring well in excess of 100kWh of power for the production of 1kg of polysilicon.

For world-class cost performance, polysilicon producers also need to recycle as much as of the feedstock as possible. A major byproduct of the TCS process is silicon tetrachloride, a toxic liquid which has few industrial uses, and which requires expensive disposal if it is not reconverted for use in the process. The efficient recycling of STC and other chlorosilanes is a key determinant of overall plant efficiency, although it adds operating cost and power consumption. While the polysilicon manufactured is not doped as n- or p-type at this point, the overall purity of the silicon is critical in determining its subsequent usefulness. High-purity silicon can be used in either IC or PV manufacture, whereas the PV market can accept lower-purity silicon. Lower-quality silicon can be compensated for to a great extent by process modification, but record-breaking efficiencies require high-quality starting materials. However, vertically integrated suppliers do have the ability to tune their cell production to make the best use of their captive silicon capacity, avoiding the variability of multiple suppliers, or opportunism of the spot market.

A further variation in the polysilicon supply side is the advent of granular silicon made by fluidized bed reactors. As discussed in the following, this may become more important as novel approaches to continuous Boule growth become more common.

Lastly, lessons are still being learned in regard to upgraded metallurgical grade (UMG) silicon, although demand remains at very low levels. UMG silicon is refined through metallurgical refining processes, which are cheaper than gaseous distillation. The capability to make cells with competitive efficiencies using UMG silicon has been demonstrated in practice, but the drive for cell efficiency retains the emphasis on PV grade-based cells.

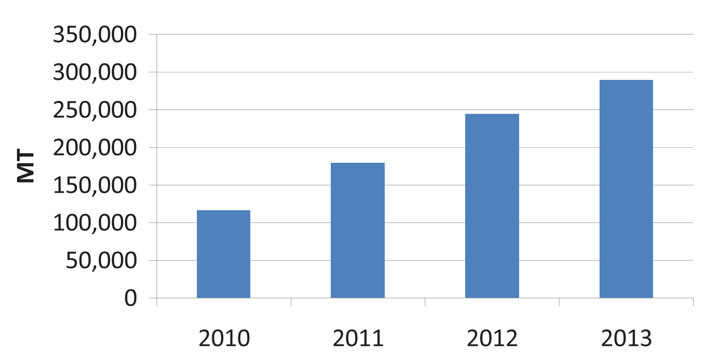


Figure 1. Forecast of global PV polysilicon production.

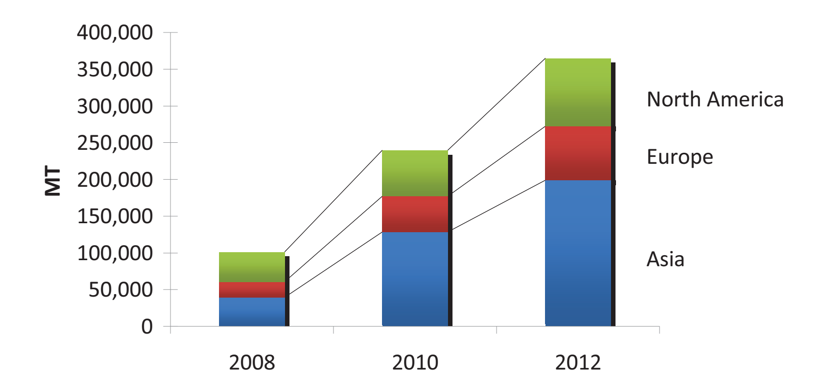


Figure 2. Polysilicon manufacturing capacity by region.

Regional trends

Historically, silicon manufacturing has followed the route taken by the chemicals industry, with major manufacturing centres in the U.S., Europe and Japan. With the development of the requirement for large quantities of silicon to fuel the explosive growth of the PV industry, some traditional suppliers of silicon have risen to the challenge by adding new capacity, but at the same time new players have started production, and others continue to emerge. These new players are shifting the regional concentration of silicon manufacturing capacity to Asia, and Chinese and Korean expansions are expected to add large amounts of capacity in the next few years.

Significant advantage can be gained in the correct selection of a manufacturing site. Electricity prices for polysilicon manufacturers vary by contract and local surplus. Some of the lowest-cost polysilicon is produced in regions with cheap hydroelectric power; in fact, a recent survey showed that global electricity prices were found to vary from US$0.03/kWh to US$0.10/kWh. This obviously represents a huge variation of cost, and is a driver of fundamental cost differentiation.

The explosive growth of polysilicon manufacturing capacity in China has been slowed somewhat by the lack of engineering capability to bring the plants to full yield quickly. Moreover, government regulations restrict the number of plants permitted, currently limited to less than 3000MT/yr, which accounts for a large part of the discrepancy between production and capacity figures shown in Figs. 1 and 2.

Apart from the obvious differentiation factor of silicon quality, production cost is a critical component in the ongoing viability of players in the silicon supply chain. Power is a key input into the manufacturing process, and large polysilicon plants need huge quantities of reliable, cheap power. Companies that can negotiate a bulk long-term supply of power at low market rates lock in price advantages. In times of tight supply all players can profit from higher prices, but in a cyclical industry where capacity addition is on a timescale significantly longer than that of demand fluctuations, overcapacity favours the manufacturers with the best scale and costs.

Global market forces

The silicon market is finishing one major long-term transition in its history, and will have to adapt to another over the short term. As little as three years ago, the consumption of silicon for ICs was equivalent in volume to that of the PV industry. Today, the picture is very different. PV silicon accounts for 76% of the silicon consumption in 2010, and will continue to increase in the future. This is a sea change in the drivers for supply, prioritizing volume, consistency, and cost over excellent quality. On the other side of the coin, the rush to add capacity, especially for newer players using a combination of custom and standard plant, has generated significant engineering challenges.

Crystallization and casting

In 2008 and 2009 multicrystalline cells maintained the majority of demand in 2010, with approximately 60% market share. However, we believe this will erode as cell and module manufacturers push to compete on efficiency.

The technology for both multicrystalline ingots and monocrystalline boules has not changed significantly. Nevertheless, efforts to increase yield and throughput are driving increased ingot sizes, as well as the development of semi-continuous monocrystalline boule growth by replenishing the crucible with granular silicon during pulling. Directional solidification furnaces have been increased in size from 450kg to 650 or even 900kg, with reduced cycle times to ensure improved productivity. Improved ingot and brick metrology have allowed better trimming to remove areas high in impurities.

The most important trend in the area of casting is the shift to mono wafers. The drive to efficiency has pushed cell makers to follow the path of selective emitters, wrapped contacts and back-contacted wafers to reduce shading and improve device efficiency. This in turn is driving a higher demand for mono wafers, and will result in increased demand for pullers over DSS furnaces.

Sawing

The conversion of boules and ingots to wafers is still accomplished by sawing, the technology behind which is undergoing rapid development to keep pace with the productivity requirements. Multiple wire slurry sawing (MWSS) has been used for wafering since the larger wafer became commonplace and rendered internal diameter saws impractical. The first significant recent change is a move from band saws for bricking and squaring to diamond wire saws. Not only does this reduce kerf, but the ability to make multiple simultaneous cuts reduces process time, while saws do not need slurry to make the operation more efficient.

In the case of IC wafers, where surface quality is critical to performance, the wafers can be thick enough to allow the removal of silicon by etch and polishing in order to achieve the required quality. In PV, the wet chemical etch of silicon to remove saw damaged material and to produce a low reflectance texture is kept to a minimum. Cells are also more tolerant to some surface defectivity. However, as the drive to thinner wafers to reduce cost is relentless, and efforts continue to produce

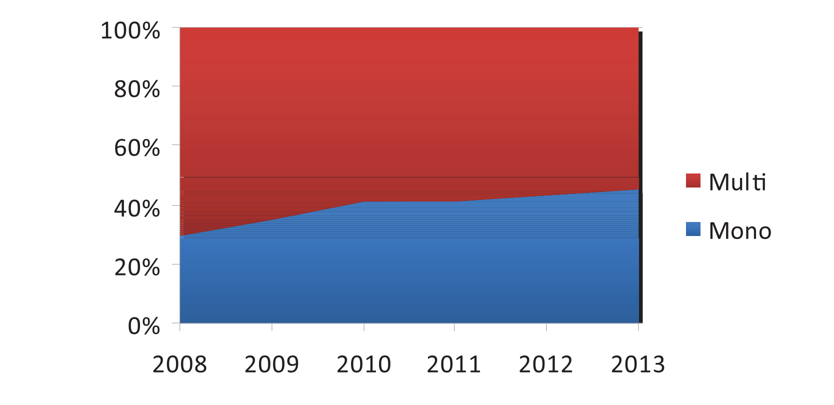


Figure 3. Split of mono- and multicrystalline wafers for cell manufacture.

high-quality, low total thickness variation (TTV), production of wafers at 120 or 100µm continues. In contrast to IC wafers, the move to a larger wafer size is not yet seen as economically important. The added capital, difficulties in processing, and consequent reliability concerns are still high enough barriers to hinder the implementation of 210mm wafers.

SiC slurries are used in combination with steel wire and various carriers and additives. Wire thicknesses and SiC grit sizes are being driven down with the intention of reducing kerf and achieving thinner silicon wafers for efficiency improvements. The limitation of keeping tension on the wire without breakage remains a significant concern, particularly as wire diameter is lost during the cut and the sawn area increases.

Silicon carbide is an abrasive that is commonly used in industrial applications. However, the requirements of the wafering process means that a higher-grade green SiC is used due to its higher 'blockiness' which produces sharper grit at faster cutting speeds. This has to be balanced with wafer thickness variations across the wafer, leading to careful control of grit diameter and morphology. Additionally, smaller grit size is more expensive to buy, offsetting some of its advantages.

The high consumption of slurry for wafering has encouraged a strong response in terms of recycling. This industry accepts formulated slurries, and using centrifuge and separation technology, separates the silicon fines from the slurry components, and then separates the components into the individual carrier and abrasive. These are then supplied back to the user for combination into slurry for reuse when combined with virgin materials. The capital cost of these installations is significant, and scale requires that they be sited close to major wafering factories. As the industry develops centres of excellence, a concentration of wafering sites will develop, and thus an increasing amount of slurry can be recycled. The yields of this process are high, which keeps overall costs down, although there is a significant amount of capital tied up in the recycled slurry. This industry of slurry recycling has grown to approximately US$660m in 2010, although plant suppliers are now offering onsite recycling systems that allow large wafering companies to recycle slurry in-house. Despite this uptake in recycling, the supply of sawing abrasive was found to be tight for much of 2010.

Despite the efficiency of the value chain, the drivers to switch to diamond wire for wafering are compelling. Although currently very few manufacturers use this method to cut wafers, diamond wire supports higher cutting rates, reduces sawing time and increases productivity, while only requiring water as a cooling medium.

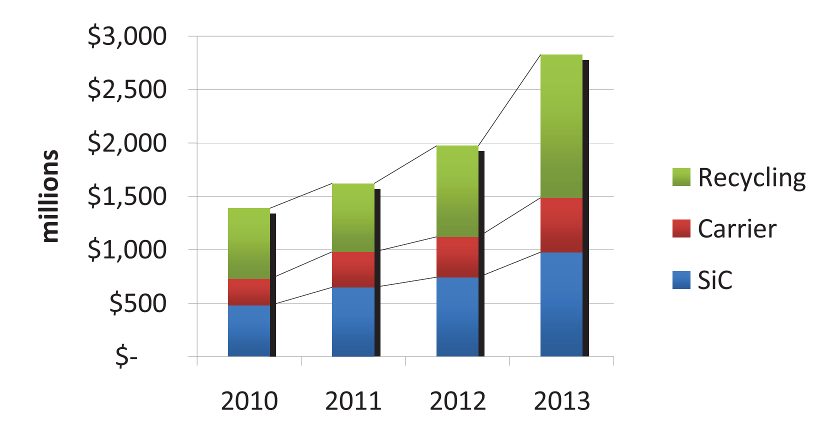


Figure 4. Revenues of sawing slurry.

Efforts are underway to develop silicon recovery methods for both the MWSS and diamond wire approaches. Potentially the largest available gain in the silicon wafer value chain, recovery methods could see the re-use of approximately €0.1 to €0.12/W of wasted silicon. Although this remains a challenging feat, it will be easier to perform from water than from a PEG/SiC mixture, and processing costs cannot exceed the value of the materials recovered. Another option is the sale of the high purity mixture of SiC and silicon for processing in the ceramics industry.

The uptake of slurry recycling can also impact other potential materials suppliers indirectly; for example, slurry performance can be improved by the addition of additives to both suppress agglomeration and help the cutting process. Current recycling technologies cannot easily remove these additives, nor can their concentration be well controlled. Consequently, recycled slurries are normally left additive-free in order to avoid these problems, a feature that has made market entry difficult for suppliers of these additives.

Novel technologies

The demonstrated limits of sawing lie at around 80µm today, but research and development continues to strive towards achieving silicon thicknesses of the order of a few tens of microns. The preferred routes today include implantation and stress cleaving, epitaxial layers on carrier substrates, silicon on porous silicon and laser cutting. Once the thin silicon slices are produced, the challenge remains of developing effective processes and equipment to process ultrathin wafers. However, the combined challenges of developing the wafer-slicing methodology and the subsequent process technology mean that implementation of these technologies are several years in the future.

Conclusions

The entire PV industry is still reliant on the political goodwill of the regional governments that support the commercial and residential investors in PV. Supply chain participants have to manage the vagaries of political decision-making while also developing strategic and tactical plans to gain share in a rapidly expanding market.

While some materials involved in the supply of wafers are highly transportable (silicon, slurries, crucibles, etc.), services such as recycling are highly localized, and cannot economically be centralized. Factors such as labour, power and cell-making clusters have dictated that the silicon, casting and sawing supply chain is globally distributed, and will remain so.

With the demand for PV-grade silicon in 2010 well over 100,000MT, and silicon cost still at about 60% of the module bill of materials, hopes for price declines through scale and increased competition become vital if we are to facilitate the final project returns. The background of reduced subsidies in nearly all PV markets will contribute further to the squeezing of profit pools, and each step will become commoditized.

On the other hand, the sheer scale of current demand – and the potential for an increase of perhaps an order of magnitude over the next decade if forecasts are realized – means that this is a market for companies with either deep pockets or strong market credibility that will allow them to raise the large amounts of capital needed to service a utility-scale PV industry that is capable of supplying 100GW of annual capacity or more.

About the Author

Mark Thirsk is Managing Partner of Linx Consulting. Mark has over 20 years' experience spanning many materials and processes in wafer fabrication. He has served on the SEMI Chemicals and Gases Manufacturers Group (CGMG) since 1999, acting as Chairman between 2001 and 2003.

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Challenges of the wire saw wafering process

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ABSTRACT

This paper discusses the wire sawing process and its impact on the wafer surface and subsurface. Surface damage is found to be the main determinant in wafer stability, while an outline of the sawing parameters that have a strong influence on the surface and subsurface damage is presented. The results indicate how it is possible to decrease the breakage rate of wafers and improve the homogeneity (e.g. TTV) of wafer surfaces. A further goal in the development of the wire sawing process is to successfully reduce material consumption. This can be achieved by sawing thinner wafers with thinner wires, which leads to a reduction of the kerf loss per produced silicon surface. The second option is to increase the material yield by decreasing the wafer breakage. It will be shown that silicon wafers with less and shorter cracks and smoother surfaces will give a higher yield, while proceeding to discuss some of the important factors that affect the microcrack formation.

Introduction

Multi-wire sawing still remains the main slicing technique for large multi- and monocrystalline silicon crystals in the photovoltaics and microelectronics industries. Since sawing contributes considerably to the wafer production cost, there is a great level of incentive to improve the sawing technique for further cost reduction in mass production. Slurry-based sawing is still the main technique used today, but sawing with fixed abrasive wires is an option for the future. Research actions and results of various groups over the last few years have led to a basic understanding of the microscopic details of the slurry-based sawing process, some of which are important to the focus of this paper. Advances in the wafer production process towards thinner wafers, higher yield, lower consumption of energy and consumables has shifted the focus to new issues.

These issues – many of which will be addressed here – have been investigated and developed using new experimental techniques by TU Bergakademie Freiberg over the last few years. For this purpose, an industrial wire saw was equipped with monitoring tools such as force and temperature sensors and a high-speed camera, allowing our researchers to obtain more of an insight into the microscopic details of the sawing process and the interaction processes of the wire, the slurry fluid and SiC particles with the silicon crystal.

Slurry-based multi-wire sawing experiments were performed under different conditions to investigate the influence of machine and material parameters on the sawing process and wafer quality. Important parameters like wire thickness and feed and wire speed were changed, while a range of slurry types were used, allowing the variation of such features as silicon carbide grain size, carrier fluids and silicon carbide loads. The as-sawn wafers were characterized by determining the fracture stress distribution, the surface roughness and subsurface damage, and the thickness variations (TTV) of the wafers. The results can be analyzed with respect to the factors that are important for further improvement of the slurry system, the wires and the sawing parameters.

Microscopic removal process of rolling and indenting particles

There is a general consensus that free-floating abrasive particles in the sawing channel remove material by rolling and indenting into the silicon crystal surface, the basic mechanism behind which is described in the following. SiC powders are currently mainly used as an abrasive; diamond powders are also an option but are not used in mass production for obvious cost reasons. In order to ensure good lubrication in the sawing channel, the particles have to be suspended in a carrier fluid, the most commonly used being polyethylene glycol (PEG). However, the role of the fluid and its relevant properties are still not completely understood.

The abrasive slurry is introduced above the wire web. This wire web then drags the slurry to the silicon ingot, which is moved toward the wire web at a feed rate of 0.4 to 0.8mm/min. The wire moves at a speed of up to 15m/s.

A closer look at the sawing channel is necessary in order to thoroughly analyse the removal process. The schematic in Fig. 1, which depicts events in the sawing channel, shows a situation whereby the silicon is being pushed bottom-up against the wire. The space between the wire and the crystal surface is filled with the carrier fluid and abrasive particles. The coarser particles are in contact with the wire and the silicon surface. As the wire pushes against the particles, it indents these particles in the silicon surface. Those particles between the wire and the ingot are mainly responsible for the material removal process, whereas the particles at the side of the channel determine the damage on the final wafer surface.

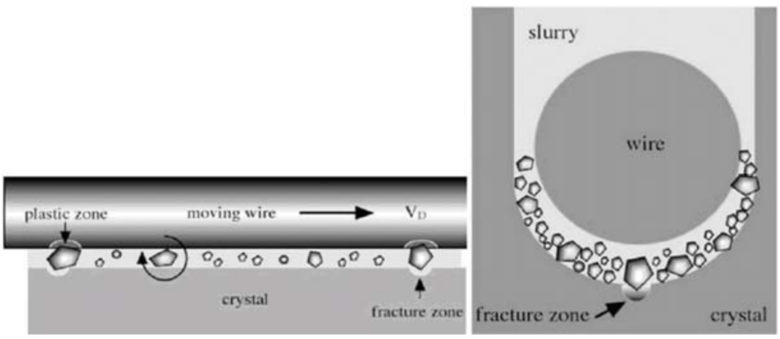

Figure 1. Left: Schematic diagram of wire, slurry with abrasive, and crystal in the cutting zone. Under external force the wire bows and exerts forces on the particles and the slurry fluid. Right: Cross section of wire, slurry with abrasive, and crystal in the cutting zone [1].

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Indentation pattern

The interaction between the abrasive SiC particles and the crystal yields a distinct damage pattern on the surface that can be analyzed using microscopic techniques. The typical surface structure consists of local indentations (Fig. 2) with a mean diameter of a few micrometers. A single indentation by a Vickers-indenter provides a good model of a single chipping event.

The structure of the wafer's surface, as shown in Fig. 3, can be explained by the indentation of loose, rolling particles into the crystal surface, which eventually chips away small silicon pieces. Since SiC particles are facetted and contain both sharp edges and tips, they can exert high local pressures on the surface. This rolling-indenting grain model forms the physical basis of our description of the wire sawing process.

Median cracks are generated as well as the abrasion by lateral cracks. These median cracks extend into the bulk material and are unavoidable in terms of the use of the wire saw technique (Fig. 4).

In-situ observations of abrasive particles

In the quest for evidence of the rolling and indenting particle process, a new method has been established that provides a direct glimpse into a sawing channel [2]. This model experiment involves the cutting of a steel wire into a transparent glass brick, giving a clear view of the rolling and indenting processes in the glass body by using a high-speed camera combined with a microscopic objective.

For the purposes of analysis, a glass ingot with a prepared sawing channel was fixed into a laboratory single wire saw, with the sawing channel located close to the camera side of the glass surface. A cutting wire with a diameter of 120µm was introduced into the prepared sawing channel. The slurry consists of PEG 300 and SiC with an F800 particle size of d50 = 6.5µm and a very diluted slurry with a load of 2 wt. % [3]. This low slurry load was necessary to allow the observation of distinguishable particles. The single wire loop was 75cm long with a speed between 2mm/s and 2m/s. A high-speed camera, which can take up to 30,000 pictures per second, was combined with a microscopic objective with a 10- to 63-fold magnification so that the motion of individual particles was rendered observable.

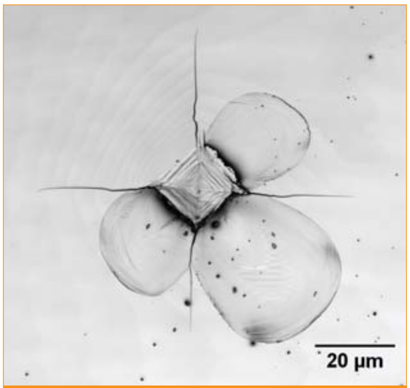

Figure 2. Damage structure after an isolated Vickers indentation. Material is removed by chipping under the load.

Figure 3. Surface of slurry wire sawn silicon wafer.

Fig. 5 presents a lateral view into the sawing channel, including the visible silicon carbide particles (black dots) below the wire where the chipping takes place. The measured height between the wire and the ingot surface is about 10 to 16µm and is determined by the size of the bigger particles. The upper part of the image shows the already-cut glass ingot as well as particles that have been flushed upwards along the side of the wire.

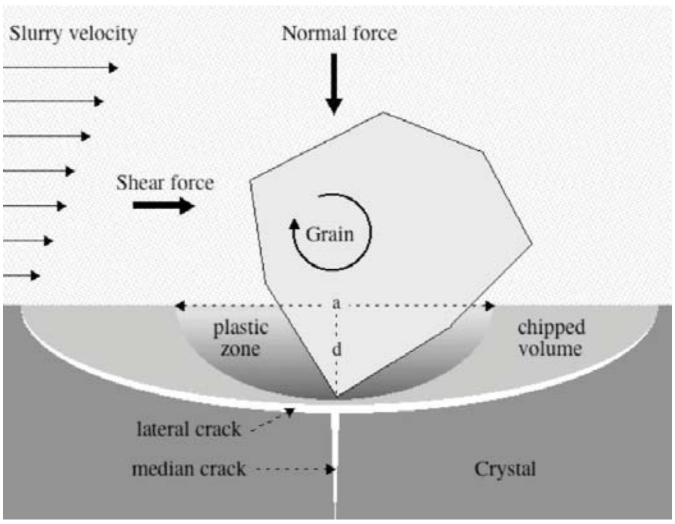

Figure 4. Schematic indentation of a particle into a brittle substrate. Under the action of normal and shear forces, first a plastic zone and then two crack systems are formed. The extension of the lateral cracks and the depth of the plastic zone give an approximate determination of the chipped volume. The median cracks partially remain in the subsurface and are part of the saw damage.

The biggest particles were found to come into contact with both the wire and the crystal surface; those particles that touch the moving wire rotate in the sawing channel (Fig. 6), which is clearly visible in images taken from a time sequence of the process in the sawing channel. The particle in the middle of the sawing channel rotates in the same direction as the wire moves as a result of contact by the wire, while the single edges of the particle are made to spin by the particle's rotation. This special particle has a low circularity.

The results confirm that cutting is carried out by particles in contact with both the wire and ingot. It also appears that the biggest particles can be removed from the sawing channel either at the wire inlet or by squeezing them sideways out of the cutting zone.

Measured parameters

The formation of cracks and therefore the removal process depends on machine parameters such as wire and feed speed, and the slurry properties [4]. Force measurements at the ingot are a useful tool for the evaluation of the impact of these parameter variations.

Force measurements during wire sawing

A silicon ingot might be lost when the wire ruptures during cutting, an error that can be avoided by reducing the tension on the wire. The total tension consists of the wire tension given by the machine and the additional tension caused by the force of the brick. Measurement of the

Figure 5. Image of the sawing channel in a glass sample as viewed from the side. The channel is illuminated from the back side with a halogen lamp. The particle movement was observed with a high-speed camera [2].

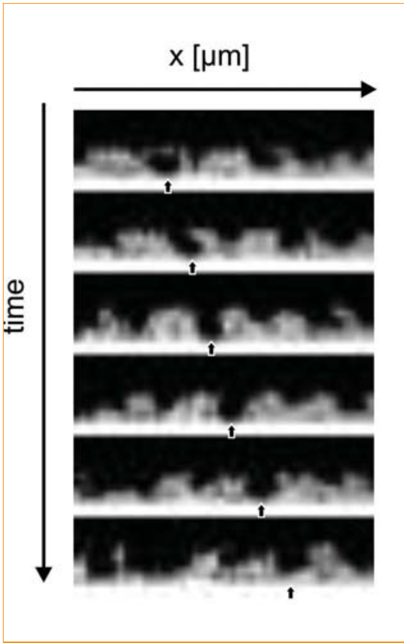

Figure 6. Successive images of the sawing channel in a glass sample showing the rotation of a single SiC particle (section width is 137µm).

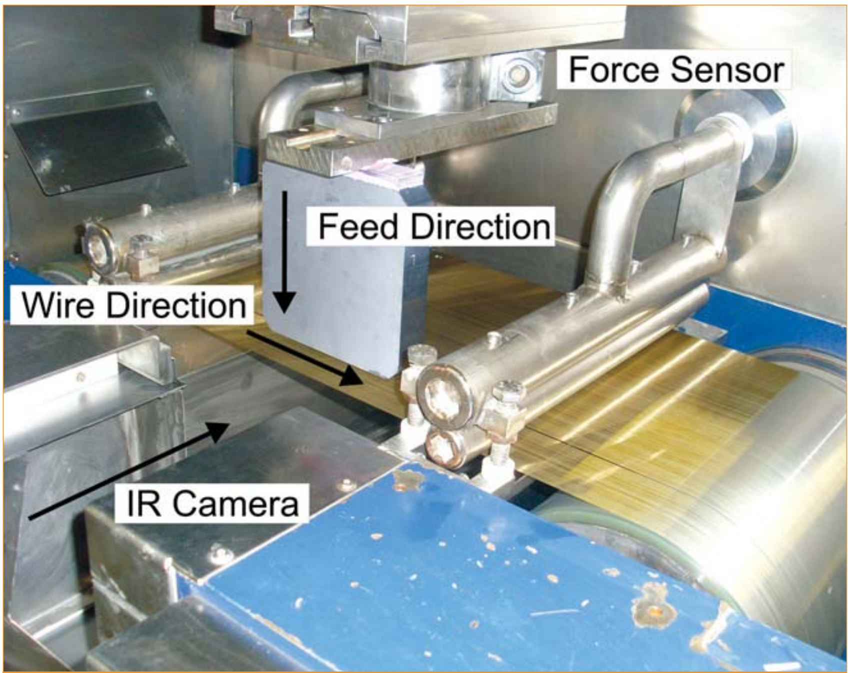

Figure 7. A view into the modified sawing chamber of a Meyer Burger DS 265 wire saw showing slurry nozzles, wire web, feed-in table with mounted force sensor and ingot, and an opening on the side for the infrared camera.

total tension requires the installation of a force sensor between the ingot and its mounting to the saw (Fig. 7). This load cell records the forces during cutting in the wire's direction, the direction of movement of the brick (feed direction), as well as the normal force on the wafer's surface. The force in feed direction is of special interest for the load of the wire; familiarity with this type of force is also essential for a thorough and accurate evaluation of the effectiveness of the sawing process. The force in wire direction describes the friction force and determines the energy loss of the sawing process. An example of such a time-dependent force measurement is given in the graph in Fig. 8, plotted from data gathered from the cutting of a multicrystalline brick with a wafer length of 156mm.

At the beginning of the sawing process, wire and table speeds increase, as does the area of brick that is in contact with the wire, leading to a gradual escalation of the forces at play. Although the force in the wire direction reaches a state of equilibrium within a few minutes, it continues to oscillate at the same frequency as the slurry temperature, which is regulated by a water cooling circuit. In this particular case, the temperature of the slurry that flows out of the slurry nozzles oscillates at an amplitude of about 1 K and over a period of about 7.5 minutes. The force in the wire direction oscillates with the same period and at an amplitude of ±0.05N/(wire·mm). Higher temperatures lead to lower viscosity and hence lower friction in the wire direction.

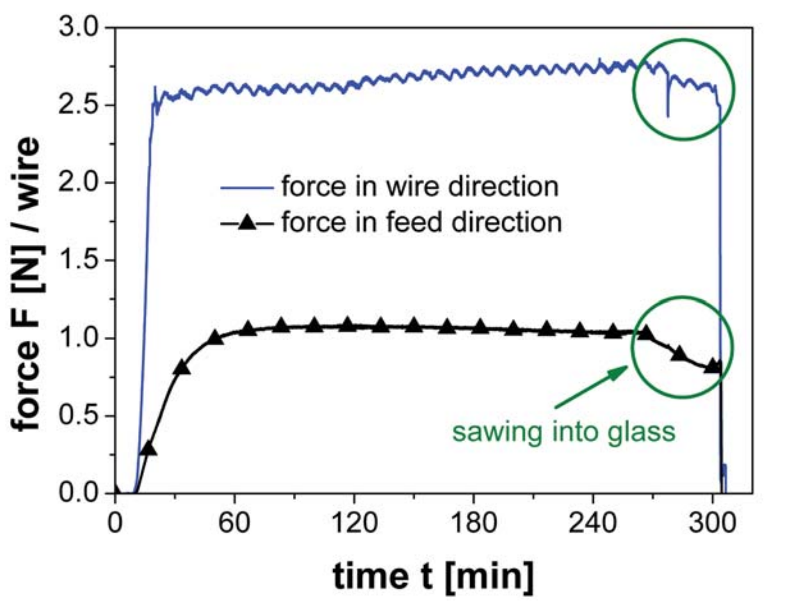

Figure 8. Forces in wire and feed direction measured at the ingot during cutting as a function of time.

The force in the feed direction needs time to reach a steady state. This 'bootup' time can take approximately 70 minutes, depending on the wafer size and the feed speed, as the wire bow must be built up. The force exerted by the bow is in equilibrium with the force in the feed direction. As the wires bow down due to the feed, they exert a force upwards. At the end of the process, the wires cut into the mounting glass plate, the wire and table speed are reduced and the forces decrease.

Measurements of transient brick temperatures during wire sawing

Equivalent information can also be obtained by observing the increase of brick temperature due to the friction. The temperature on the side face of the ingot is measured with an infrared (IR) camera, which is positioned normal to the wafer surface [5,6].

Fig. 9 shows a typical temperature distribution with a gradual increase of temperature of about 15 K from the wire entrance (left side) to the wire exit (right side). The parameters that influence the removal process also have an effect on the friction in the sawing channel. The forces at play in the wire direction are basically in agreement with the heat development in the brick.

Slurry fluid

The slurry fluid is charged with the responsibility of carrying out several tasks at once. It has to transport the abrasive particles into the sawing channel and the abraded silicon chips out of the sawing channel. In addition, it acts as a removal mechanism for the iron particles that are worn from the wire. For sawing purposes, the SiC particles have to be dispersed homogeneously in the slurry fluid, which in turn transmits the kinetic energy from the wire onto the abrasive particles. The slurry also has to avoid contact between wire and ingot, and thus reduce the lubrication force. Any reduction in the slurry's viscosity lowers the TTV [7]. In contrast, an increase in lubrication force causes an increase in the distance between wire and ingot, as well as an increase in the TTV. Finally, the slurry cools the ingot during sawing.

The slurry viscosity is the main factor behind the internal friction and lubrication in the sawing channel (Fig. 10). Attention must be paid to the process by measuring the forces at play in the wire direction as slurry can splash against the front brick side at the wire inlet, resulting in an additional force on the ingot. This force was subtracted from the total measured force to obtain the net friction force [5]. Preliminary results also show a weaker dependence on slurry viscosity for the forces in the feed direction.

Knowledge of the slurry's temperature is essential for accurate determination of the slurry viscosity in the sawing channel. For instance, the temperature in the sawing channel rises from 33°C at the wire inlet to 47°C at the wire outlet point, as depicted in Fig. 9. This causes a reduction of the slurry viscosity along the wire, which has an impact on the sawing performance (Fig. 10). Although this effect is not completely understood, it is clear that this effect is reduced for a slurry fluid with a lower temperature dependence on the viscosity.

Fig. 11 shows the viscosity of different slurries as a function of temperature. The degree of dependence, depicted by the slope of the curves in the graph, decreases from PEG300 to PEG200 and decreases further for mineral oil. The viscosity of the PEG200/F800 slurry decreases more severely with rising temperatures than does the viscosity of mineral oil/F800 slurry. Between 45°C and 53°C, the viscosities of these two slurries are quite similar.

The slurry viscosity is also dependent on the mass fraction of SiC particles; slurries containing 42 to 49 wt. % of SiC are usually applied. Keeping the mass concentration constant, the slurry viscosity rises significantly for smaller grit sizes (Fig. 12). In practice, finer SiC grit sizes are used to ensure that wafer surface damage is kept

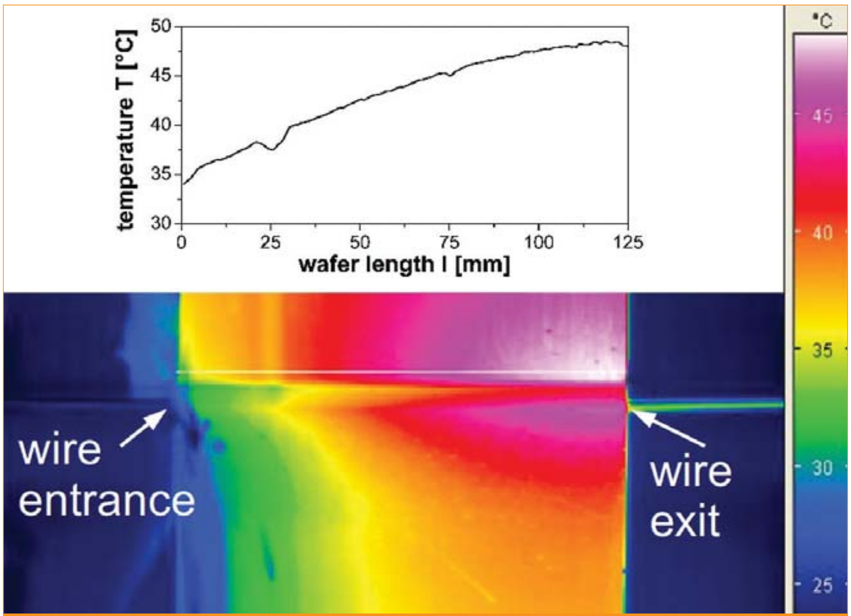

Figure 9. Temperature distribution at the ingot surface measured with an infrared camera.

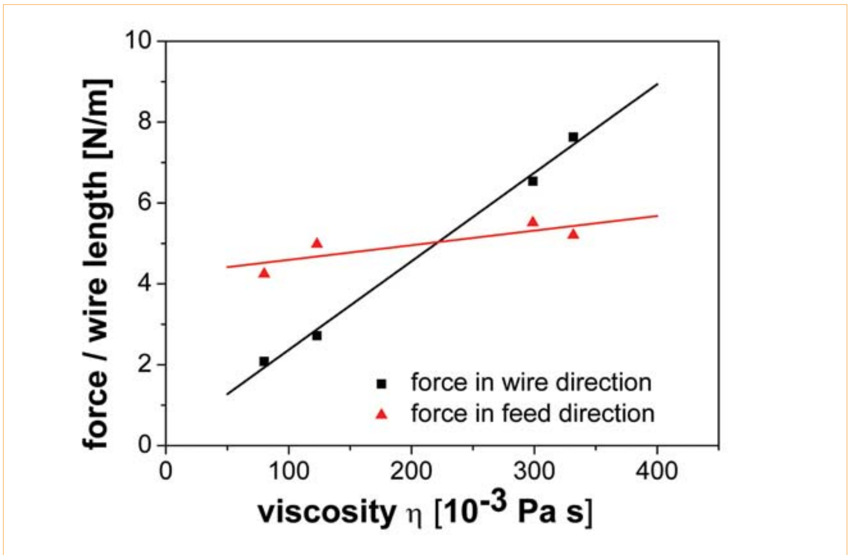

Figure 10. Measured forces per unit wire length during cutting vs. slurry viscosity (at room temperature, for different slurries).

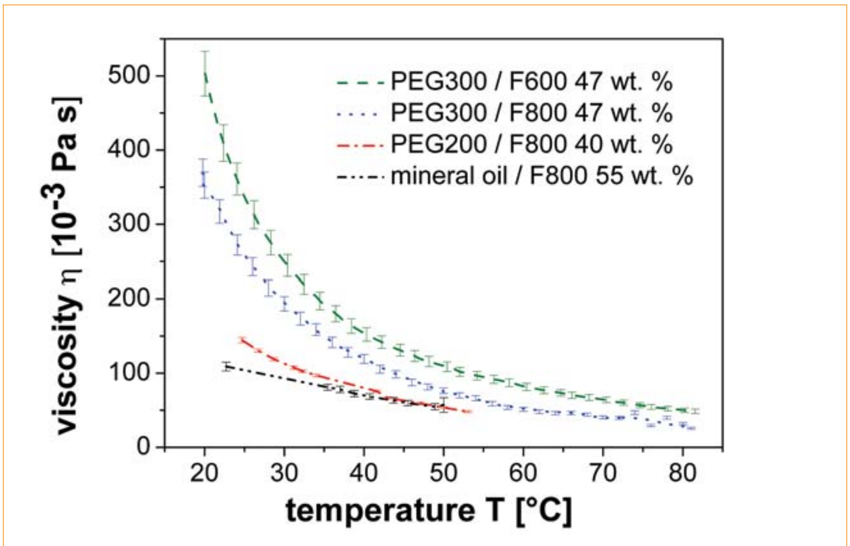

Figure 11. Slurry viscosity vs. temperature.

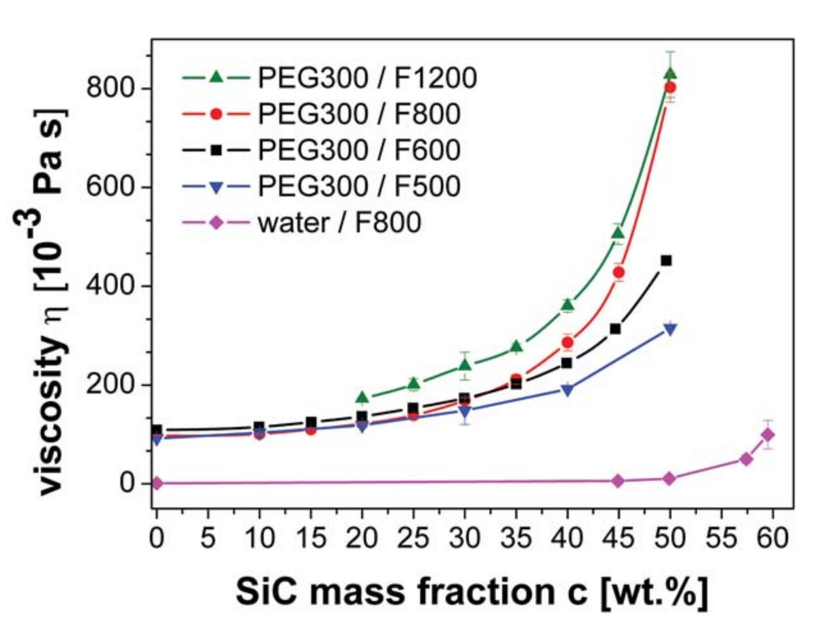

Figure 12. Slurry viscosity vs. SiC mass fraction.

to a minimum – a factor that is especially important when sawing thinner wafers.

However, more energy is needed when using finer grit sizes (Figs. 10 and 12), while the total thickness variation decreases [7,8]. Furthermore, the flow properties of the slurry at room temperature are greatly affected, which might increase the risk of wire breakage. Finally, for reduced grit sizes of SiC, the concentration at which the viscosity diverges is also reduced. Therefore a reduction of SiC content is necessary in order to adjust to the optimum viscosity regime; conversely, an SiC content that is too low reduces the sawing performance such that the optimum performance regime becomes limited.

In addition to the influence of the abrasive concentration and the temperature, the flow characteristic of the slurry also depends on the carrier fluid. The change of the slurry fluid to PEG200, mineral oil or even water is a feasible option to keep the slurry viscosity optimal. The fluid should be optimized in respect to temperature dependence of the viscosity, heat conductivity, surface tension and the difference in density between the carrier fluid and SiC – all of these parameters can influence the sawing process. Nevertheless, the impact of the slurry's properties on the sawing performance is still not completely understood.

Wafer quality

A detailed evaluation of the sawing process would not be complete without a closer look at the wafer's surface quality. Such scrutiny also allows inspectors to draw some conclusions as to the wafer's surface properties and its likely behaviour in regard to the cutting process. It is extremely important to characterize the wafer surface and document any damage accurately.

The wafer surface can be described in terms of its roughness and subsurface damage, while the wafer thickness, total thickness variation (TTV) and the kerf width [8,9] can offer additional information regarding the cutting process.

Cracks are generated by indenting particles. The microcracks, which go from the wafer surface into the body of the wafer, directly determine the wafer stability. These

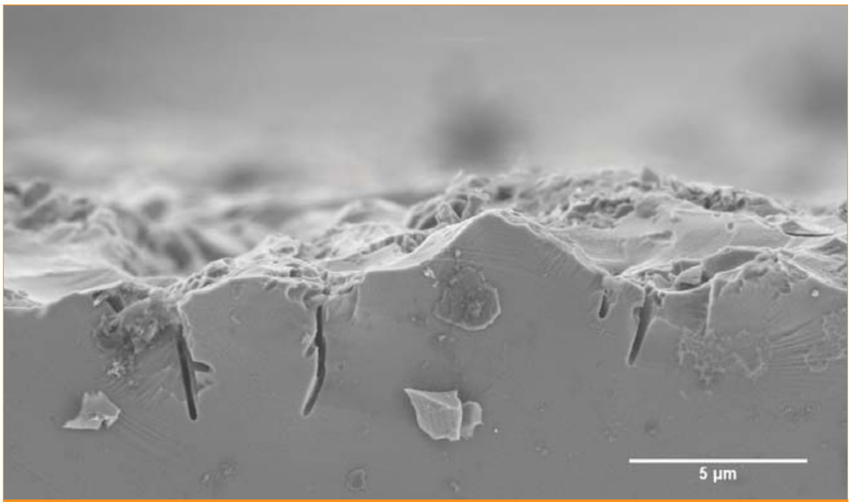

Figure 13. Cleavage edge of an as-cut wafer after etching observed with a scanning electron microscope.

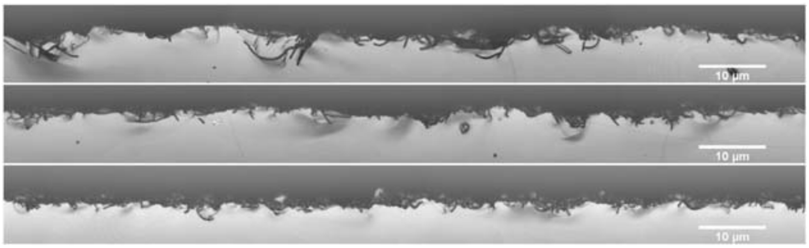

Figure 14. Cleavage edge as observed with a confocal microscope at the wire inlet (top), at the centre of the wafer (middle) and the wire outlet (bottom). Image scope is 120µm × 12µm.

cracks depend on the shape, the size and the indenting force of particles, wire load and wire speed. Several different measurement methods exist that can describe the frequency of cracks, crack depth and fracture stresses of a wafer charge.

Crack investigation at cleaved edges

Access to sharp images of the as-sawn wafer surface and three-dimensional height information are extremely advantageous in the investigation of rough surfaces. To this end, the application of confocal microscope measurements has turned out to be very helpful. Images showing the crack distribution and damaged wafer surface can also be gained by scanning electron microscopy (SEM), as shown in Fig. 13, but investigating a large amount of cracks using this technique would indeed be a tedious task.

The confocal microscope was used to determine the crack size distribution and the crack density of wafer surfaces near the wire inlet and wire outlet on cleaved cross sections of a monocrystalline silicon wafer. Samples were broken into parts and etched by Secco-etching-solution to widen the cracks to allow for better investigation [10], a method that is only applicable to monocrystalline silicon because of the necessity for cleaving. The three images in Fig. 14 show the cleavage edge as observed with a confocal microscope of the wire inlet, middle of the wafer and the wire outlet.

Crack investigation at bevelled surfaces

Another technique developed by TU Bergakademie Freiberg is the characterization of subsurface damage on bevelled polished specimens. The depth distribution of microcracks becomes visible on polished surfaces which are at a slight incline to the original damaged wafer surface [11]. The surfaces are slightly etched to widen the cracks, allowing the calculation of the depth of the microcracks. This method works both for single and multicrystalline silicon.

Fig. 15 shows an example of the coarse section and a detailed view of a bevel polished surface. The bottom part of the left micrograph corresponds to the as-sawn wafer surface. The transition region from the as-sawn surface into the laid-open inside of the wafer is enlarged in the right part of the image. The black thread-like lines are penetrative microcracks; the black areas are indents and pits. By measuring the micrographs and surface profile of the bevel polished surfaces, it is possible to ascertain which crack goes deepest into the volume of the wafer and its depth. The crack depth was measured along the wire direction on bevelled surfaces for different SiC grit

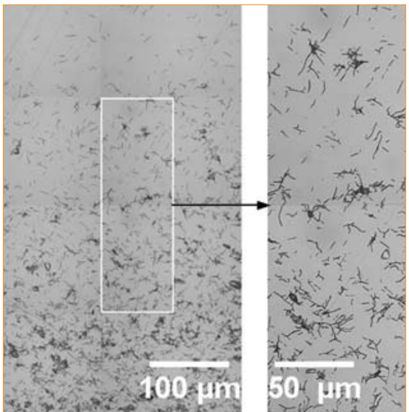

Figure 15. Micrograph of a polished and etched bevel cut.

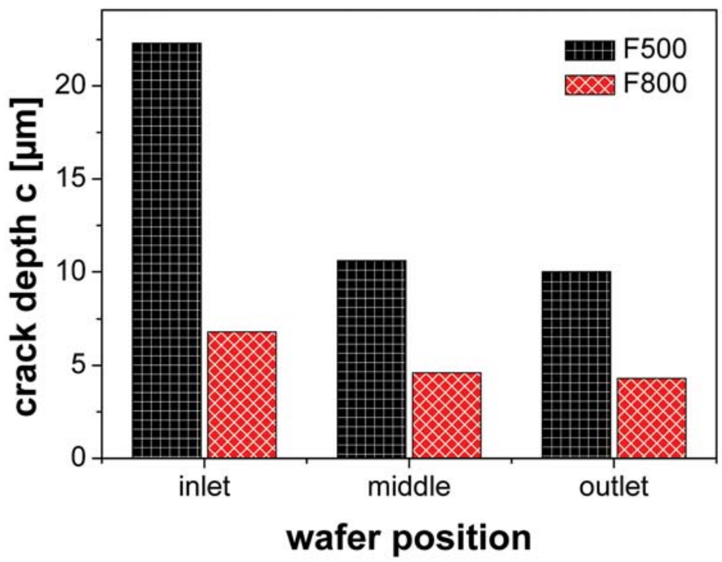

Figure 16. Crack depth as a function of position on the wafer for wafers sawn with different particle size distributions.

sizes leaving the other sawing parameters constant.

Results of crack depth measurements

The distribution of cracks in a wafer is inhomogeneous. Cracks tend to be longer at the wire inlet, decreasing in length towards the wire outlet (Figs. 14 and 16), Furthermore a decrease of roughness can be clearly seen (Fig. 14).

Crack depth results were obtained for wafers sawed with particle size distributions of F500 and F800 (see Fig. 16). Investigations conducted on bevelled surfaces show that the crack depths are strongly influenced by the size distribution of SiC sawing particles. Finer grit sizes reduce the damage depth.

Spatial crack distribution and crack density

Counting the number of cracks along the cleavage edges of the three images in Fig. 14 shows that the number of cracks increases from wire inlet to wire outlet. In order to prove this observation, the crack size distribution and the crack density in a larger area were determined by evaluating several images of 64 × 294µm in size. At least 1mm of cross-sectional sample length has to be measured to ensure a statistically reliable result.

A decrease in the crack size is also to be found in the depth distributions in the form of a shift from deep cracks to shallower ones (Figs. 17 and 18). The local crack density is obtained by counting the total number of cracks (Fig. 19). While the wire inlet features fewer but larger (4.5µm) cracks, the wire outlet tends to generate more numerous but shorter (2.5µm) cracks.

The finding that the fracture stress distribution of a batch of wafers depends not only on crack size but also on the density of the cracks is an extremely important result, and one that is quite often not taken into account. On the one hand, it is necessary to reduce the crack size, but at the same time, the number of cracks induced into the material should not increase. Both size and density of cracks are entered into Weibull statistics [12] and influence the characteristic fracture stress σ_0 (Equation 1).

Mechanical properties

All the experimental results about the microcracks penetrating from the surface of the sawn wafer into the volume confirm that the crack lengths follow a distribution. This crack length distribution is influenced by the grit size of sawing particles, the sawing parameters and possibly the shape of the particles. In addition, the distribution varies over the wafer surface.

Weibull analysis

As silicon is brittle at temperatures lower than 880K [14], these crack length

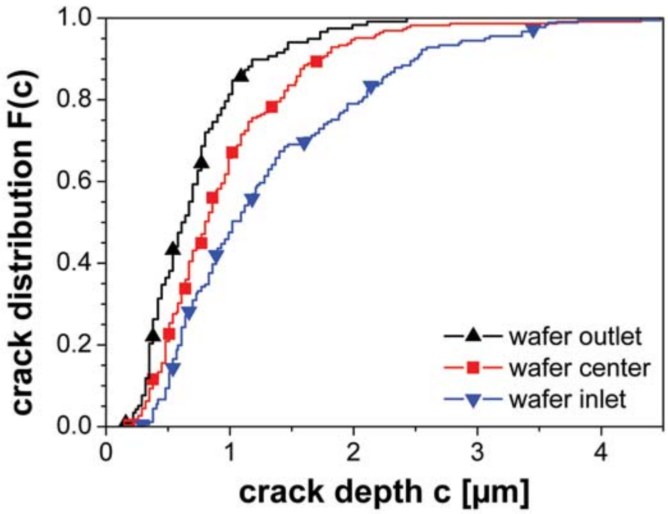

Figure 17. Crack depth distributions F(c) along the cleavage edge at different positions on the wafer's surface.

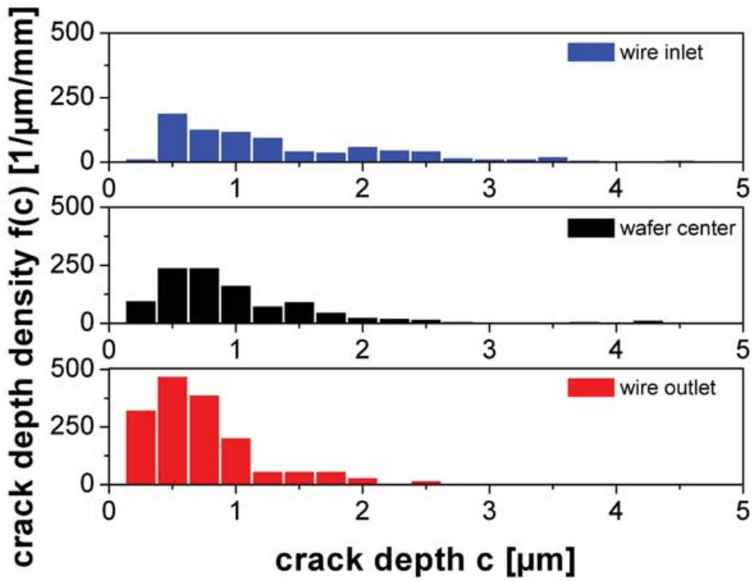

Figure 18. Histogram of the counted crack depths at different positions along the wafer's cleavage edge.

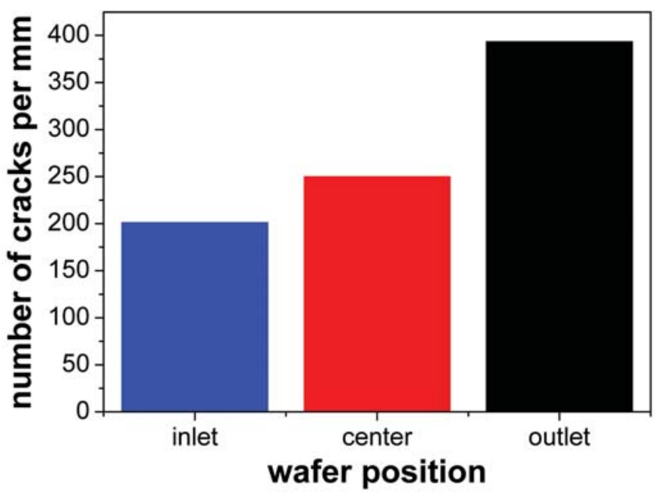

Figure 19. Total number of cracks along the cleavage edge at different positions on the wafer's surface.

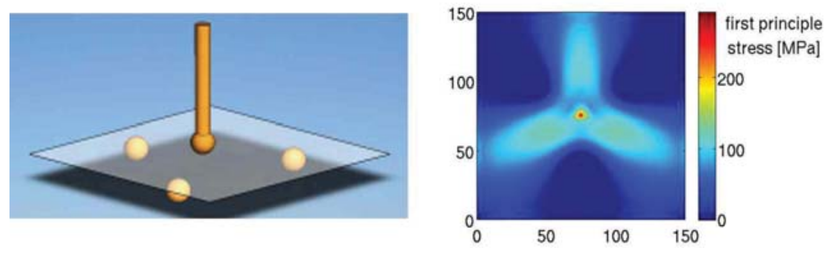

Figure 20. Left: fracture test setup. Right: finite element calculations of stresses generated in a silicon wafer through 5mm displacement in a biaxial fracture test setup (Young's modulus = 165GPa; wafer thickness = 200µm).

distributions are directly responsible for the mechanical properties of the wire-sawn wafer [13]. The 'weakest link,' or the longest crack in a loaded wafer, will undoubtedly cause mechanical failure. Brittle fracture of the wafer occurs instantaneously if any crack is loaded with stresses exceeding the strength of that crack. When loading different wafers in a batch of comparable wafers, the fracture stresses will be different for all wafers and will form a fracture stress distribution. Statistical considerations based on the inhomogeneous Poisson process of crack lengths or strength result in the Weibull theory and predict a Weibull distribution of fracture stresses [13]:

$$F(\sigma) = 1 - \exp\left\{-\left(\frac{\sigma}{\sigma_0}\right)^m\right\} \quad (1)$$

Here $F(\sigma)$ is the failure probability ($0 \leq F(\sigma) \leq 1$) for a load σ; σ_0 is the so-called characteristic fracture stress where 63% of all wafers are broken; m is the Weibull parameter that characterizes the width of fracture stress distribution. The higher the Weibull parameter m, the narrower the fracture stress distribution. The characteristic fracture stress σ_0 is a function of the loaded volume [13]. The greater the loaded volume, the higher the probability of there being a crack of critical length in the volume. The tested wafer volume is not changed for a fixed experimental fracture test setup. Thus, σ_0 is a feasible parameter for the comparison of batches of wafers with different mechanical properties.

Weibull plots are graphs that plot the fracture stresses of a batch of wafers in the form *ln (ln (1/(1- F(σ))))* as a function of *ln(σ) (or log (ln (1/(1-F(σ))))* as a function of *log(σ))*. Weibull distributed data plots as straight lines. The Weibull module *m* is the slope of the line and $m{\cdot}\ln(\sigma_0)$ is the axis intercept. The steeper the line in the graph, the narrower the fracture stress distribution, while lines that tend more towards the left of the graph represent a weaker batch of wafers than those that tend towards the right.

The estimation of Weibull parameters σ_0 and m should be conducted using the 'Maximum-Likelihood' method [15]. Although the tested volume *V* can be neglected when comparing batches of wafer with the same load test, it plays an important role during the comparison of different fracture test setups.

Depending on the surface type undergoing characterization, there is a variety of different modes of fracture tests available [16]. The biaxial fracture test yields the highest load in the centre of the tested specimen's surface and therefore tests the as-sawn wafer surface [17]. Thus, the biaxial fracture test has been widely used to investigate the impact of wire sawing parameters on mechanical properties of wafers. By cutting the sawn silicon wafers into smaller specimens using a laser beam, this test can even deliver locally resolved fracture stress distributions [18]. A second test set-up uses four-line bending, which exerts a homogeneous stress between the inner bars, both on the surface and on the specimen edges. As long as the cracks on the wafer edges are longer than on the surface (which is frequently the case), this test mainly characterizes fracture properties of the specimen edges between the inner bars. This test can be used to characterize the mechanical stability of the overall wafer,

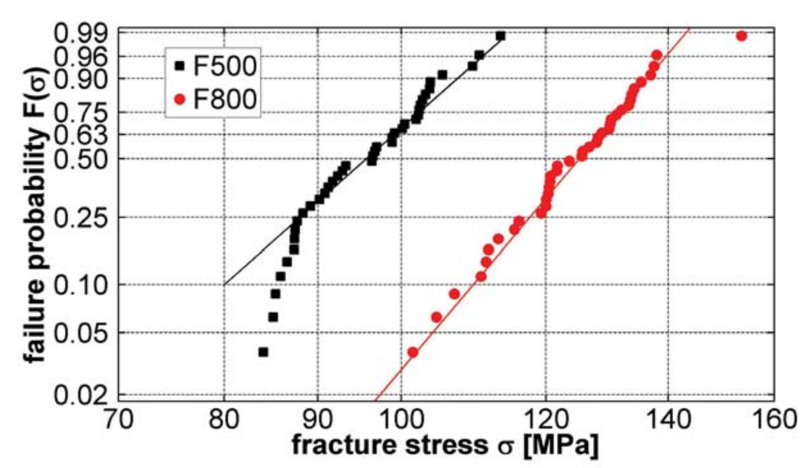

Figure 21. Weibull plot of fracture stress distribution of wire-sawn silicon wafers with varying particle size distribution (sawing parameters: slurry: PEG 300; SiC: 47 wt. %; 14m/s wire speed, 0.6mm/min feed rate.

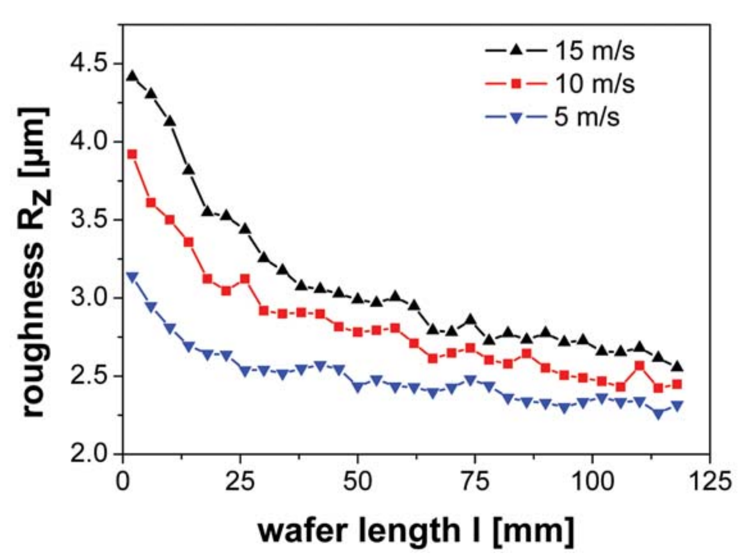

Figure 22. Roughness profiles from wire inlet to wire outlet region for wafers sawn at different wire speeds.

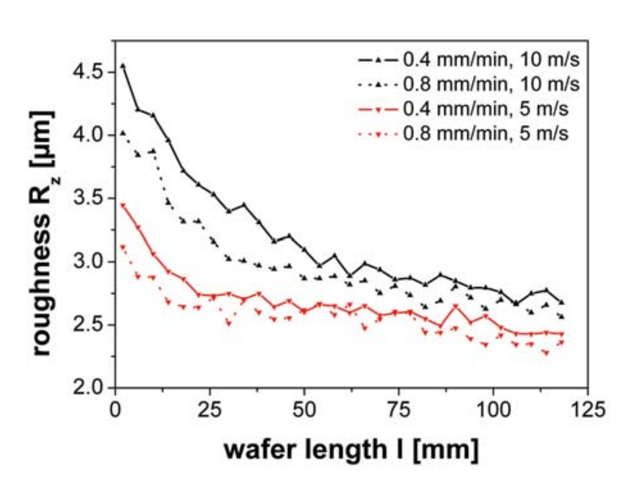

Figure 23. Roughness profiles from wire inlet to wire outlet region for wafers sawn at different wire speeds and feed rates.

including wafer edges, and to check the benefits of the damage etch process [19].

Finite element analysis

Wafer bending tests lead to high deflections of specimens, especially as wafer thicknesses become smaller. In such a case, standard analytical solutions for the calculation of fracture stresses from measured forces are not suitable. Finite element calculations for each wafer geometry and geometrical test setup are required to deduce stress-displacement curves from corresponding measured force-displacement curves [20]. Fig. 20 gives an example of calculated stresses generated in a silicon wafer through displacement in a biaxial fracture test setup.

Fracture test results

The force-displacement curve of Si wafers up to fracture has to be determined in practice. At least 30 to 40 wafers of equal properties should be tested for the statistical Weibull analysis and the determination of the fracture strength distribution [13]. Fig. 21 shows the biaxial fracture test results for batches of wafers sawn with two different SiC-grit size distributions. The line of measured fracture stresses for the F500 sawn wafer lies to the left of the line of measured fracture stresses of the F800 sawn wafers. Thus, the wafer batch sawn with F500 is weaker than the batch of wafers sawn with F800. The F500 wafers show a characteristic fracture stress of σ_0 = (99±3)MPa with a Weibull module of m = 13±3, whereas the results for the F800 wafer are σ_0 = (129±4)MPa where m = 12±3.

Wafer surface – wafer roughness

Aforementioned results have shown that the subsurface damage of a wafer is inhomogeneously distributed. The cracks at the wafer's side, at the point where the wire enters the ingot during sawing, are deeper than at the wire's exit side; similarly, the crack density is higher at the wire exit. Similar patterns are found for wafer roughness, which decreases from wire inlet to wire outlet. Higher wire speeds lead to higher roughness (Fig. 22). The impact of the wire speed at the wire inlet is greater than at the wire outlet.

The surface roughness is less sensitive to the feed rate than to the impact of wire speed. A decrease in the roughness is achieved by increasing the feed rate (Fig. 23). Again, this influence is greater at the wire inlet than at the wire outlet. Roughness (Figs. 22 and 23) and crack depth (Fig. 16) are both functions of the position at the wafer surface, and change in the same way as both parameters originate from the same indentation process during wire sawing.

Our studies have found that the crack depth at the wire inlet depends on the grit size and the sawing parameters, whereas at the wire outlet the crack depth depends mostly on the SiC grit size.

Materials

Conclusions

The results presented herein can offer some guidelines for further developments in the wire-sawing process – particularly relevant considering the need for thinner wafers in the future. The issues that are relevant here are the stability of the wafers to obtain high yield in production and the reduction of silicon material, supplies and energy consumption.

High-speed camera investigations have confirmed that sawing occurs as a result of the direct pressure of the wire on the abrasive particles. The largest particles indent into the ingot and cause material removal and microcrack formation on the wafer surfaces. The wafer damage consists of a rough surface and microcracks, which extend into the bulk. It was shown that the saw damage on the wafer surfaces varies and tends to be higher on the side at which the wire entered the sawing channel. On the other hand, the microcrack density increases towards the exit side. Both factors contribute to the fracture strength of the wafers. The saw damage of the wafer edges depends on the ingot side preparation before the wafers are cut and may be higher than on the surfaces.

The inhomogeneous saw damage has to be taken into account when testing the wafer fracture strength. Different parts of the wafer are tested by the various wafer test methods. Since at present no standard test method has been established, care and attention is required when comparing results from different groups.

The surface damage, which occurs mainly at the wire entry side of the wafers, can be reduced by the use of finer grit sizes, but this also increases the forces on the wire. This limits the use of thinner wires at present as it challenges the fracture stresses for wires. Experimentation and analysis has also suggested that there appears to be an optimum grit size for a given wire diameter.

Furthermore, the extent of the saw damage inflicted also depends on sawing parameters, such as wire and feed speed and tension, and can be reduced to some extent by selecting appropriate parameters – however, this can place restrictive limits on the operation windows in production.

The results also show the influence of the slurry, where viscosity appears to be the major factor. Both the forces in the wire direction (friction) and in the feed direction increase with the viscosity, which in turn increases the saw damage and the forces on the wire. The slurry viscosity depends on the viscosity of the base fluid, the solid fraction of the SiC powder, the particle size, and possibly the shape of the powder grains. Since the temperature during sawing varies along the sawing channel, one also has to take into account the temperature dependence of the viscosity. There is also some indication that if the slurry viscosity becomes too low the surface profile develops wider grooves (saw marks) at the wire exit and the risk of wire rupture increases. At present, the best approach to optimizing the slurry parameters remains unclear.

The edge and surface damage occurs at different slicing steps, requiring the application of different strategies in order to improve the overall stability. Considering the wafer surface damage, our results indicate that there may be limitations to producing wafers thinner than 120μm using the presently available materials for wires, carrier fluids and SiC powders.

Acknowledgements

The authors would like to thank Meyer Burger for the generous loan of an industrial wire saw, which enabled them to carry out experiments for over four years. In particular, they want to thank Dr. Fabiano Assi from Meyer Burger, who supported the work and made valuable contributions to the understanding of wire sawing.

References

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

[2] Kaminski, S. et al. 2010, "The Role of the Slurry Transport in Multi-Wire Sawing of Solar Silicon Wafers", *Proc. 25th EU PVSEC / WCPEC-5*, ISBN 3-936338-26-4, pp. 1312–1317.

[3] FEPA-Standard 2006, "Shapes and Dimensions for Precision Superabrasives", 42–2.

[4] Wagner, T. et al. 2010, "Spatial Distribution of Wafer Subsurface Damage Induced by Wire Sawing", *Proc. 25th EU PVSEC / WCPEC-5*, ISBN 3-936338-26-4, pp. 1267–1271.

[5] Rietzschel, R. et al. 2008, "Optimization of the wire sawing process using force and temperature measurements", *Proc. 23rd EU PVSEC*, ISBN 3-936338-24-8, pp. 1301–1304.

[6] Rietzschel, R. et al. 2010, "Investigation of Polyglycol Based Slurries for Multi Wire Sawing with Lower Forces and Less Hygroscopicity", *Proc. 25th EU PVSEC / WCPEC-5*, ISBN 3-936338-26-4, pp. 1596–1599.

[7] Anspach, O. et al. 2008, "Investigations on Single Wire Cuts in Silicon", *Proc. 23rd EU PVSEC*, ISBN 3-936338-24-8, pp. 1098–1103.

[8] Anspach, O. & Lawerenz, A. 2010, "Understanding the role of abrasives used in the multi-wire sawing process", *Photovoltaics International, 6th Edition*, pp. 36–43.

[9] DIN EN 50513 (VDE 0126-18) 2009, "Solar wafers – Data sheet and product information for crystalline silicon wafers for solar cell manufacturing", Beuth Verlag GmbH, Berlin, Germany.

[10] Secco d'Aragona, F. 1972, "Dislocation Etch for (100) Planes in Silicon", *J. Electrochem. Soc.*, Vol. 119, Issue 7, pp. 948–951.

[11] Funke, C. et al. 2004, "Towards thinner wafers by multi wire sawing", *Proc. 19th EU PVSEC*, pp. 1226–1269.

[12] Wiegand, S. 2003, "Statistische Analysen zur Bruchfestigkeit von Porenbeton und Halbleiterwerkstoffen - Weibull-Theorie und Geostatistik", Diplomarbeit, TU Bergakademie Freiberg.

[13] Munz, D. & Fett, T. 1989, "Mechanisches Verhalten keramischer Werkstoffe", *Springer Verlag*.

[14] Sen, D. et al. 2010, "Atomistic Study of Crack-Tip Cleavage to Dislocation Emission Transition in Silicon Single Crystals", *Physical Review Letters*, PRL 104, pp. 235502-1-235502-4.

[15] DIN 51110 Teil 3, 1993, "Prüfung von keramischen Hochleistungswerkstoffen, 4-Punkt-Biegeversuch, Statistische Auswertung, Ermittlung der Weibull-Parameter".

[16] Funke, C. et al. 2008, "Surface properties of wire sawn wafers", *Proc. 11th Scientific and Business Conference SILICON*, Rožnov pod Radhoštěm, Czech Republic, ISBN 978-80-254-3278-5, pp. 53–58.

[17] Funke, C. et al. 2004, "Biaxial fracture test of silicon wafers", *Adv. ENG. Mater.*, Vol. 6, pp. 594–598.

[18] Orellana Pérez, T. et al. 2010, "Mechanical characterization of epitaxial wafer equivalents from block casting to thin film deposition", *Proc. 25th EU PVSEC / WCPEC-5*, ISBN 3-936338-26-4, 2010, pp. 3619–3625.

[19] Funke, C., Wolf, S. & Stoyan, D. 2009, "Modeling the Tensile Strength and Crack Length of Wire-Sawn Silicon Wafers", *J. Sol. Energy Eng.*, Vol. 131, Issue 1, pp. 011012-1–011012-6.

[20] ANSYS® Multiphysics™, Academic Research, Release 12.1.

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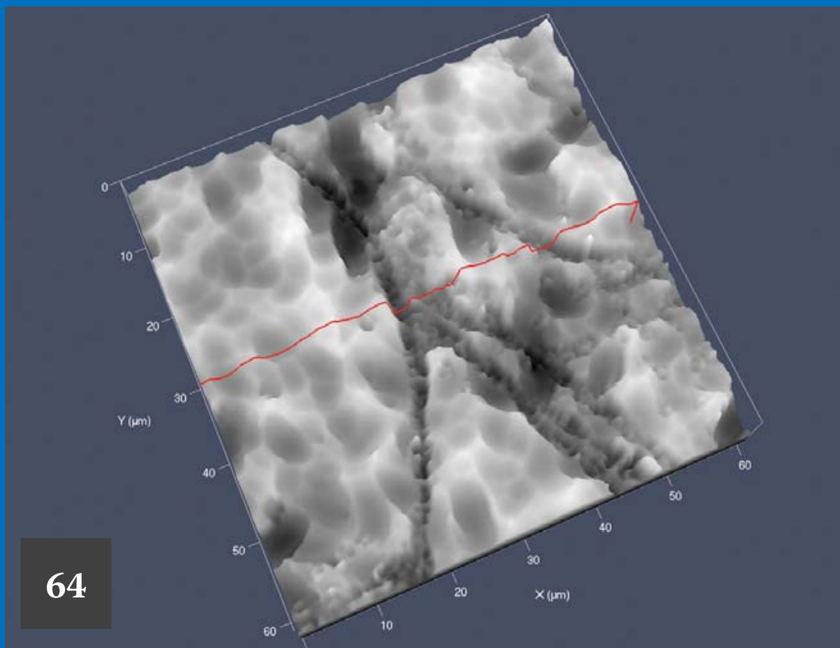
Cell Processing



News

News

Suniva signals 19% solar cell efficiencies in volume production

Production has started on a second-generation solar cell at Suniva that is claimed to achieve efficiencies above 19%, a record for monocrystalline-based cells in volume production using conventional screen-printing processes, according to the company. Suniva is the first to adopt ion implantation techniques for emitter performance improvements.

Suniva's third-generation cell technologies are built around multiple proprietary cell structures certified by NREL as achieving 20% efficiency.

The use of ion implantation in Suniva's manufacturing process is based on years of development collaboration with equipment supplier, Varian Semiconductor Equipment Associates. Varian has claimed that a potential 2% efficiency gain is achievable through the use of ion implantation techniques when migrating to selective emitters and back-contact designs. In Suniva's case, the doping technique produced a 1% efficiency gain, without these more advanced cell configurations.

Cost reductions also come from the elimination of certain process steps that normally required with conventional cell processing.

Part of a 3MW (DC) grid-connected solar farm in Karnataka, India, equipped with Suniva modules.

Cell Efficiency News Focus

Fraunhofer ISE researchers claim near 20% efficiency for silicon solar cells

Researchers at the Fraunhofer Institute for Solar Energy Systems (ISE) have concluded that large-area silicon solar cells are closer than ever to achieving 20% efficiency ratings. The newly researched cell structures differed in the type of silicon material, the base and the type of emitter used. Solar cells with a negatively conducting base are referred to as n-type; those with a positive conducting base are p-type cells and the emitter has the same inverse polarization of the base.

In studying the n-type silicon solar cells with an aluminium-alloyed emitter, Fraunhofer ISE researchers were able to obtain 19.3% efficiency. The research team formed the emitter by screen-printing a paste that contained aluminium, followed by a short high-temperature firing period. Furthermore, when studying the n-type solar cell with a boron-diffused emitter whose surface had an added new layer of aluminium-oxide, the cells produced 19.6% efficiency.

When testing the p-type solar cells, the research team had a phosphorous diffused emitter and used the laser-fired contact (LFC) technology that Fraunhofer ISE developed to achieve 19.6% efficiency.

All test solar cells were process on 125 × 125mm^2 monocrystalline silicon wafers. The Fraunhofer ISE research team noted that there were no added adjusting or structuring steps needed, which led to a simplified, yet quicker processing procedure. Currently, 80% of the crystalline silicon solar cells that are manufactured average between 14% and 19% efficiency, but with the results the team produced, Fraunhofer ISE believes that 20% efficiency is only a small matter of time away.

Yingli Green reports record revenue and shipments: Panda cells at 19.89% efficiency

Yingli Green exceeded financial guidance for its fourth quarter and full-year results. PV module shipments increased by 102% year over year to 1,061.6MW, exceeding guidance previously given of 1,020MW to 1,040MW. Module shipments in 2009 had been 525.3MW. Total net revenue in the fourth quarter reached US$616.1 million, while PV module shipments increased by 21.6% quarter over quarter, a new record.

Total net revenues for 2010 were US$1,893.9 million, exceeding previous guidance of US$1,780 million to US$1,810 million. Gross profit was US$629.2 million, representing a gross margin of 33.2%, exceeding guidance of 32.0% to 32.5%.

The company increased capacity by 400MW in polysilicon ingots and wafers, PV cells, and PV modules in the third quarter of 2010 to support demand and included 300MW Panda cell production capacity in Baoding and 100MW production capacity in Hainan. Commercial production of Panda cells reached a new cell efficiency historical high of 19.89%.

Yingli Green also highlighted that it had been selected to supply approximately 70% of the total amount of 272MW PV projects under the Golden Sun Program in China, which was organized via a bidding process. The majority of shipments to these projects are scheduled to be delivered in the second half of 2011.

centrotherm photovoltaics claim selective emitter line achieved 18.5% efficiencies

centrotherm photovoltaics has claimed its updated monocrystalline solar cell selective emitter line has achieved average efficiencies of 18.5%. The efficiencies were produced for customer Dongfang Magi Solar and are claimed to be well above the industry average. Batches of several thousand standard 156 × 156mm (240cm^2 surface) solar cells were said to have been produced with these efficiencies.

JA Solar unveils high-power multicrystalline silicon solar cell with 18.2% conversion efficiency

JA Solar's R&D team has developed and revealed its new high-power multicrystalline solar cell that is claimed to sport a conversion efficiency of 18.2%. Using its new Maple technology, the company states that its cells feature silicon crystals that are broader, flatter and have less grain boundaries than traditional multicrystalline silicon. This new technology is said to allow for less energy waste and better conversion efficiency.

JA Solar notes that its new cells are closer to monocrystalline solar cells when compared in terms of conversion efficiency, but the company asserts that its new Maple cells can be made with lower-cost multicrystalline silicon production techniques.

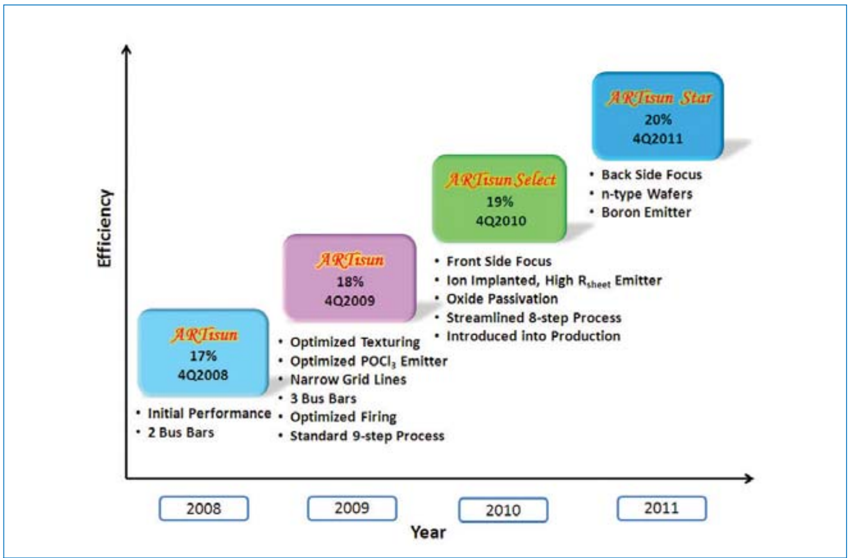
During the pilot production in large-volume manufacturing conditions, the Maple cells are said to have yielded 18.2% conversion efficiencies leading JA Solar to aim for commercial production to begin during the second half of this year.

Suniva and VSEA team on boron implantation for n-type solar cell to boost efficiencies to 20% plus

Continuing their early partnership to introduce ion implantation into the mainstream PV fabrication flow, Suniva and Varian Semiconductor Equipment Associates (VSEA) are to collaborate on the development of implantation of boron in n-type solar cells. Suniva is targeting its ARTisun Star cell to approach 20% cell efficiencies in volume production in the first quarter of 2012.

Suniva recently revealed that ion implantation of phosphorous on its second generation ARTisun Select p-type wafers achieved 19% efficiency in volume production. The National Renewable Energy Laboratory (NREL) has already certified 20% plus efficiencies on several laboratory-scale cells that utilize Suniva's advanced designs for ARTisun Star.

Suniva noted that a combination of boron implantation and precise patterned doping were critical steps in boosting cell efficiencies for high-volume manufacturing at competitive costing.



Suniva's roadmap progression from first production in 2008 through three major developments, culminating in 20% production cells in 2011. The first two developments (2009, 2010) have been completed on schedule.

Cell Production News Focus

Varian Semiconductor debuts Solion PV ion implant technology

During its exhibition at the SNEC PV Power Expo 2011, Varian Semiconductor Equipment Associates unveiled its new Solion PV ion implant platform for the Chinese market. Partnering with seven Chinese PV manufacturers, Varian looks

BTU's Tritan metallization firing system.

to implement its Solion technology into volume manufacturing by mid-year.

Varian asserts that Solion allows solar module manufacturers to produce higher cell efficiencies at a lower production cost by substituting the diffusion process with the ion implant. By using this new technology, Varian maintains that manufacturers will be able to eradicate multiple production steps while enhancing cell uniformity and tighter binning. Per the company, early users of the Solion ion implant have applied the patterned implant technology for the production of crystalline solar cells in volume with conversion efficiencies over 19%.

Solar3D to use Silvaco simulation software to speed development of high-efficiency cells

Solar3D is expressing an optimistic outlook that it will have a working prototype of its new solar cell by year end thanks to their recent installation of Silvaco's software for their computer simulation technology. Solar3D states that with Silvaco's software, they will be able to more easily complete complex calculations that analyze how light will be directed at each point of light contact. Having this ability, concludes Solar3D, will allow them to create an optical element, or lens, that should diminish the reflection of light and the re-absorption of electrons.


Solar3D's modules.

BTU International signs licensing agreement for DuPont's catalytic oxidation technology

BTU International has signed a worldwide licensing agreement to use DuPont Packaging Graphics' catalytic oxidation technology. Developed to block volatile organic compounds (VOCs), the technology can be used in tandem with BTU's Tritan metallization firing systems and is expected to lower the cost per watt of solar cells.

Q-Cells, IHK develop training programme for employees

A select group of Q-Cells employees will be presented with certificates for solar cell production monitoring by the German Minister of Finance, Dr. Reiner Haseloff, today after attending a training seminar organised by IHK Bildungszentrum Halle-Dessau. The 10 employees will be charged with monitoring yield quality during cell manufacturing.

The training programme was created two years ago by IHK and Q-Cells as part of an attempt to develop their respective workforces through industry-specific qualifications. Work is already underway for the next training seminar and the development of a further IHK training programme for specialist staff in the industry.

ALD technology to be commercialized for volume c-Si cells by SoLayTec

Dutch research organisation TNO spin-off company SoLayTec has received an investment from Rena and Brabant Development Agency (BOM) to bring its atomic layer deposition (ALD) technology for volume manufacturing of c-Si solar cells to commercialization. Financial details were not disclosed.

Research by the Technical University of Eindhoven has claimed that cell efficiencies can be improved by depositing aluminium oxide as a rear-surface-passivating dielectric layer to passivated emitter and rear cell (PERC)-type crystalline silicon (c-Si) solar cells, resulting in conversion efficiencies of 20.6%.

ALD is being used in the semiconductor industry but has been limited by the slow throughput and subsequent cost of the process, compared to existing deposition techniques (e.g., PVD and PECVD).

The BOM and RENA investment is designed boost the development of a high-volume tool, capable of processing more than 3000 wafers per hour in 2012, enabling the full commercialization of the technology in the solar industry.

Centrotherm photovoltaics €342 million in new orders prompts added capacity

Prompted by increased orders during the Q4 2010, centrotherm photovoltaics feels that it is off to a good start in 2011. During 2010's fourth quarter, new orders saw a 192% increase to €342 million over the previous year's same period orders of €117 million. The company specifically points to orders from China and Taiwan during the fourth quarter as influencing the positive results.

Also lending to the order increase was the high demand for manufacturing systems of crystalline solar cells and customers repeat purchases of centrotherm's tube furnaces for phosphorus diffusion and batch-type systems for anti-reflective coating of solar cells.

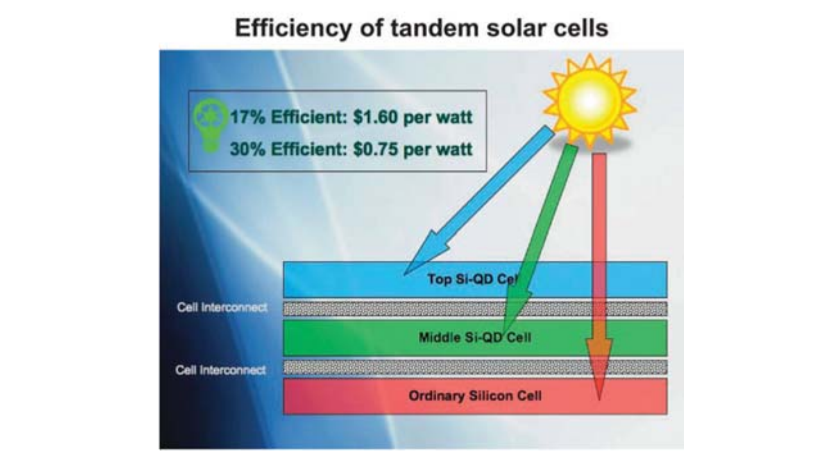
centrotherm anticipates delivery of 100 systems per month in the future, another increase from 2010, which saw a capacity increase to 60 systems per month. In order to support the continued success of production structures and processes, the likes of flexible shift operation and manufacturing capacities have been added.

R&D News Focus

Chinese cell manufacturer initial testing validates Natcore's antireflective coating technology

Natcore Technology's antireflective (AR) coating technology was independently validated by Chinese solar cell manufacturer, Hunan TLNZ Solar Technology. Natcore researchers in Ohio prepared and sent numerous silicon wafers with the company's antireflection coating to Hunan, who was selected by the Chinese government to complete the cell finishing and conduct testing.

All the wafers were coated with Natcore's liquid based deposition (LPD)



Natcore's tandem solar cell structure.

technology and were examined for composition and quality by Hunan, who then added metal front and back contacts to the cells and proceeded to test their efficiency. Per Hunan, cell efficiencies reached as high as 15% during the initial testing for the AR coating and the solar cell manufacturer noted that the standard deviation of efficiencies for all the cells was within the normal industry accepted limit.

Additionally, in its testing, Hunan distinguished the process steps that needed to be included in a commercial production system, which should allow for the cells that use Natcore's AR technology to reach or exceed 17% efficiency in production on a regular basis. Given this result, Natcore China was given the go ahead to finalize the creation of a beta test system.

Varian Semiconductor reveals more details about DOE-backed advanced solar cells development project

Just days after the U.S. Department of Energy (DOE) revealed that Varian Semiconductor Equipment Associates was a grant recipient in its SunShot program for the development of U.S solar technologies, the company has expounded on the research and development that it is conducting, which led to the US$4.8 million award by the DOE.

As it currently happens, conventional solar cells have metal collectors on the front surface that are claimed to lead to lower efficiencies by blocking sunlight. On the other hand, Interdigitated backside contact (IDC) solar cells that use metallic conductors on the back of the cell are said to gather more energy since the front of the cell is completely exposed to the sun. Varian asserts that IBC solar cells generate more power per unit since they hold a higher efficiency, which leads to lower module cost, lower balance of system costs and an increase in the amount of power that can be generated.

More traditional manufacturing processes have come to mean that IBC cells are more expensive to make, which has put a damper on the widespread use of IBC cells. For its R&D project, Varian is proposing an ion implant process that will allow cell makers to reduce the cost of IBC cell manufacturing by diminishing the number of process steps by 30% to 40%. Per the company, the ion implant process will also decrease manufacturing variability, cell handling, cell breakage and manufacturing cycle time while leading to an amplified production. Varian maintains that IBC solar cells made with this ion implant will not only have higher efficiencies, but also cost less per watt than current front-side contact technology.

CVD Equipment posts final 2010 order figures of US$25 million

CVD Equipment has posted final sales figures for 2010 of US$25 million – a year-on-year rise of 152%. This number was helped by CVD's fourth consecutive quarter-on-quarter rise in new orders, which brought in US$8 million for Q4.

Sales figures for CVD's FN, Conceptronic and SDC divisions increased by 200%, 53% and 40% respectively, and with interest in renewable energy generation and nanotechnology fields showing no sign of abating, it is likely these numbers will continue to rise in 2011.

Emcore wins panel supply contract for NASA mission

Emcore has won the right to supply NASA's Goddard Space Flight Center (GSFC) in Maryland with solar panels for its Magnetospheric Multiscale (MMS) mission. The US$10 million contract will see four MMS spacecrafts equipped with Emcore's ZTJ solar cells; the cells will be produced at Emcore's manufacturing facilities in Albuquerque, New Mexico. Launch date for the unmanned mission is August 2014.

Roth & Rau bags multiple orders worth €31.9 million

So far in January, Roth & Rau has received multiple orders, primarily for its SiNA antireflective coating system worth €31.9 million. Roth & Rau noted that its intensive product development work over recent years is testament to orders now being secured for advanced c-Si cell processes.

The company had previously noted that sales of its next-generation SiNA platform had the equivalent capacity of 1.85GWp, while the company had also received letters of intent for further SiNA systems with a total capacity of 1.45GWp.

DEK Solar places wafer alignment camera order with CyberOptics

CyberOptics said that it had recently received a significant order for PV equipment supplier, DEK for wafer alignment camera's. DEK Solar uses the technology in its new Eclipse metallization line. CyberOptics sales in the PV equipment market are growing on the back of capacity expansion plans of PV manufacturers, especially in Asia, where DEK has its strongest customer base. CyberOptics also reported consolidated sales for 2010 of US$56.9 million, an increase of 110% from US$27 million in 2009.

MKS Instruments receives follow-on order from Chinese firm

In Q4 2010, MKS Instruments received a follow-on order from a major Chinese cell manufacturer for its new RF power supplies, networks and control products. The equipment will be shipped in Q2 and be used for the production of thin-film cells.

BTU International grabs more diffusion furnace orders from Chinese cell customer

BTU International has received two new orders, which are estimated to hold a value of over US$18 million, for its Meridian in-line diffusion furnaces from a new and existing Asia-based customer. The diffusion furnaces, for both orders, will be used for capacity expansions with delivery beginning this quarter and continuing through the third quarter 2011. The two new orders will bring BTU's in-line diffusion tool shipments total to over 2GW.

CTDC subsidiary signs module purchase agreement with GPS&T

China Merchants Zhangzhou Development Zone Trendar Solar Tech, a subsidiary of China Technology Development Group (CTDC), entered into a purchase agreement with Goldpoly Science & Technology Industry. The supply deal, whose worth was not revealed, will see GPS&T, a subsidiary of Time Infrastructure Holdings, furnish Trendar Solar with 100MW of polycrystalline solar cells throughout 2011.

Ultrasonic Systems wins large spray coating system order from China

An order for 20 PV-360 spray coating systems has been won by Ultrasonic Systems from an unidentified customer in China. The tools are used to apply phosphoric acid, boric acid, and other proprietary dopants in high-volume c-Si solar cell production applications and are capable of 4,300 wafers (125mm) per hour, according to the company. Financial details and shipment/installation dates were not disclosed.

Amtech grabs another US$32 million in new diffusion tool orders

Amtech Systems' subsidiary, Tempress Systems, started the New Year off on a positive note, receiving US$32 million in new diffusion processing systems in January alone. The company notes that the orders were made by both new and existing Asia-based companies.

Topcell Solar places order worth US$25 million with Applied Materials

A single equipment order worth approximately US$25 million has been placed by Taiwan-based c-Si start-up, Topcell Solar International with Applied Materials. Topcell Solar is semiconductor foundry firm, UMC wholly owned subsidiary. The order was placed with Applied Materials Italia, according to Taiwan stock exchange filings, suggesting the tools were from its subsidiary Baccini, for c-Si cell processing equipment.

Topcell Solar is targeting to increase c-Si capacity to 450MW by early 2011 and reach 800MW by the third quarter of this year.

Amtech to compete with Varian in PV applications for ion implantation

Citing the need to protect its core solar cell diffusion technology and equipment from the adoption of ion implantation technology for advanced cell fabrication, Amtech Systems is acquiring a controlling (55%) interest in a China-based ion implant technology firm, Kingstone Technology Hong Kong Ltd.

The move by Varian Semiconductor to offer implant technology, via its Solion system, is claimed to reduce processing steps, impacting the number and type of diffusion steps.

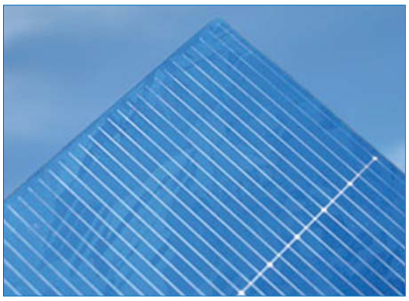
Whang noted that a combination of technology expertise in both ion implant and diffusion processes created the best opportunity to maximize the development of an implant machine for the solar market.

Amtech will have exclusive worldwide rights to sell and service any solar ion implant machine developed by Kingstone Semiconductor, which is expected to take approximately two years to come up with a next-generation system.

Under the terms of the acquisition, Amtech will pay $5.5 million in the form of cash and stock, and will pay up to $4 million in the form of a contingent promissory note. A further US$4 million pursuant to the contingent note are to be made to fund Kingstone's development of the tool.

Product Reviews

DuPont MCM



DuPont Microcircuit Materials offers Solamet PV701 metallization paste for MWT solar cell designs

Product Outline: DuPont Microcircuit Materials (MCM) has introduced DuPont Solamet PV701 photovoltaic metallization paste. The paste is said to enable the manufacture of back-contact cell designs delivering up to 0.4% greater conversion efficiency for solar cells of Metal Wrap Through (MWT) technology for back-side interconnected silicon solar cell designs.

Problem: The function of the back-side silver or silver-aluminium conductor is to act as the interconnect part of the second electrode in the solar cell. Key requirements in achieving improved cell efficiency include a strong ohmic contact and good solderability of back-side interconnected silicon solar cell designs.

Solution: DuPont Solamet PV701 photovoltaic metallization paste is specifically developed as an enabler to provide up to 0.4% greater efficiency in MWT cell designs versus standard cell designs. MWT is a specialized cell structure that transfers the bus bars on the front side to the back side, reducing shading on the front side of the cell. The connections are made through holes in the silicon with the same composition as the bus bars. Solamet PV701 claims excellent electrical contact to front-side silver grid structures, high-mechanical strength, low shunting, high-line conductivity and good solderability as a p-contact metallization.

Applications: P-contact metallization paste for MWT technology for back-side interconnected silicon solar cell designs.

Platform: DuPont Solamet photovoltaic metallizations are part of a broad and growing portfolio of products represented by DuPont Photovoltaic Solutions (DPVS).

Availability: February 2011 onwards.

DuPont MCM

DuPont Microcircuit Materials Solamet PV36x metallization pastes offer 0.8% boost to BSF-based cells

Product Outline: DuPont Microcircuit Materials (MCM) has introduced a new series of aluminium photovoltaic metallization pastes for rear-side passivated crystalline silicon solar cell designs. DuPont's Solamet PV36x pastes are said to outperform conventional aluminium compositions by delivering up to 0.8% greater conversion efficiency for solar cells when used in local back surface field (BSF) designs.

Problem: Revolutionary cell designs such as local BSF need highly-specialized metallization pastes designed to deliver efficiency gains and perform well in processing. Current commercial aluminium pastes designed for conventional cells have poor adhesion to passivation layers used with local BSF designs, typically SiO_x and/or SiN_x, unless they contain some glass frit. If the aluminum paste contains glass frit, voids can form at the edge of the aluminium-silicon contact area.

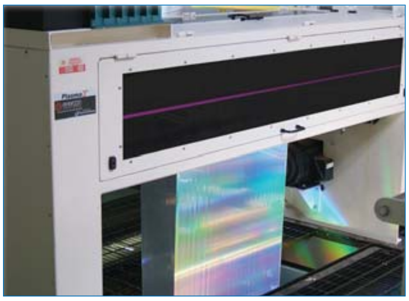
Solution: Solamet PV36x pastes claim to overcome this challenge, while enabling up to 0.8% greater efficiency with these types of designs. The pastes have been developed to maximize adhesion and minimize voids, with controlled local alloying combined with high lateral conductivity.

Applications: Aluminium photovoltaic metallization pastes for rear-side passivated crystalline silicon solar cell designs.

Platform: DuPont Solamet PV361 is designed for laser-fired local contact formation. DuPont Solamet PV362 is optimized for local BSF contact formation under conventional firing conditions. Both products are compatible with the latest Solamet tabbing silver pastes and new DuPont Solamet PV701 photovoltaic metallization for MWT designs.

Availability: Currently available.

Enercon



Enercon's Plasma4 in-line APT system offers high volume continuous production

Product Outline: Enercon Industries Corporation is introducing the new Plasma4 in-line atmospheric plasma surface treatment system for the cleaning and functionalizing of roll-to-roll materials used for fabricating photovoltaic systems.

Problem: An increase in the use of wet processing steps, which adds to chemical waste disposal issues, is leading to new interest in plasma technology in the atmospheric plasma treatment (APT) continuous mode for dry etching, surface cleaning and adhesion promotion. Vacuum plasma techniques are highly dependent on the materials and cycle times and are difficult to migrate to high-volume continuous production environments.

Solution: The system uses reactive gases that are diffused toward the surface under the influence of electrical fields. Low molecular weight materials fragments are knocked off the surface to expose a clean, fresh surface. A percentage of the reactive components in plasma with sufficient energy will bond to the freshly exposed surface, changing the chemistry of the surface. In roll-to-roll applications, using plasma technology can effectively clean thin metal substrates from rolling oil deposits. In crystalline silicon cell applications, APT can be used for cleaning the metal/alloy back contact layer.

Applications: Plasma4 can be used for cleaning and functionalizing roll materials used for crystalline silicon, thin-film silicon and organic PV materials.

Platform: Enercon offers a wide range of atmospheric plasma systems for treating a variety of materials, including patterned glass, float glass, EVA film, Tedlar film, PVF composite films, copper foils, stainless steel foils and aluminium foils.

Availability: Currently available.

Efficiencies of 22% at low cost: the future of mass-produced laser-doped selective emitter solar cells

Matt Edwards, Centre for Photovoltaics, University of New South Wales, Sydney, Australia

ABSTRACT
Laser-doped selective emitter (LDSE) technology, invented and patented by the University of New South Wales (UNSW), is presently generating considerable interest in the photovoltaics industry due to its low cost, high efficiency, and suitability for mass production. The excellent results achieved to date – as high as 19.7% on small area laboratory test devices [1], and 19.0% on industrial large-area 156mm wafers [2] – are attracting a similarly impressive array of commercial partners. Nearly 10 companies are at various stages of implementation of LDSE technology variants into production and pilot production. This paper takes a closer look at the potential for mass production of LDSE-based solar cells.

Introduction
UNSW's LDSE technology continues to attract an impressive array of commercial partners. Part of the LDSE technology's popularity is related to the ease of retrofit of a standard screen print solar cell line. With a few extra tools, a simple selective emitter technology can be realised with a large performance gain. While other selective emitter technologies on the market generally make heavy use of aligned screen-printing techniques, which restrict efficiencies to little more than 18.5% [3] and involve the use of expensive Ag and Al screen printing pastes, UNSW LDSE makes use of self-aligned, rapid plated metallization and inexpensive, low-temperature laser doping and patterning techniques. These techniques:

- Reduce front-side shading losses to as low as 3%
- Allow metal lines to be placed closer together increasing fill factor
- Significantly increase blue response and short circuit current by as much as 10%
- Reduce metal-Si interface area and recombination at these interfaces, thus increasing cell voltage, and
- Involve no optical alignment techniques or associated yield loss.

This improvement in solar cell front-surface design allows efficiency gains of at least 1% absolute over standard screen print solar cells at a reduced product cost. But perhaps the biggest advantage with LDSE technology is the range of opportunities it opens up for improved rear-surface design. In conjunction with effective rear-surface passivation and point contact techniques, efficiencies are expected to increase to 21% and as high as 22% within two years on standard p-type Cz material. This by far eclipses what is possible with screen printing technology, and does not require screen print pastes which can easily account for a third of the conversion cost of screen print solar cells. As a result, large savings are realised in the cost of product.

> "Next-generation LDSE is highly suited to mass production, with significant savings in cost of ownership predicted at the wafer, cell and module level."

The next-generation LDSE solar cells share many high-efficiency features of UNSW's world-record PERL cell structure, having excellent spectral response for both blue and red light and open circuit voltages already easily exceeding 670mV on p-type Cz silicon, well above the values ever demonstrated using screen-printed contacts. Unlike the PERL structure, next-generation LDSE is highly suited to mass production, with significant savings in cost of ownership predicted at the wafer, cell and module level.

UNSW, with its extensive years of research, has compiled a comprehensive portfolio of patents on LDSE that also extends to variants of the LDSE technology.

Single-side LDSE process
A schematic of the standard, single-sided LDSE cell structure is shown in Fig. 1. The structure features front surface metallization formed using rapid light-induced plating, while the rear contact is a standard screen printed Al contact. The selective emitter diffused regions are formed by application of a phosphorus dopant source to a silicon nitride passivated silicon wafer, followed by laser melting of the silicon surface. This

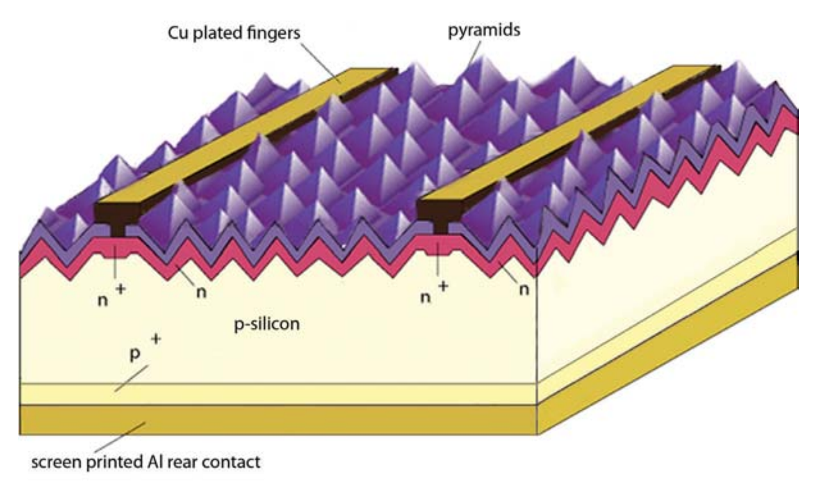


Figure 1. Standard single-sided LDSE solar cell, showing laser-doped selective emitter front surface with plated metallization and screen-printed rear Al BSE.

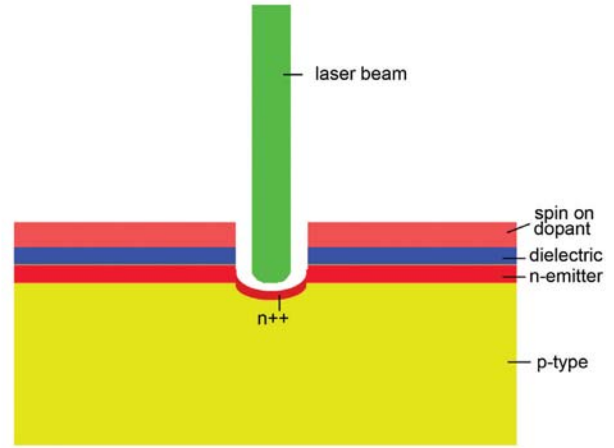


Figure 2. The laser doping process. The dielectric layer is removed while a dopant source is incorporated into the molten silicon, forming a selective emitter and plating mask in one step.

process is depicted in Fig. 2. During melting, the silicon mixes with dopant atoms to create a heavily diffused region on recrystallization. Simultaneously, the silicon nitride passivation layer is ablated where the laser beam is applied, creating openings which can be used as a self-aligned plating mask.

Fig. 3 shows the process steps required for fabrication of an LDSE solar cell. The front end of the process is almost identical to that of a standard screen print solar cell process flow. Incoming silicon wafers are damage etched and textured, followed by light emitter diffusion which can be as light as 200Ω/sq. The profile and sheet resistance of the emitter is non-critical. A PSG removal is followed by an edge isolation procedure which can ideally be done in the same tool using a rear wet etch. Following this, a silicon nitride layer is deposited using PECVD or sputtering techniques.

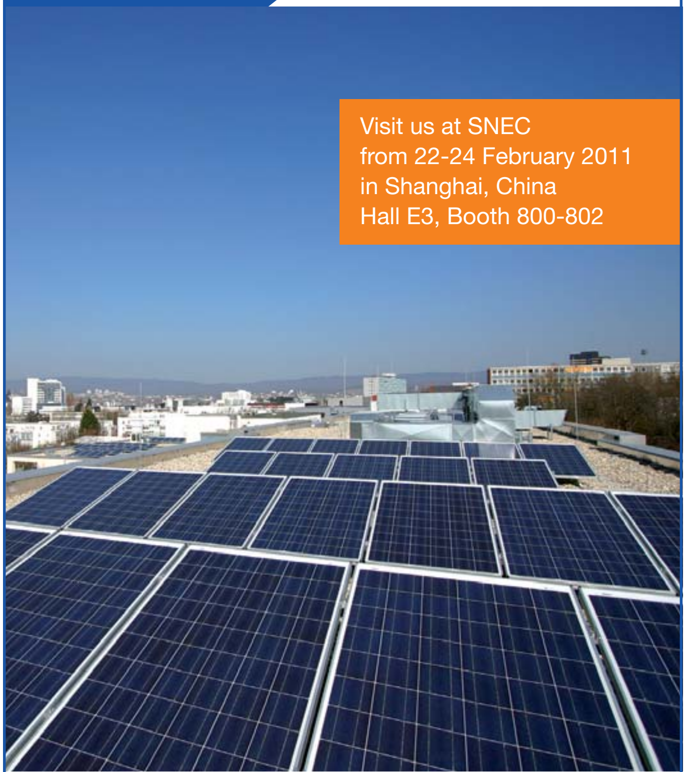
Whereas a screen printed cell would at this point have its front Ag contacts printed, followed by rear Ag busbars and rear Al BSF printing and cofiring, the LDSE cell requires only rear Ag busbar and rear Al BSF printing and firing. After the rear contact formation, the front surface is laser doped followed by plating and sintering of the front contacts. Due to the similarities between the LDSE process and the screen print solar cell process, it is easy to retrofit an existing screen print line for LDSE, with only a dopant applicator, laser, plating bath and sintering furnace required as additional tools.

The light-induced plating (LIP) process involves a rapid Ni plate and sinter, followed by a rapid Cu plating step and very thin Ag or Sn capping layer to prevent Cu contamination of module encapsulation layers. Unlike older electroless plating methods which were very slow, the Ni LIP process lasts a matter of seconds and the Cu plating step only takes several minutes. The light-induced plating technique developed at UNSW forms very narrow metal lines as little as 20–30µm across. With careful process control, these narrow fingers can be formed as high as 15–20µm and almost semicircular in cross section, with very good adhesion [2,4,5]. With simple optimization of laser doping and plating processes, the peel strength of plated metal lines can be as high as 3N, comparable to that of screen printed cells.

Finally, for the purposes of module fabrication, LDSE cells may have conductive glued or soldered interconnects as desired by the module manufacturer.

Single-side LDSE cost of ownership

UNSW's advanced laser doping and plating techniques reduce front-side shading losses from around 7% to as low as 3%, and allow metal lines to be placed closer together reducing resistive losses in the emitter, increasing fill factor and allowing the emitter to be very lightly diffused. The lightly diffused emitter significantly improves the blue response and short circuit current by as much as 10%. At the same time, the narrow metal lines give a reduced metal-Si interface area and with optimized



	SP	LDSE
Saw Damage Removal & Texturing	✔	✔
Diffusion	✔	✔
PSG Etch/Junction Isolation	✔	✔
PECVD SiNx	✔	✔
Screen Printing and Drying	Front Ag	✖
	Dry	✖
	Rear Ag	Rear Ag
	Dry	Dry
	Rear Al	Rear Al
Belt Furnace for Drying Firing	✔	✔
Dopant Application	✖	✔
Laser Doping	✖	✔
Ni/Cu/Ag Plating	✖	✔
Ni Sinter	✖	✔
Testing	✔	✔

Figure 3. Single-side LDSE process sequence compared to the standard screen print solar cell process sequence. Laser doping and plating are the only extra processing steps, and LDSE does not require printing of the front contacts.

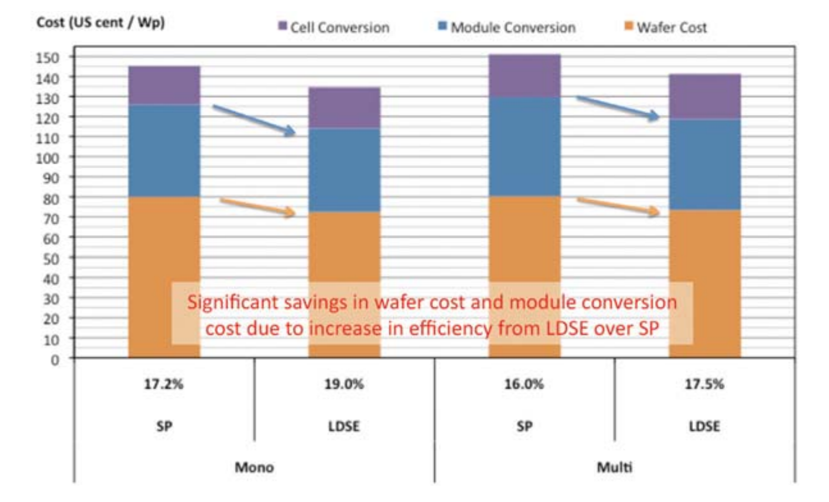


Figure 4. Overall cost of ownership for LDSE solar cells compared to that of standard screen print solar cells. Savings in wafer cost and module conversion due to higher power density are realised.

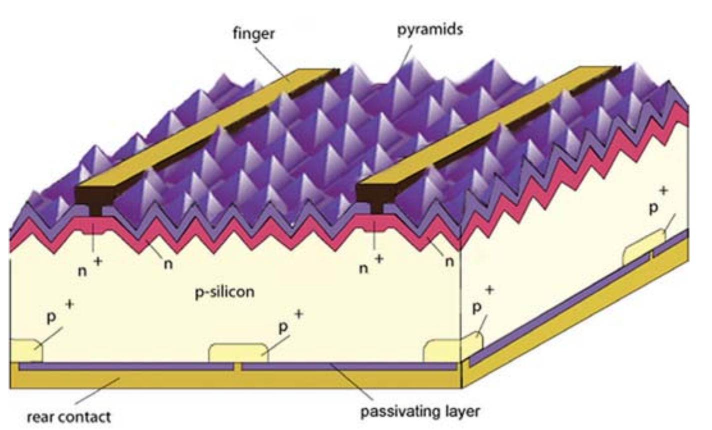


Figure 5. Double-sided LDSE solar cell, showing laser-doped selective emitter front surface and passivated, locally diffused rear surface with point contacts.

heavy laser doping (as low as 5Ω/sq), dark saturation current losses at these interfaces are reduced, increasing cell voltage. The techniques also involve no optical alignment techniques or associated yield loss.

Due to the above high-efficiency features, single-sided LDSE cells reach efficiencies of 19.0% on p-type Cz monocrystalline material and 17.5% on p-type multicrystalline silicon in manufacturing. This compares to around 17.2% on p-type Cz and 16.0% on multicrystalline for industry standard screen printed solar cells. Using these efficiencies, the cost of ownership for LDSE can be compared to that of standard screen print solar cells using commercially available cost of ownership modelling software. The cost of ownership model assumes fabrication on a production line in China running at 2,400 cells per hour with a wafer size of 156 × 156mm, with a yield of 95% and an overall equipment effectiveness of 87%. The model also takes into account production equipment capital cost, building utilities and services (fixed and running cost), labour cost (indirect and direct cost), electrical power, process gasses, DI water and chemicals, metal plating costs (for the LDSE process), and printing paste, screens and screen cleaner (for the screen print process). At around US$0.20/W for both mono- and multicrystalline material, the cell conversion cost for LDSE is similar to that for a standard screen print cell.

However, due to the high efficiency and therefore higher energy density of the LDSE technology, significantly lower wafer and module conversion costs result in a lower cost of ownership for the LDSE technology (around US$1.35/W on mono, US$1.40/W on multi) compared to screen print technology (around US$1.45/W on mono and US$1.50/W on multi). This lower cost of ownership is depicted in Fig. 4, with further savings to be expected in balance of systems and installation costs for the LDSE technology.

> “Single-sided LDSE cells reach efficiencies of 19.0% on p-type Cz monocrystalline material and 17.5% on p-type multicrystalline silicon in manufacturing.”

LDSE technology is an attractive option compared to many other selective emitter solar cell designs on the market, as it does not require the use of optical alignment techniques, and due to the lack of high temperature processing it is also suitable for multicrystalline material.

The single-sided LDSE cell provides a

	SP	LDSE	D-LDSE
Saw Damage Removal & Texturing	✔	✔	✔
Diffusion	✔	✔	✔
PSG Etch/Junction Isolation	✔	✔	✔
PECVD SiNx	✔	✔	✔
Screen Printing and Drying	Front Ag	✖	✖
	Dry	✖	✖
	Rear Ag	Rear Ag	✖
	Dry	Dry	✖
	Rear Al	Rear Al	✖
Belt Furnace for Drying Firing	✔	✔	✖
Dopant Application	✖	✔	✔
Laser Doping	✖	✔	Front & Back
Ni/Cu/Ag Plating	✖	✔	✔
Ni Sinter	✖	✔	✔
Rear Surface Metallization	✖	✖	✔
Testing	✔	✔	✔

Figure 6. D-LDSE process sequence compared to the single-side LDSE and standard screen print solar cell process sequences. The D-LDSE cell requires no screen printing at all, eliminating expensive screen print paste usage.

competitive edge to screen printed solar cell technology, but with the new LDSE technology appearing to further enhance these cost and performance advantages. Test devices indicate that the new LDSE with passivated rear surface has the potential to reach efficiencies as high as 22% on standard p-type CZ wafers, with corresponding open circuit voltages above 700mV, values far exceeding those achievable by screen printing technology. This should lead to even greater savings in cell conversion cost in addition to wafer and module conversion cost.

Double-side LDSE process

A schematic of the double-sided LDSE (D-LDSE) cell structure is shown in Fig. 5. The structure features many of the high-efficiency features found in UNSW's world-record PERL cell, with several new rear-surface technologies enabling a high-quality rear passivation, local selective diffusions and self-aligned point contacts. In addition to the improved rear, the structure features the usual high-quality LDSE textured front surface incorporating narrow self-aligned plated metal lines.

Fig. 6 shows the process steps required for fabrication of a D-LDSE solar cell. The process is similar to single-sided LDSE fabrication, the main differences being the application of a passivating layer to the rear surface which is laser doped along with the front surface. The rear surface is then metallized using a range of industrial techniques that do not involve screen printing. In this way, screen print tools and expensive print pastes can be completely eliminated for this cell design.

Double-side LDSE cost of ownership

In addition to the usual high-quality LDSE front surface, the high-efficiency features present at the double-sided LDSE rear surface increase efficiency above 20%. A high-quality rear passivating layer, point contacts giving a smaller metal-semiconductor interfacial area, along with heavy diffusion at the point contacts, all contribute to dramatically lower dark saturation current losses at the rear surface and allow open circuit voltages to approach 700mV (pilot production voltages already easily exceeding 670mV have been achieved), even on p-type Cz material, far exceeding what was previously thought possible for this material. The improved rear surface also enables an improved red response, further increasing short circuit current, while several effective industrial metallization schemes ensure minimal additional resistive losses. As for the single-sided LDSE process, the processing techniques are all industrially feasible and require no optical alignment techniques or associated yield loss.

Where the screen printed rear surface limits single-sided LDSE cells to around 19% on p-type Cz monocrystalline material and 17.5% on p-type multicrystalline silicon, D-LDSE cells appear capable of comfortably exceeding 21% on Cz and 19% on multicrystalline material. This is again compared to around 17.2% on p-type Cz and 16.0% on multicrystalline for industry standard screen printed solar cells. Using these efficiencies, the cost of ownership for D-LDSE can be compared to that of standard screen print solar cells using commercially available cost of ownership modelling software. It is again assumed that fabrication is on a production line in China, with 2,400 cells per hour, a wafer size of 156 × 156mm, a yield of 95% and an overall equipment effectiveness of 87%.

Fig. 7 compares the cell conversion cost of D-LDSE cells compared to standard screen print cells. Where the single-sided LDSE cell conversion cost was close to that of standard screen print solar cells, with cost advantages coming at the wafer and module levels, the D-LDSE cell should cost less than US$0.14/W on mono material (compared to around US$0.19/W for the screen print cell) and about US$0.15/W on multi material (compared to around US$0.21/W). These significant savings are due mainly to the elimination of the screen print process and expensive screen print pastes, along with the large increase in power output per unit area for this cell technology.

Fig. 8 shows the overall cost of ownership for double-sided LDSE technology at the module level. The very high energy density of the double-sided LDSE technology results in further savings in wafer and module conversion costs, giving a significantly lower cost of ownership (US$1.17/W on mono and US$1.23/W on multi) to standard screen print technology (US$1.45/W on mono and US$1.51/W on multi) and other screen printed selective emitter technology on the market today. Further savings are to be expected in balance of systems and installation costs for the D-LDSE technology.

The single-sided LDSE cell provides a competitive edge to standard screen print solar cell technology. The most exciting aspect, however, is that the new LDSE technology with passivated rear surface, capable of efficiencies as high as 22%, leads to even greater cost savings in cell conversion costs in addition to wafer and module conversion cost.

Finally, the D-LDSE technology is an attractive option compared to other high-efficiency solar cell designs on the market, as it does not require the use of expensive float-zone feedstock, transparent conducting oxides (TCOs) or photolithographic patterning of contacts. Again, unlike other high-efficiency technologies, it is also suitable for multicrystalline material.

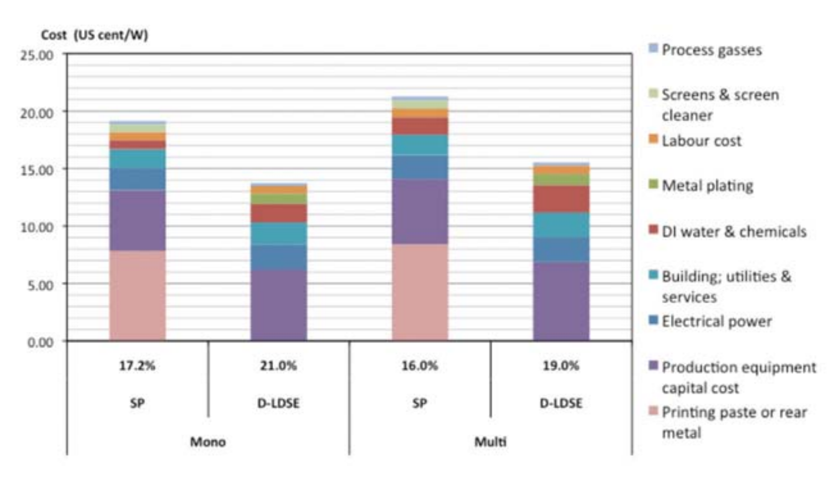


Figure 7. Cell conversion cost of ownership for D-LDSE solar cells compared to that of standard screen print solar cells. Significant savings are realised due to much higher efficiencies and elimination of screen print processes and metal pastes.

Overcoming LDSE challenges

As with any new technology, there have been hurdles to overcome in order to ensure the technology can gain widespread acceptance. At UNSW, many years have already been spent on evaluating and overcoming the challenges associated with LDSE technology. As previously mentioned, many of the process steps are identical to those required for standard screen print cells, the only new processes being the laser doping and plating steps. The remaining challenges associated with LDSE are generally ones that need to be addressed through selection of appropriate equipment and corresponding optimization of these processes. By using an approved continuous wave laser to perform the laser doping, most of the reported surface damage normally caused by nanosecond q-switched lasers can be avoided. UNSW has evaluated several lasers over the years and gives all collaborators an approved list of lasers (and other processing tools) that will work.

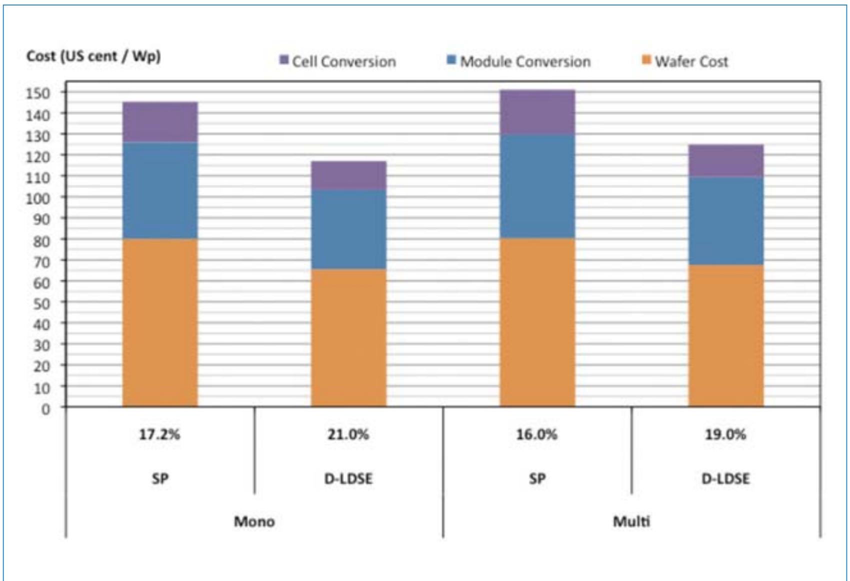


Figure 8. Overall cost of ownership for LDSE solar cells compared to that of standard screen print solar cells, showing very significant savings in wafer and module conversion costs.

Cell Processing

The laser doping speed also needs to be optimized to allow a continuous laser-doped line. This ensures that the plating is of good quality and shunt paths through the emitter are avoided. It appears that the optimal speed is easily fast enough to allow very short cycle times and high throughput for mass production. Likewise, plating and sintering conditions need to be optimized to ensure good adhesion, prevent shunting and create an effective barrier against copper contamination. Fortunately, it again turns out that optimum temperatures are low and plating times short, leading to compatibility with mass production.

> "By using an approved continuous wave laser to perform the laser doping, most of the reported surface damage normally caused by nanosecond q-switched lasers can be avoided."

At UNSW, questions about plating reliability and adhesion are often received. With good process control and optimization of laser doping and plating processes, the peel strength of plated metal lines should be as high as 3N, comparable to that of screen printed cells. Furthermore, with process optimization, these narrow fingers can be formed as high as 20µm and almost semicircular in cross section, with very high throughput. LDSE modules have also been through the usual rigorous durability tests performed for all industry modules, with favourable results.

Conclusion

UNSW's laser-doped selective emitter technology is highly suited to industrial fabrication and has several advantages over traditional screen print solar cell technologies, both conventional homogeneous and selective emitter. Single-side LDSE variants are in pilot production at several different companies and are achieving efficiencies as high as 19.0% on p-type Cz and 17.5% on p-type multicrystalline silicon. High-efficiency features of single-sided LDSE technology include 30µm-wide, self-aligned, rapid plated metal fingers with heavily doped selective regions under the fingers and lightly doped emitter. These features improve J_{sc} by as much as 10% (through significantly reduced shading loss and improved blue response) and improve open circuit voltages (through reduced recombination under the front contacts).

The next generation of double-sided LDSE solar cells will also feature rear point contacts with heavy selective diffusions, along with effective rear-surface passivation. D-LDSE will thus contain many of the high-efficiency attributes of UNSW's world record-holding PERL technology. Through the improved open circuit voltage this allows even on Cz or multicrystalline material, efficiencies are expected to exceed 21% on p-type Cz and 19% on p-type multi by 2012, while also being suited to mass manufacture. While cell conversion cost for single-sided LDSE is similar to that of conventional screen print solar cells, its increased efficiency results in cost savings at the wafer and module level and an overall decrease in cost of ownership.

For D-LDSE however, the cost of ownership is significantly lower than that of standard screen printed solar cells at the wafer, cell and module level. This is due to its superior efficiency and elimination of expensive screen print pastes and processes. LDSE solar cells have, after optimization, also proven to be reliable and durable under normal rigorous industry testing regimes. LDSE's superior cost of ownership, ease of manufacture, self-aligned low temperature processing, suitability to low-cost silicon and thin wafers, reliability and ease of adaptation to existing screen print solar cell lines are set to ensure it remains the technology of choice for savvy solar cell manufacturers. It is likely to take its place as the favoured alternative to supersede screen printed solar cells as the low-cost, high-efficiency solar cell technology of the future.

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References

[1] UNSW; publication pending.

[2] Tjahjono, B.S. et al. 2010, "18.9% Efficient Laser Doped Selective Emitter Solar Cell on Industrial Grade p-Type Czochralski Wafer", *Proc. 25th EU PVSEC*, Valencia, Spain.

[3] Hahn, G. 2010, "Status of selective emitter technology", *Proc. 25th EU PVSEC*, Valencia, Spain.

[4] Sugianto, A. 2010, "Investigation of Al-Doped Emitter on N-type Rear Junction Solar Cells", *IEEE Transactions on Electron Devices*, Vol. 57, Issue 2, pp. 525–529.

[5] Wang, S. et al. 2009, "Overcoming Overplating Problems on Acid Textured Multicrystalline Wafers with Silicon Nitride Coated Surfaces", *Proc. 24th EU PVSEC*, Hamburg, Germany.

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Study of dark lines on the polycrystalline silicon solar cell and their influence on cell electrical properties

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ABSTRACT
The aim of this work is to study the effects of dark lines on the face of polycrystalline silicon solar cells. The formative processes of dark lines were observed by laser scanning microscopy. Following the initial appearance of a few etch pits on the surface of the cells, extending the etching time saw these etch pits increase in size, eventually merging to form a single line, known as a 'dark line.' Dark lines are lines that are linked together by a series of contiguous dislocation outcrops and have the potential to reduce silicon wafer lifetime, adversely affect both the electroluminescence and the quantum efficiency of a solar cell, and have resulting negative effects on the cell's electrical properties.

Introduction

Of the two types of silicon solar cells in commercial production – silicon-based film solar cells and crystalline silicon solar cells – the latter looks set to capture a major market share and to continue to hold the top spot over the next 10 years [1]. These cells can be further classified into monocrystalline silicon and multicrystalline silicon solar cells. Although the latter have lower efficiencies than monocrystalline silicon solar cells, the low production cost of the starting material for multicrystalline silicon cells brings with it greater potential for cost reduction.

Research is ongoing regarding the various methods of increasing the efficiency of multicrystalline silicon solar cells and enhancing the sector's market competitiveness. This research has involved such investigations as texturing, rapid thermal process (RTP), gettering processes and surface and body passivation [2]. However, improving the properties of multicrystalline silicon is the most vital factor behind increasing the efficiency of the resulting solar cells. 'Defect engineering' in multicrystalline silicon [3–9], which improves the macroscopic properties of Si by artificial microscopic control of structural elements, has come to be regarded as one of the most promising approaches to the development of crystal growing. This technique of manipulating defects to yield high-quality multicrystalline Si ingots is one that is being extensively pursued throughout the industry.

The $HNO_3/HF/H_2O$ solution system is currently the most widely used method of multicrystalline silicon wafer texturing in the industry. These dark lines tend to appear in an arbitrary distribution on the surface of multicrystalline silicon wafers after texturing. Preliminary studies suggest that the lines have a direct bearing upon the electrical properties of these cells, prompting the authors to carry out this study on the formative processes, mechanisms and essence of dark lines and their influence on the electrical properties of cells.

The formation process of dark lines

For the purposes of observing the formation of these dark lines, four sister wafers were prepared for comparative analysis. The four wafers each feature similar grain shape and distribution, and were etched in a $HNO_3/HF/H_2O$ solution system for 30, 60, 90 and 180 seconds, respectively. Laser scanning microscopy (LSM) was used to observe the differences between the dark lines that formed on the wafers with respect to their different etching durations.

Fig. 1(a) shows the surface topography of the wafer that was etched for 30 seconds. At the beginning of the etching process, some etching pits were visible; however, these pits

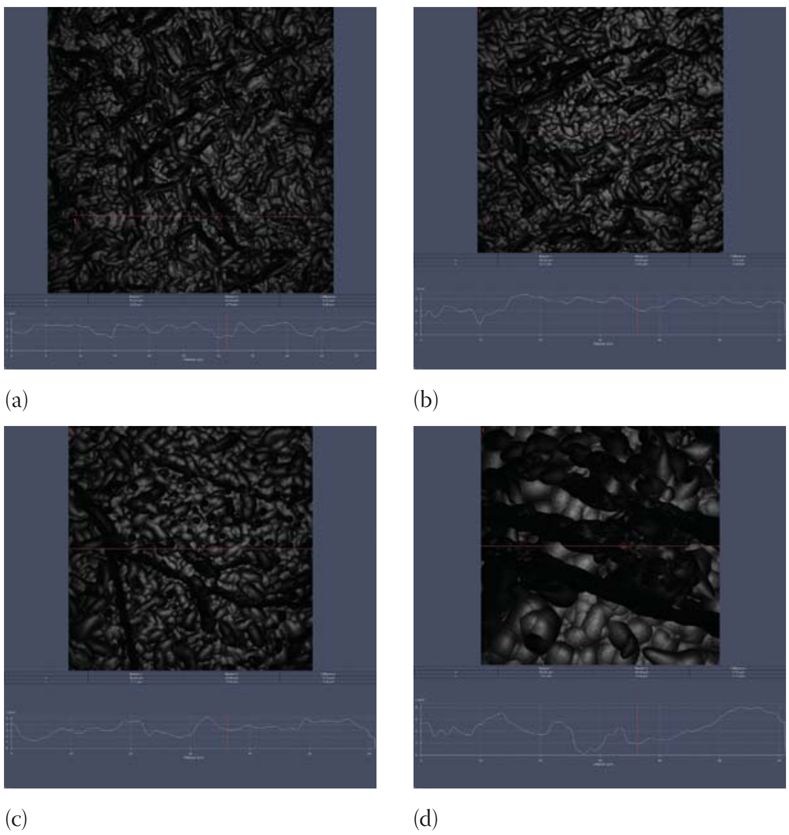
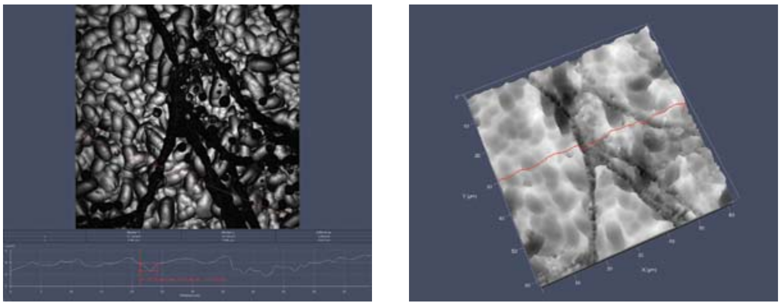
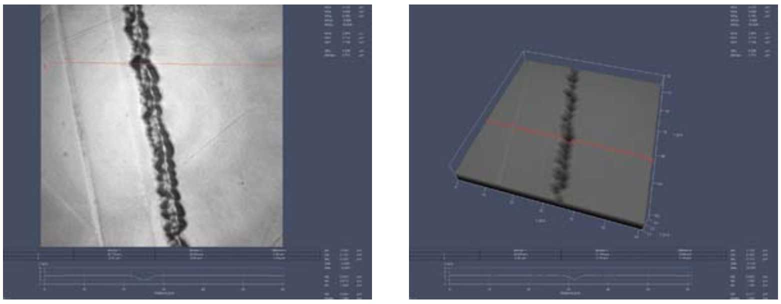


Figure 1. Formative processes of dark lines on surfaces of wafers etched for (a) 30 seconds; (b) 60 seconds; (c) 90 seconds and (d) 180 seconds.



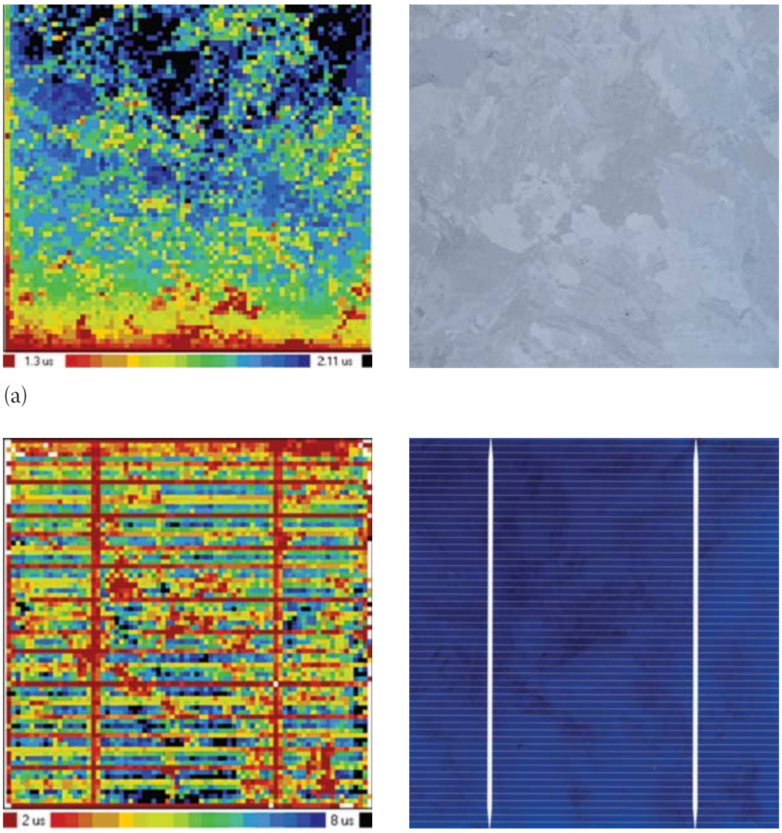
(a) (b)

Figure 2. Dark lines on multicrystalline silicon wafers in 2D (a) and 3D (b).



(a) (b)

Figure 3. Low angle grain boundary on monocrystalline silicon wafers 2D (a) and 3D (b).



(a)

(b)

Figure 4. Lifetime scanning images of a multicrystalline silicon wafer (a) and cell (b). Wafer: avg: 1.822µs; min: 0.646µs, max: 2.33µs; cell: avg: 4.418µs, min: 0.254µs, max: 94.963µs.

were in close proximity but not attached to each other. Fig. 1(b) shows the surface topography of the wafer etched for 60 seconds. As the etching time was extended, the pits expanded, and some proceeded to link together to form a line, but some of these dark lines were not fully developed.

The image in Fig. 1(c) shows the surface topography of the wafer that was etched for 90 seconds. On comparing this image with the images in Figs. 1 (a) and (b), it is clear to see that the lines in image (c) have become deeper and wider. There are also some underdeveloped dark lines, while several of the scattered etching pits have become clearer. This resulting surface topography is extremely similar to that found in large-scale production. Fig. 1(d) shows the surface topography of the fourth wafer, this time etched for 180 seconds. In this sample, the dark lines and pits were over-etched, while the dark lines themselves were too deep and wide for the wafers to have been used in a conventional solar cell manufacturing process.

The formative mechanism of dark lines

As can be seen from the formative processes of dark lines, etching pits are the 'stepping-off point' for the study of the formation mechanisms behind dark lines. Firstly, the etching pits were more easily etched than any other areas of the multicrystalline silicon wafers in question, regardless of the degree of etching. Secondly, many scattered etching pits were visible, and they feature the same variation trend as the etching pits that eventually linked together to become the dark lines. Thirdly, the dark lines and etching pits were the same on both sides of the multicrystalline silicon wafers, so it can be deduced that these lines are the outward manifestations of the wafers' internal structures.

> "Etching pits are the 'stepping-off point' for the study of the formation mechanisms behind dark lines."

Figs. 2 and 3 show dark lines on a multicrystalline silicon wafer and a low angle grain boundary on a monocrystalline silicon wafer, respectively. Comparing these 2D and 3D LSM images shows that the two have very similar microstructures, both consisting of an amount of etching pits linked together to form a line.

Contiguous dislocation, a feature that is easily etched along the dislocation line, and the etching pits on the face of multicrystalline silicon wafers form the dislocation outcrops after the acid etching step. Dark lines, then, are lines that are

linked together by a series of contiguous dislocation outcrops, frequently occurring in the grain – very different from the composition of high angle grain boundary.

Kun Huang's *Solid-state physics* explains the phenomenon as follows: "There are different areas in one grain, and the angles between crystal lattices are very small. It may be taken for granted that the low angle grain boundaries in one grain are formed by the arrangement of a series of contiguous dislocations" [10], leading us to the conclusion that low angle grain boundaries take the form of dark lines after acid etching.

Influence of dark lines on electrical properties of cells

Wafer and cell lifetime

Fig. 4 shows lifetime scanning images of a multicrystalline silicon wafer (a) and cell (b). It is clear from these images that low lifetime areas correspond with the areas that feature dark lines, and that both the wafer and the cell are in accordance with this situation. The extent of the influence is different owing to the differences between the type and concentration of impurities and defects in question. However, generally speaking, the areas with dark lines tend to have lower lifetime, even taking into account the presence of SiN_x passivation film.

Electroluminescence (EL)

Considering the danger these dark lines can pose to the lifetime of wafers and cells, the next logical step was to investigate the level of damage inflicted by them on the cell's electrical properties. Six sister wafer sets were arranged according to the quantity and distribution of their dark lines, with the quantity of lines increasing from wafer (a) to wafer (f). The wafers were then made into cells and subjected to tests for electrical properties and EL.

Fig. 5 shows EL images of the different cell classes. The dark areas within the EL images correspond to the areas that showed the presence of dark lines. It was also found that the degree of luminescence within these zones is much lower than other areas that did not feature the dark lines. It can be concluded, therefore, that the areas that formed the dark lines have weaker electroluminescence properties, and consequently, these areas are lower in efficiency.

Table 1 shows the electrical properties of the different cell classes under investigation in this study. As the number of dark lines increases, cell electrical properties such as V_{oc}, I_{sc} and FF decrease gradually, a pattern that fits the trend of EL. Furthermore, the distribution of these dark lines has as great an effect as these electrical properties. Similar quantities of decentralized dark lines are far less harmful to the cell than dark lines that cluster together.

Quantum efficiency (QE)

As a result of this relationship between the quantity and distribution of dark lines and the resulting cell's electrical properties, it is safe to state that dark lines form one of the most vital factors in terms of determining the cell's electrical properties. The impurities and defects that gather together and form these dark lines lead to a drop in electrical properties of the solar cell.

Fig. 6 shows the quantum efficiency (QE) and reflectivity result of the areas with and without dark lines. It can be seen from the graph that the area with dark lines has lower reflectivity in the 300–600nm wavelength, while in the 600–1100nm wavelength, both areas have almost the same reflectivity. As regards IQE, the 300–1100nm wavelength area shows lower values than the area without dark lines. This gap is seen to get wider from 700nm to 1100nm, a direct result of the increase in impurities and wafer defects. As a result of the effects of reflectivity in the 300–600nm wavelength, the areas with and without dark lines have the same EQE. In the 600–1100nm range, the EQE of the area with dark lines is lower due to the disadvantage

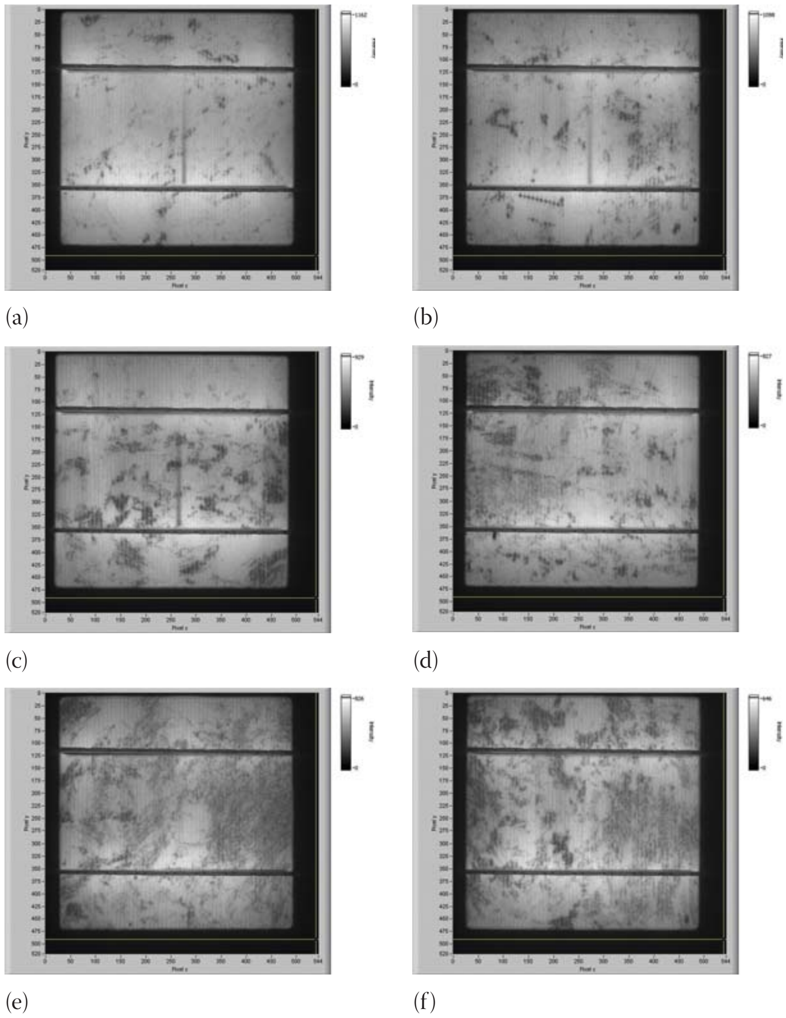


Figure 5. EL images of six different cell classes (see data in Table 1).

	J_{sc}/mA/cm^2	U_{oc}/v	FF/%	N_{cell}/%
a	34.97	0.629	77.14	0.1696
b	34.74	0.623	77.91	0.1687
c	34.56	0.622	77.12	0.1658
d	34.17	0.623	76.70	0.1632
e	34.02	0.619	76.38	0.1609
f	33.56	0.618	76.47	0.1586

Table 1. Electrical properties of the six different cell classes.

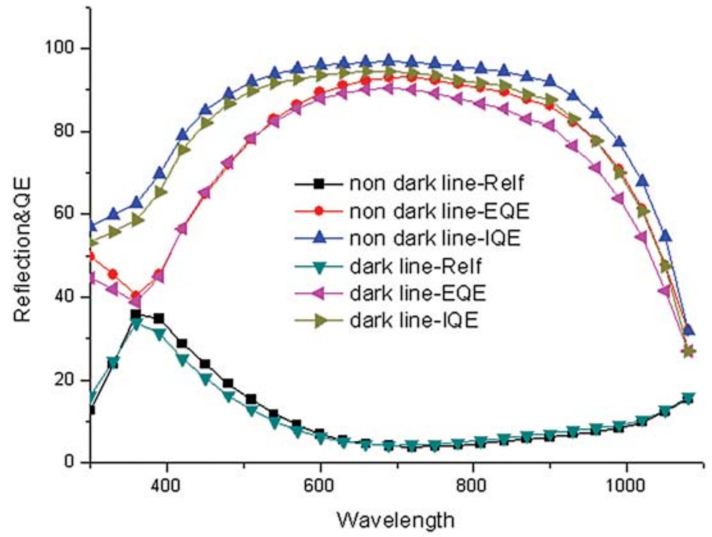


Figure 6. Quantum efficiency and reflectivity results of the areas with and without dark lines.

of IQE; however, this range does not have the benefit of reflectivity.

Summary

The study conducted in this paper arrived at a series of conclusions. The formative processes of dark lines were observed by LSM, showing the appearance of several etch pits on the surface. As etching time increased, these etch pits became bigger, some linking together to form one line, now known as a dark line, or lines that are linked together by a series of contiguous dislocation outcrops.

Dark line were found to have the potential to reduce the lifetime of silicon wafers, while also having an adverse effect on electroluminescence, quantum efficiency and various other electrical properties. The quantity and distribution of these dark lines is one of the most crucial factors in improving the electrical properties of multicrystalline silicon cells. It is possible that this problem can be addressed by the development of a crystal growth technique that is capable of manipulating such defects, allowing the creation of high-quality multicrystalline Si ingots, which are the building blocks of high efficiency multicrystalline silicon solar cells.

Acknowledgements

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References

[1] Jiang, Q. 2010, "Study of development strategy and investment of 2010-2015 China PV", Beijing: Investment Consultant Research Centre.

[2] Sun, X. 2004, "Investigation on acid texturing of poly-Si and properties of silicon nitride after rapid thermal process", Zhenzhou University.

[3] Buonassisi, T. et al. 2005, "Engineering metal-impurity nanodefects for low-cost solar cells", *Nat. Mate*r. Vol. 4 (9), pp. 676–9.

[4] Buonassisi, T. et al. 2007, "Transition metal co-precipitation mechanisms in silicon", *Acta Materialia*, Vol. 55, pp. 6119–26.

[5] Pickett, M.D. & Buonassisi, T. 2008, "Iron point defect reduction in multicrystalline silicon solar cells", *Appl. Phys. Lett.*, Vol. 92, p. 122103.

[6] Hartman, K. et al. 2008, "Dislocation density reduction in multicrystalline silicon solar cell material by high temperature annealing", *Appl. Phys. Lett.*, Vol. 93, p. 122108.

[7] Schultz, O. et al. 2006, "High-efficiency solar cells on phosphorus gettered multicrystalline silicon substrates", *Prog. Photovoltaics*, Vol. 14, p. 711.

[8] Takahashi, I. et al. 2008, "Impact of defect density in Si bulk multicrystals on gettering effect of impurities", *Jpn. J. Appl. Phys.*, Vol. 47, p. 8790.

[9] Krain, R., Herlufsen, S. & Schmidt, J. 2008, "Internal gettering of Fe in multicrystalline Si at low temperature", *Appl. Phys. Lett.*,Vol. 93, p. 152108.

[10] Huang, K. 1998, *Solid-state physics*, Beijing: Higher Education Press.

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Processing of highly-efficient MWT silicon solar cells

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ABSTRACT

This paper focuses on the latest developments from research on MWT (metal wrap-through) solar cells at Fraunhofer ISE. An overview of the current cell results for mc-Si and Cz-Si material with both Al-BSF and passivated rear side is presented. Recent progress in cell technology and challenges to reaching efficiencies of 20% for industrially processed large-area MWT solar cells are also discussed. Up to recently, MWT cell efficiencies of up to 19% for Cz-Si and up to 17.5% for mc-Si have been reached with industrially feasible processing. Improvements to the design of the MWT cell to increase cell efficiency and to allow an easy module assembly are also presented in this paper, as are first calibrated IV measurements of MWT solar cells.

Introduction

The most common industrial cell and module production approaches are mainly based on screen-printed H-patterned silicon solar cells. Therefore, today's modules suffer from high front-surface shading and from series resistance losses in the tabbing material. Both loss mechanisms are caused by the presence of an external contact, the so-called busbar, on the front surface. To reduce these losses significantly, the busbar has to be transferred to the rear surface. This can be realized by metal wrap-through (MWT) technology [1] while using only industrially-applicable production technologies [2]. The main advantage of the MWT technology among the rear-contact cell technologies is its need for only two additional process steps for cell production in comparison to conventional technology, which requires laser via drilling and rear-contact isolation. The via-metallization can be done in the same process step as the rear-solder pad metallization [3].

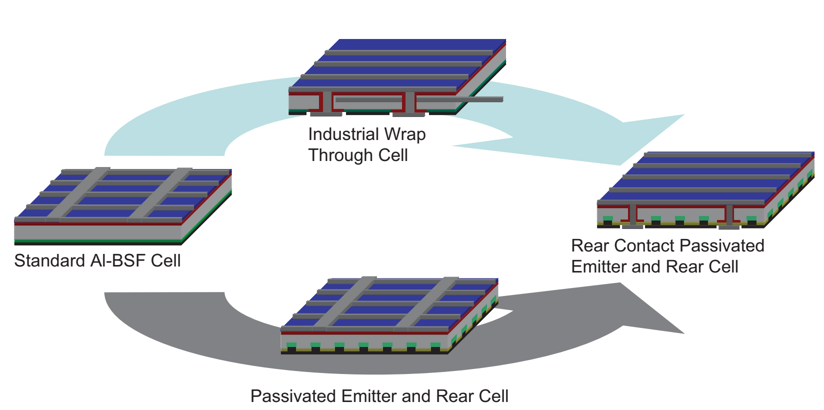

Figure 1. Fraunhofer ISE technology roadmap for future cell devices.

Hence, the MWT technology allows high efficiencies [4–6, 8] while production costs are still on a low level. Therefore the costs per Wp can be reduced at low economical risks. The transfer of the MWT technology from laboratory to industry is already ongoing and has been successful so far [3, 7–9]. This paper presents a detailed overview of the current status of MWT research and development at the PV-TEC pilot-line [10, 11] at Fraunhofer ISE, focusing on recent progress in cell processing and characterization.

Furthermore, the combination of the MWT technology with rear surface passivation is presented. The combination of industrial wrap-through cell technologies like the MWT technology with passivated emitter and rear cell (PERC) technologies is the most important part of the technology roadmap of Fraunhofer ISE (see Fig. 1) in order to improve cell efficiencies for large-area lab-scale series-processed solar cells

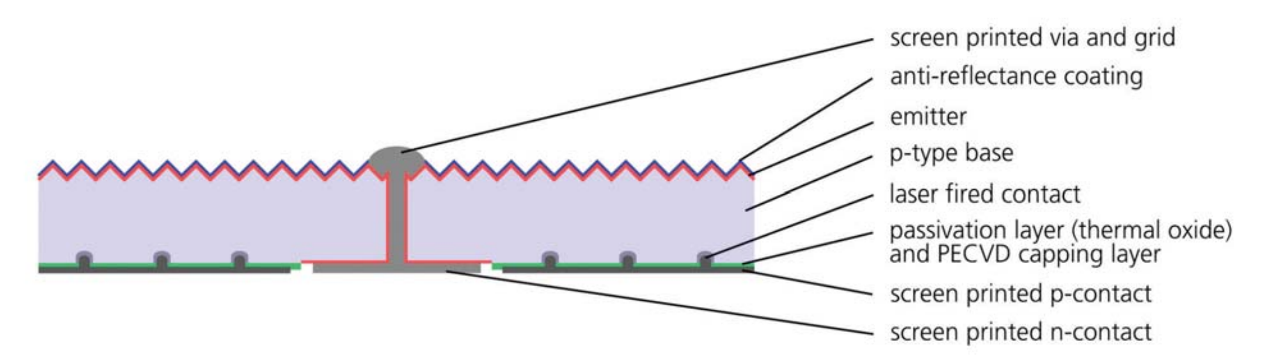

Figure 2. Schematic structure of the MWT-PERC devices presented in this work.

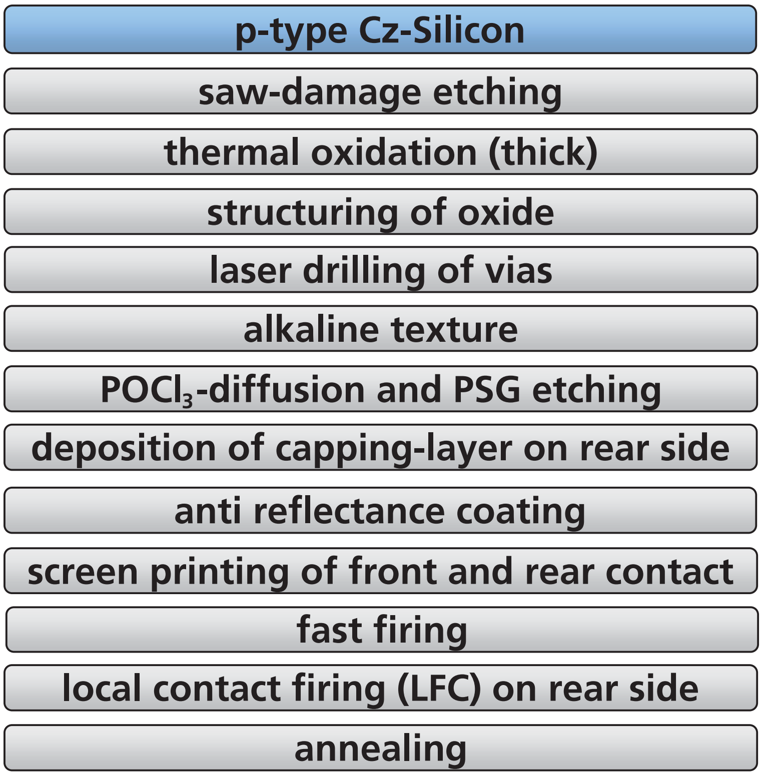

Figure 3. Process sequence for the fabrication of Cz-Si MWT-PERC devices.

towards 20%. The so-called MWT-PERC approach should enable a clear increase in cell efficiency.

Approach

In order to develop a highly-efficient MWT solar cell and module technology on a cost-efficient level, we have chosen to use a multi-stage approach. On the one hand we focus on the development of an MWT pilot-line process for industrial mc- and Cz-Si material which can be transferred to industry in a short timeframe. On the other hand, we have developed an industrially feasible process with a very high-efficiency potential (over 19%) on FZ-Si [12] in order to characterize MWT cells in detail and thus to improve processing of MWT cells.

Moreover, we successfully finished our first experiments with screen-printed MWT-PERC devices (see Fig. 2) on mc-Si and Cz-Si by applying a dielectrical layer, e.g. silicon oxide [13, 14] or aluminium oxide [15–17], on the rear surface. Cell thicknesses down to ~120µm are realized with the MWT-PERC approach without any bowing effects, thus producing high yield. A typical process sequence for the MWT-PERC approach with thermal oxide as the rear passivation layer is presented in Fig. 3. In this approach, the oxide also acts as the masking layer during diffusion and texturing processes. Within this work, cell processing of Cz-Si MWT-PERC devices is based on this process sequence, shown in Fig. 2. Additionally, for some MWT cells the front metallization was performed by a seed and plate approach with aerosol jetting for seed-layer formation followed by light-induced silver plating (LIP) [18]. More details about Cz-Si MWT-PERC devices are available in literature [19].

For mc-Si MWT-PERC devices, a process based on aluminium oxide – deposited by PECVD – as rear passivation layer and screen-printed front and rear contacts is used within this work. Results of aluminium oxide processing and characterization work at Fraunhofer ISE can be found in [15–17]. In order to protect the Al_2O_3 passivation layer from the screen-printed aluminium rear contact during the contact firing, an SiN capping layer is applied by PECVD on the rear side. The rear-side emitter is structured by a diffusion barrier. The backend processing (ARC deposition and so on) is similar to the process sequence presented in Fig. 3.

Screen-printing pastes for the front and via-metallization are developed in a joint project with Heraeus to ensure high cell efficiencies. The development of the via-metallization paste is of particularly high importance in order to reduce shunting and series resistance losses in the via-contact and therefore to optimize MWT cell processing. More details about current results with mc-Si MWT cells and the challenges of the MWT via paste development were presented by R. Hoenig and M. Neidert [20, 21].

Processing of the MWT cells employed the PV-TEC pilot-line [10]. In the case of Cz-Si MWT cell processing with aluminium back-surface field (Al-BSF), the experiments were carried out mainly at the PV lab of Bosch Solar Energy AG [9, 22]. An MWT layout with three continuous rear busbars (see Fig. 4) is used for all MWT cells unless specified otherwise.

In order to confirm the advantages of the MWT technology on the module level, MWT prototype modules were processed and compared to conventional modules as a first step. New MWT cell designs are under development with partners from the cell and module industry to ensure ease of module assembly [23].

A new inline processing-capable measurement system was developed to aid in delivering high-precision and fast IV measurements for MWT cells, which were in turn fixated during the IV measurement by use of vacuum [24]. First calibrated IV measurements performed

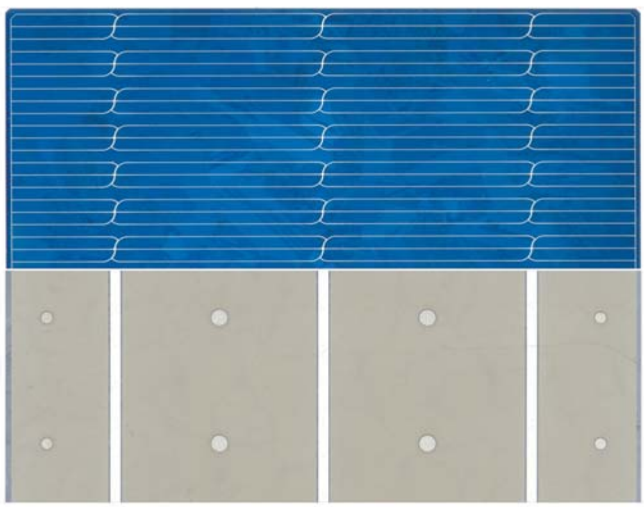

Figure 4. Front and rear of a typical mc-MWT solar cell (156 × 156 mm²) with three continuous rear busbars processed at Fraunhofer ISE [25].

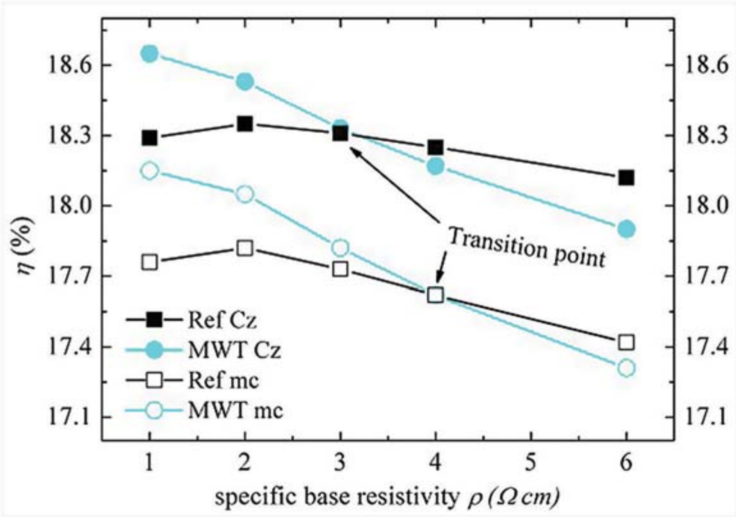

Figure 5. 2D "Sentaurus Device" simulation of an MWT and conventional solar cell [26]. The simulation shows a transition point depending on the bulk lifetime (mc, Cz) and base resistivity. Boron oxygen-induced degradation effects of the bulk lifetime are disregarded. The absolute values for the bulk lifetime are based on estimated input parameters; in the case of mc-Si in particular, an overestimation is likely.

at the Fraunhofer ISE CalLab PV Cells are presented in the coming sections.

Furthermore, loss mechanisms in MWT cells (e.g. losses due to via resistance [24], lateral base resistance [2], J_0-related recombination [3], etc.) have to be analyzed and minimized. A 2D simulation, as shown in Fig. 5, was carried out by the so-called "Sentaurus device" in order to clarify the origin of MWT loss mechanisms. In Fig. 5, the calculated efficiency is plotted against the base resistivity for low (mc-Si) and high (Cz-Si) bulk lifetime. The simulation is based on the design of a typical MWT solar cell (156 × 156mm^2) with three rear busbars without interruptions as shown in Fig. 4, using a conventional H-patterned solar cell with three busbars as a reference (indicated by 'Ref' in the graph legend).

Fig. 5 shows that a high efficiency gain can be achieved for MWT cells, especially for mc-Si with low base resistivity (< 2Ωcm). For Cz-Si cells, especially for those with high base resistivity (> 3Ωcm), the cell design shown in Fig. 4 leads to efficiency losses for MWT cells caused by lateral resistance losses in the base and by recombination losses in the rear n-contact region [26]. Hence, either the base resistivity has to be reduced or the rear MWT cell design must be optimized to achieve an efficiency gain. One possibility for an optimization of the cell design is presented in this work; others are discussed by K. Meyer [22].

Results and discussion

Most current-voltage (I-V) measurements are carried out using newly developed measurement equipment [24]. All cell measurements are performed by an industrial cell tester; best cells are partly measured by the Fraunhofer ISE CalLab PV Cells.

Results for MWT Cell with Al-BSF

Table 1 lists the best results of MWT cells with aluminium BSF rear side. The mean difference (Δ) when compared to conventionally processed solar cells is also presented for all IV parameters in absolute values. For a precise comparison, only sister wafers are used.

Cell Processing

Device type	V_{oc}(mV)	J_{sc}(mA/cm^2)	*FF*(%)	η(%)
mc-Si[1]	614	34.9	78.3	**16.8**
Δ(mc-Si)	+2	+1.0	-0.5	**+0.5**
Cz-Si[1]	619	37.2	77.2	17.7
Δ(Cz-Si)	0	+0.9	-1.6	0
Cz-Si[2] (new)	626	37.8	77.0	**18.2**
Δ(Cz-Si new)	+3	+1.0	-1.0	**+0.3**

[1]Independently confirmed by Fraunhofer ISE CalLab PV Cells (after degradation); measurement uncertainty: ±2%rel. for η.
[2]I-V measurements with cell tester after processing, measurement uncertainty: ±3%rel. for η.

Table 1. I-V data for the best MWT cells with Al-BSF rear measured on an industrial cell tester and partly independently confirmed by the Fraunhofer ISE CalLab PV Cells. The mean difference Δ to conventionally processed solar cells (sister wafers) is also presented (absolute values). The Cz-Si results labelled 'new' are based on a new rear-side design. The cell area is 156 × 156mm^2; base resistivity for mc-Si is ~0.5–2.0Ωcm, for Cz-Si ~2–4Ωcm.

Device type	V_{oc}(mV)	J_{sc}(mA/cm^2)	*FF*(%)	η(%)
mc-Si (~130µm)[1]	628	36.0	76.6	17.3
mc-Si (~130µm)[2]	630	36.0	76.9	17.5
Cz-Si (~120µm)[2]	628	39.0	75.9	18.6
Cz-Si (~170µm)[2]	630	39.9	74.8	18.8
	seed and plate approach (front contact):			
Cz-Si (~170µm)[2]	639	40.3	73.6	19.0

[1]Independently confirmed by Fraunhofer ISE CalLab PV Cells (after degradation); measurement uncertainty: ±2%rel. for η.
[2]I-V measurements with cell tester after processing, measurement uncertainty: ±3%rel. for η.

Table 2. I-V-data for the best MWT-PERC cells with passivated rear side measured on an industrial cell tester and partly independently confirmed by the Fraunhofer ISE CalLab PV Cells. The cell area is 125 × 125mm^2 for Cz-Si and 156 × 156mm^2 for mc-Si. The cell thickness after processing is given in brackets. The base resistivity for mc-Si is ~0.8Ωcm; for Cz-Si it is 1.7Ωcm (~120µm) and 2.7Ωcm (~170µm). For one Cz-Si group, the seed and plate approach was used for front metallization.

For mc-Si, a sufficient efficiency level (up to 16.8%) is reached. However, the moderate voltage level indicates that the used mc-Si material does not have the highest material quality. Nevertheless, a clear efficiency gain of 0.5% absolute (~3% rel.) is achieved with the MWT cell technology. The estimated efficiency gain in Fig. 5 (~0.5% at 1Ωcm) is confirmed. This underlines the high potential of the MWT concept for mc-Si material.

For Cz-Si material (~2–4Ωcm), the efficiency level is ~1% absolute higher than for mc-Si as expected, but no significant efficiency gain can be observed for MWT cells with three continuous rear busbars (cell design as presented in Fig. 4). A similar behaviour is shown by the simulations that were carried out (see Fig. 5). For Cz-Si material with a base resistivity of ~3Ωcm, no efficiency increase is expected for the MWT approach. The reasons for this behaviour are discussed in detail in [26]. A main reason is the rear busbar region without p-contact (Al-BSF), which leads to significant FF losses especially for high-quality material with high base resistivity. Due to strong boron oxygen-induced degradation effects for a low base resistivity, the Cz-Si base material remains unchanged; however, a modification of the rear busbar region can significantly improve the FF for MWT cells [26]. Therefore, the MWT rear design was optimized, and the rear n-contact region was significantly reduced.

A new MWT cell batch ('Cz-Si new' in Table 1) was processed with an optimized rear design, resulting in efficiencies up to 18.2%. This is so far the highest MWT efficiency achieved for AL-BSF rear sides within this work. Due to the rear design optimization, an efficiency gain of about 0.3% absolute (~1.7% rel.) mainly based on decreased fill factor losses is observed for MWT cells. Hence, the high potential of the MWT concept is also shown for Cz-Si material.

Device type	V_{oc}(V)	J_{sc}(mA/cm^2)	Δ*FF*(%)	Δη(%)
MWT	3.64	35.6	-3.8	-1.3
Conv.	3.60	34.4	-5.5	-1.5
Δ(MWT-Conv.)	+0.04	+1.2	+.1.7	+0.2

Table 3. I-V results of a comparison of an MWT and a conventional Cz-Si mini-module (each consisting of six cells). ΔFF and Δη signify the following differences in % absolute: FF/η (module) minus FF/η (cell); measurement uncertainty: ±3%rel. for η.

Results for passivated MWT cells (MWT-PERC)

To improve cell efficiencies further, the MWT cell concept is combined with the PERC concept [19] as described earlier. The results of the best so-called MWT-PERC devices are listed in Table 2.

For mc-Si material, sufficient efficiencies up to 17.3% are reached in the first run. Hence, an efficiency gain compared to the Al-BSF approach of about 0.5% absolute (~3% rel.) is achieved due to rear-side passivation. Further cell batches including the mentioned optimization of the MWT rear design are already in process focusing cell efficiencies towards 18%.

Thus far, Cz-Si materials reached efficiencies of up to 18.8% within the first runs using screen-printed front and rear contacts. With the seed (aerosol jetting [27]) and plate (Ag-LIP) approach for the front contact, efficiencies of 19.0% were achieved, leading to the conclusion that the MWT efficiency is increased by over 0.5% absolute (>3% rel.) due to rear-side passivation. The slightly increased efficiency for the thicker Si material can most likely be explained by an optimized front grid which was used in this batch and by more effective light capturing due to the thicker base material. Both effects lead to a clear increase in J_{sc}. The FF decrease for the thicker Cz-Si can be explained by the higher base resistivity (see Fig. 5). The gain in both J_{sc} and V_{oc} as well as the FF loss for the seed and plate approach can be explained by a reduction of the finger width (reduced shading) and by the use of an emitter with higher sheet resistance.

The next cell batches should see efficiencies in the region of 20% either by the use of higher doped base material and/or by the mentioned optimization of the MWT rear-side design, coupled with the introduction of the seed and plate approach for the front contact. The final cell thicknesses of ~120µm show the feasibility of the MWT-PERC approach to be used for industrial processing of very thin mc-Si and Cz-Si wafer material.

MWT module results

Two mini modules (one MWT and one conventional), each consisting of six Cz-Si solar cells, were processed [9]; Table 3 displays the I-V results for both modules. An efficiency increase of ~0.2% absolute (~1.5% rel.) is reached on the module level for the MWT technology. This increase is driven by the decrease of series resistance losses due to an optimized MWT tabbing technology, which allows more tabbing material on the rear without additional shading. The reduced FF difference (ΔFF) for the MWT technology confirms the reduction of the series resistance losses on the module level. The clear increase in J_{sc} for the MWT technology can be explained by less shading due the absence of front busbars and tabs.

Mini-modules with very thin (~120µm) MWT-PERC devices were processed first. For the Cz-Si material, module efficiencies of ~16.5% were achieved. The moderate value can thus far be explained by a non-optimized MWT rear side for module interconnection. Further experiments with an optimized MWT rear design are already underway; further details regarding module technology for back-contacted solar cells are presented in [23].

Conclusion

We demonstrated the industrial fabrication of large-area metal wrap-through silicon solar cells with Al-BSF rear sides as well as with passivated rear surfaces (MWT-PERC approach) in our PV-TEC pilot-line using Cz- and mc-Si material. For mc-Si MWT cells with Al-BSF, an efficiency gain of about 0.5% absolute is achieved compared to conventionally processed cells (sister wafers). For Cz-Si materials, efficiencies up to 18.2% are achieved with an optimized rear side with less rear n-contact metallization. Hence, the high potential of the MWT concept has been illustrated on both materials.

MWT-PERC devices reached efficiencies of up to 19.0% on Cz-Si and up to 17.5% on mc-Si, confirming the high efficiency level which is achievable with the MWT-PERC approach. Moreover, MWT-PERC devices with thicknesses down to ~120µm are successfully processed on industrial equipment, showing the high cost reduction potential of the MWT-PERC concept for very thin wafer material.

A further efficiency gain for the MWT technology is demonstrated on the module level by using an optimized MWT tabbing technology. To achieve MWT efficiencies towards 20%, two main strategies were selected. Firstly, an optimization of the MWT rear-side design, which is mainly based on the reduction of the rear n-contact area, will increase the MWT efficiency. Secondly, the use of wafer material with low base resistivity will push the MWT efficiencies further if boron oxygen-induced degradation effects can be neglected.

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References

[1] van Kerschaver, E. et al. 1998, *Proc. 2nd WCPEC*, Vienna, Austria, p. 1479.
[2] Clement, F. et al. 2009, *Solar Energy Materials & Solar Cells*, Vol. 93, p. 1051.
[3] Clement, F. et al. 2009, Proc. *34th IEEE PVSC*, Philadelphia, USA, p. 1.
[4] Clement, F. et al. 2009, *Proc. 24th EU PVSEC*, Hamburg, Germany, p. 2172.
[5] Inoue, S. et al. 2008, *Proc. 23rd EU PVSEC*, Valencia, Spain, p. 1.
[6] Bennett, I.J. et al. 2009, *Proc. 24th EU PVSEC*, Hamburg, Germany, p. 3258.
[7] van den Donker, M.N. et al. 2008, *Proc. 23rd EU PVSEC*, Valencia, Spain, p. 1.
[8] Dross, F. et al. 2007, *Technical Digest 17th Int. PVSEC*, Fukuoka, Japan, p. 410.
[9] Lahmer, D. et al. 2009, *Proc. 24th EU PVSEC*, Hamburg, Germany, p. 2168.
[10] Biro, D. et al. 2006, *Proc. 21st EU PVSEC*, Dresden, Germany, p. 621.
[11] Biro, D. et al. 2009, *Proc. 24th EU PVSEC*, Hamburg, Germany, p. 1901.
[12] Fellmeth, T. et al. 2009, *Proc. 24th EU PVSEC*, Hamburg, Germany, p. 711.
[13] Biro, D. et al. 2009, *Proc. 34th IEEE PVSC*, Philadelphia, USA, p. 1594.
[14] Mack, S. et al. 2009, *Proc. 24th EU PVSEC*, Hamburg, Germany, p. 1574.
[15] Saint-Cast, P. et al. 2009, *Applied Physics Letters*, Vol. 95, p. 151502.
[16] Kania, D. et al. 2009, *Proc. 24th EU PVSEC*, Hamburg, Germany, p. 2275.
[17] Saint-Cast, P. et al. 2010, *IEEE Electron Device Letters*, Vol. 31, p. 695.
[18] Hoerteis, M. 2009, Ph.D. thesis, University of Constance.
[19] Thaidigsman, B. et al. 2010, *Proc. 25th EU PVSEC*, Valencia, Spain.
[20] M. Neidert, et al., *Proc. 24th EU PVSEC*, Hamburg, Germany, p. 1424.
[21] Hoenig, R. et al. 2010, *Proc. 35th IEEE PVSC*, Honolulu, Hawaii, USA.
[22] Meyer, K. et al. 2010, *Proc. 25th EU PVSEC*, Valencia, Spain.
[23] Wirth, H. et al. 2010, *Proc. 25th EU PVSEC*, Valencia, Spain.
[24] Glatthaar, M. et al. 2010, *Proc. 25th EU PVSEC*, Valencia, Spain.
[25] Clement, F. et al. 2009, *Solar Energy Materials & Solar Cells*, Vol. 94, p. 51.
[26] Fellmeth, T. et al. 2010, *Proc. 25th EU PVSEC*, Valencia, Spain.

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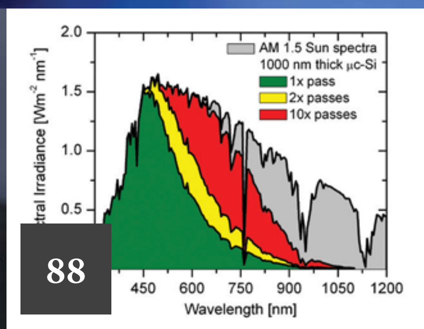


88
AM 1.5 Sun spectra
1000 nm thick μc-Si
1x pass
2x passes
10x passes
2.0
1.5
1.0
0.5
450
600
750
900
1050
1200
Wavelength [nm]

Thin-film PV conversion efficiencies on the rise, as United Solar, Avancis set new records

Uni-Solar's massive PECVD tool deposits the key thin-film ingredients in its amorphous-silicon process.

The U.S. National Renewable Energy Laboratory (NREL) has confirmed new world record conversion efficiencies for a pair of thin-film solar photovoltaic devices. United Solar has achieved an initial 12% efficiency on a large-area thin-film silicon cell using its Nano-Crystalline technology, while Avancis has reached 15.5% on a copper-indium-selenide (CIS) module, according to NREL.

The record-setting Uni-Solar cell, with an area of 400cm^2, was encapsulated in the company's proprietary polymer. The triple-junction design incorporates nanocrystalline silicon layers on a flexible stainless-steel substrate and increases the cell's efficiency by about 50%, relative to current Uni-Solar cells in production. The company said it expects to be in production with the nano-enhanced technology in 2012.

The champion CIS module, based on Avancis' monolithically integrated design, was 30 × 30cm^2. The Saint-Gobain subsidiary said it achieves 12% efficiencies on full 130W panels in series production at its 20MW factory in Torgau, Germany.

The engineering department works exclusively with processes and materials that are actually in use in series production, so the findings of the research department can be quickly implemented in industrial applications, according to Avancis. The company said it plans to implement many of the improved processes in the pair of 100MW factories it is building or getting ready to set up in Torgau and South Korea, respectively.

Business News Focus

DuPont MCM, Holst Centre team up for printed electronics, including OPV

DuPont Microcircuit Materials (MCM) and Holst Centre have formed a partnership to focus on advancing the technology of printed electronics, specifically in the areas of printed structures on flexible substrates, which are used in a variety of markets including flexible display, RFID, lighting, biomedical and organic photovoltaics (OPV).

DuPont MCM will become part of the 'Printed Structures on Flexile Substrates' program and work towards creating favourable printed metallic structures on flexible substrates in terms of conductivity, fine line deposition and low-energy sintering. Different roll-to roll compatible printing techniques will be examined, including screen, flexography and inkjet. Furthermore, alternative conductor metallurgies will also be investigated in addition to reactive systems for depositing conductive traces.

News

Yissum, Vaxan sign nanoparticle ink research and licensing agreement with Israeli university

Yissum Research Development, the Technology Transfer Company of the Hebrew University of Jerusalem and Vaxan Steel have signed a licensing and research agreement to develop silver nanoparticles and silver-coated copper nanoparticles for conductive inks. The contract stipulates that Yissum provide Vaxan with an exclusive sales license for Asia – excluding Israel and former Soviet states – in return for research fees and royalties from future sales.

The inks, created by scientists at the Institute of Chemistry at the Hebrew University, can be used in unison with a variety of printing technologies, including inkjet printing of electronic circuits on silicon wafers in the thin-film photovoltaic industry.

First Solar collaborates with Arizona Public Service for 17MW PV project in Gila Bend

Arizona Public Service (APS) is expanding upon its AZ Sun program with the development of a new 17MW PV facility in Gila Bend, Arizona. With the Paloma Solar Plant, APS's AZ Sun program will have committed 83MW of solar capacity out of the 100MW it aims to finance and own upon the program's completion, which is intended for sometime in 2014. First Solar was contracted by APS to design and build the Paloma Solar Plant and expects to have it online by September.

Although no financial details for the deal between APS and First Solar were released, APS notes that the solar facility will use 300,000 thin-film PV panels mounted on fixed-tilt steel frames – a first for an APS solar plant. The solar project will be constructed on an alfalfa farm in Gila Bend, a city that is also home to Abengoa Solar's Solana CSP installation, for which APS negotiated a 30-year PPA to purchase all of Solana's generation beginning in 2013.

ISET signs joint collaboration MOU with Korea's K&K Solar and Yeungnam University

International Solar Electric Technology (ISET) will be jointly collaborating with Korea-based K&K Solar and the Yeungnam University of Korea. Although no specific collaboration details or financial terms were released, ISET commented that the signed memorandum of understanding was aimed towards technology commercialization and advanced development, allowing ISET to continue the advancement of its thin-film CIGS solar panels.

The MOU was signed at ISET's facility in Chatsworth, California by Dr. Kapur, Youn-Sik Kim, president of K&K Solar, Dr. Jae Hak Jung, director of the Regional Innovation Center for Solar Cell & Module and Dr. Chinho Park, director of the Institute for Solar Energy Research and the Solar Cell Materials and Process R&D Workforce Cultivation Program. ISET's Chatsworth facility is currently in pilot production of the company's thin-film CIGS modules and is set to eventually expand production capacity to 30MW per year.

Source: ISET

Production of CIGS thin-film modules at ISET's facility in Chatsworth, California.

Ascent Solar signs reseller deal with Polymeur Sun for Malaysia and Singapore region

Polymeur Sun will be acting as an authorized reseller of Ascent Solar Technologies thin-film CIGS modules for BIPV and portable power solutions in the Singapore and Malaysia regions. Ascent Solar looks forward to this agreement with Polymeur Sun promoting the company's name with different Southeast Asia regions that are in the development stages of their solar markets.

Solyndra finishes 1.2MW French installation for Nazca

Solyndra has finished work on a 1.2MW system in the southern French commune of Cavaillon for EPC contractor Nazca. The system, which is being connected to the grid today, is fitted on the roof of AZ Méditerranée's food conditioning facility and is the second array Solyndra has installed for Nazca. More than 6,800 Solyndra panels will populate the 17,500m2 roof and they will help generate 1,500MWh of electricity per annum.

Southern California Edison signs PPA with First Solar for Silver State South plant

Southern California Edison (SCE) has signed a power purchase agreement with First Solar for its 250MW (AC) Silver State South plant. First Solar's ground-mounted system, which will be located on 2,500 acres of public land near Primm, Nevada, will start generating electricity in 2014 and be fully operational in May 2017.

Development of Silver State South will create around 300 construction jobs and, when completed, is to be connected to SCE's proposed Eldorado-Ivanpah 220kV transmission line.

New Mexico's 30MW Cimarron Solar plant begins commercial operation

The 30MW (AC) Cimarron Solar Facility in Colfax County, New Mexico has reached completion and began its commercial operation in early December 2010. The solar project was developed and built by First Solar, who also supplied 500,000 CdTe solar modules for the solar plant, constructed over 364 acres. Southern Company and Ted Turner cooperated with each other for the acquisition of the project from First Solar in March 2010. First Solar will continue to provide maintenance and operation services under a long-term contract for the facility.

Built next to Turner's Vermejo Park Ranch, the Cimarron Solar Facility will deliver power to member electric cooperatives of Tri-State Generation and Transmission Association. The Denver-based Tri-State Transmission is a non-profit wholesale power supplier to 44 electric cooperatives and agreed to a 25-year power purchase agreement for the solar electricity produced at the Cimarron facility.

Texas and Georgia rooftop solar installations incorporate Solyndra modules

Two new solar installations in different U.S. states have chosen Solyndra's CIGS panels for their rooftop solar power systems. In Texas, GridPoint was chosen by Irving Independent School District to design, engineer and install a 582kW solar system on the roof of Lady Bird Johnson Middle School. Using Solyndra's panels, the new middle is set to open this August and is claimed to be the largest net zero-energy school in the U.S.

Source: Solyndra

Rooftop installation featuring Solyndra's cylindrical CIGS modules.

Further to the east in Rome, Georgia, United Renewable Energy used Solyndra CIGS thin-film panels on a 95.2kW installation on the rooftop of Marglen Industries plastic bottle recycling plant. The companies assert that this is the largest project in the Southeast to utilize Solyndra's cylindrical thin-film solar energy system with 476 of the company's solar modules installed.

Ascent Solar signs CIGS module distribution contract with SW Solarwatt

SW Solarwatt has signed a contract with Ascent Solar Technologies to distribute its CIGS thin-film modules for building-integrated photovoltaic (BIPV) projects in Greece and Cyprus. The agreement will allow Ascent Solar to gain a foothold in the rapidly-growing east Mediterranean solar market and see its modules used on a variety of on- and off-grid developments. Ascent Solar has also signed a similar distribution deal with Green Earth Energy, which will exclusively distribute its modules in the German and Benelux markets.

Testing and Certification News Focus

Sulfurcell CIGS module receives TÜV Rheinland endorsement

TÜV Rheinland has endorsed the 12.6% efficiency of Sulfurcell's second generation 94W thin-film PV module. Sulfurcell will start shipping its new CIGS module to customers in Q3.

The TÜV backing comes just a month after Sulfurcell announced it would be receiving €18.8 million in equity financing from existing investors. These funds will go towards the acquisition of additional CIGS equipment and ongoing R&D work to help the company achieve 14% efficiency within the next 12 to 18 months.

Q-Cells CIGS, multicrystalline modules don't buckle under Australian desert conditions

At a test field in Alice Springs, Australia, Q-Cells recently found that its solar modules tested with peak performances, delivering significant power output in some of the driest weather conditions in Central Australia. The company's Q.Smart solar module, of CIGS thin-film technology, and a prototype of its Q.Pro and Q.Base, of polysilicon technology, were tested over the past few months at the Desert Knowledge Australia Solar Centre (DKASC) alongside other similarly sized systems.

The Q.Smart modules were tested between August 2010 and January 2011 yielding an average energy output of 5.8kWh per installed kW-peak per day. In comparison, systems from U.S.- and Japanese-based manufacturers had an average output, under the same conditions, between 5.1 and 5.3kWh/kWp/day.

The Q.Pro and Q.Base crystalline solar modules also performed well during the test period between March 2010 and January 2011. The QC-05 prototype module generated an average energy yield of 5.3kW-hours per installed kilowatt-peak per day. Q-Cells is planning to bring out a new generation of its Q.Pro and Q.Base modules in all key markets this year.

OPV materials firm Plextronics gets ISO 14001 certification

Organic PV and OLED materials and process developer Plextronics has achieved ISO 14001:2004 certification. The company was awarded this designation by ABS-QE for its compliance with environmental process standards and effective environmental management systems. Those standards and systems are used in the production and other operations related to conductive polymers and inks for use in printed electronic applications.

ISO 14001 is an internationally-recognized standard developed by the International Organization of Standardization that defines requirements for the implementation of environmental management systems via operational processes and procedures.

Stion modules receive ANSI/UL, IEC accreditation

Stion has received ANSI/UL 1703 and IEC 61646 accreditation for its 110 and 120W CIGS thin-film solar panels. The Elevation Series are the largest U.S.-manufactured, monolithically-integrated panels to gain industry accreditation to date.

Manufacturing of the panels is currently based in San Jose, CA. When Stion's Hattiesburg facility becomes operational, production responsibilities will be shared between the two sites.

Stion's Elevation Series module.

NREL confirms 41.4%-efficient Solar Junction CPV cell; firm on DOE loan shortlist

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) has confirmed that CPV cell supplier Solar Junction has achieved conversion efficiencies of 41.4% on a multijunction cell sampled from the company's demonstration production line. The early-stage firm also revealed it is one of a small group of candidates – and the only CPV cell company – that have been chosen for "post-selection due diligence" to receive a DOE loan guarantee, which would help support expansion plans for a 250MW factory at its base of operations in San Jose.

The company cites three advantages that its cells have over existing and growing number of next-generation MJCs: materials bandgap tunability of 0.8–1.42eV, which optimizes performance and fosters rapid efficiency improvements; lattice-matched device architecture, which ensures reliability to industry standards; and proprietary ultraconcentration tunnel junctions that can push performance to levels over 1,300 suns and eliminate possible damage caused by localized concentration variations.

The Federal loan guarantee process is in the midst of "ongoing negotiations," so Allen would not disclose any details of the amount, possible timing of award of the loan, or timeline for the proposed production ramp if and when the company makes it through due diligence and receives the loan.

The proposed 250MW manufacturing hub would be built in the same location as Solar Junction's headquarters and demo line in San Jose, a facility the company has leased for over two years.

EPIR, NREL achieve breakthrough CdTe cell efficiency

EPIR Technologies has joined a select group of solar cell developers by creating a polycrystalline cadmium telluride (CdTe) cell for commercial use with an efficiency exceeding 15%. The cells were developed with the help of a team of scientists from NREL and the 15.2% efficiency achieved far surpasses the previous best figure on soda-lime glass of 14.4%.

The record-breaking numbers were driven by a fill factor of 77.6% – one of the highest values ever recorded for a CdTe cell. EPIR did not disclose any information on when the CdTe cell would be ready for consumer distribution.

R&D News Focus

Leibniz Institute for New Materials develops efficiency-enhancing CIGS PV barrier layer

A team of scientists at the Leibniz Institute for New Materials (INM) has developed a glass-like barrier layer that separates the metal carrier from the absorber film. The new material is said to increase the efficiency of metal-based CIGS thin-film solar cells by as much as 13%.

The diffusion barrier – which is transparent, flexible, and only a few microns thick – is applied on the metal carrier by means of a sol-gel process, according to the INM group. The scientists said they have produced DIN A3 size foils using a combination of dip coating and slot coating. By employing a traditional roll-to-roll printing process, continuously layered foils could be produced at lengths up to 50m and widths of about half a metre.

Arkema, INES to collaborate on PV polymer materials research

Arkema and CEA teams from the French Institut National de l'Energie Solaire (INES) have joined forces to create what is being called the first private/public mixed research laboratory in France dedicated to the development of polymer materials for various photovoltaic module technologies.

This new joint laboratory, located on INES's site near Chambéry (Savoie), will pool Arkema's expertise in polymers, polymer films and nanomaterials with the expertise of the INES CEA teams in the design and development processes for innovative PV modules, silicon and thin layers. The cooperative venture will be in place for an initial four-year period, according to the partners.

Suntrix CPV system with Cyrium solar cells deployed in 200KW power plant in China

A 200kW high-concentration photovoltaic power plant featuring Suntrix tracking systems and modules equipped with Cyrium III-V solar cells has been opened by Qingdao HG Solar Energy in China. Construction of the HCPV system began in November 2010 and was completed this month.

Collaboration on this demonstration project began several months ago between Suntrix and Cyrium Technologies and highlights the opportunity that exists in China for HCPV systems, according to the companies.

Cyrium received support from Environment Canada's Asia Pacific Partners (APP) program, as part of the Canadian government's efforts to bring Canadian and China-based companies together to facilitate cross-border collaboration on cleantech projects.

Suntrix's HCPV system has a concentration ratio of 576.

Two more thin-film module manufacturers enter the UK market

Looking to expand their sales footprint by entering the UK PV market, both Inventux Technologies and Abound Solar have announced receipt of MCS (Microgeneration Certification Scheme) certification for their modules. Both companies cited the growing UK market for solar, though less than 50MW were installed in the country last year, according to official figures.

Inventux with its micromorph silicon thin-film modules and Abound with its CdTe thin-film modules would be directly impacted by any planned changes to the UK FiT, which is now being seen as almost a capped system rather than a true FiT. Support for residential rooftop installations is preferred over large-scale installations by the coalition government.

Thin-Film Order Focus

Ultrasonic installs PV-480 coating system for U.S. thin-film manufacturer

Ultrasonic Systems has recently installed and commissioned its PV-480 coating system for an unspecified U.S. CdTe solar panel manufacturer. Ultrasonic advised that the solar panel manufacturer intends to use the system for the application of cadmium chloride solution in its absorber layer activation process.

TSMC places US$20 million equipment order with Mirle Automation

Taiwan-based equipment and automation firm Mirle Automation has received multiple orders from TSMC worth a combined US$20 million for a batch of solar production tools. Further details of the purchase were not disclosed.

However, the primary equipment that Mirle makes that would be in line with TSMC's manufacturing operations for thin-film PV. The company makes a range of thin-film equipment such as AZO conductive glass vacuum sputtering equipment and laser marking systems through to complete turnkey lines.

TSMC has previously announced plans to enter the thin-film market in collaboration with CIGSS thin film start-up Stion. The semiconductor foundry said last September that it would invest approximately US$258 million to build both an R&D and manufacturing facility, with the first-phase equipment move-in planned for the second quarter of 2011. Documents filed by TSMC to the Taiwan Stock Exchange do not reveal the nature of the capital equipment purchase.

Oerlikon Solar receives order for KAI system from China's Dong Xu

Oerlikon Solar has received an order from leading Chinese photoelectric glass manufacturer Dong Xu for its KAI thin-film silicon coating equipment. The fully-automated KAI PECVD system will form the central part of Dong Xu's new thin-film silicon production line.

Designed for the deposition of amorphous and microcrystalline photovoltaic absorption layers, the KAI system will mass-produce large modules with the help of its Plasma Box technology. Dong Xu's order will not only help improve its manufacturing yield and efficiency but also help increase Oerlikon's presence within China.

CVD Equipment Corp wins multiple orders worth US$9.3 million

New orders in January received by CVD Equipment Corporation totalled US$9.3 million and included orders for both production and research equipment in the fields of solar, LEDs and nanotechnology. The company did not breakout the orders specific to PV manufacturing. To meet customer demand, the small cap is planning to raise up to US$20 million in new capital to support the expansion of product offerings, personnel, equipment and facilities.

First Solar signs new supply and recycling contracts with 5N Plus

The main supplier of high-purity cadmium telluride (CdTe) to First Solar, Canadian-based 5N Plus, has signed a new recycling agreement and three new supply agreements that initially increase the quantity of CdTe supplied to the thin-film leader by 30% but reach a 60% increase by 2013. The new agreements, which run until December 31st, 2015, replace previous contracts.

5N Plus also announced plans to build a new recycling plant in Malaysia, which is expected to be operational by mid-2012. The new plant is intended to expand the company's recycling presence in Asia and provide recycling services for various solar cell manufacturing byproducts, including those produced by First Solar, which has module plants in the country.

MVSystems earns new orders for thin-film cluster tools; granted extension by DOE for R&D work

MVSystems (MVS) has received a new order for its cluster tool system from Hebei University in Baoding, China. The system is set to be used for the advancement of solar cells using amorphous and nanocrystalline silicon materials. Concurrent to the Hebei University order, MVS also received an order from the University of Toledo, Ohio for an added chamber in order to increase the capability of its cluster tool for rigid and flexible substrates, which MVS installed in 2009.

Source: MVSystems, Inc.

MVSystems' cluster tool for prototype production (PECVD and sputtering).

In addition to its new tool orders, MVS was granted an extension for its research and development in solar to hydrogen conversion. Conducted in a partnership with the National Renewable Energy Laboratory, the R&D is focused on developing WO3, CIGS and amorphous carbide photoelectrode driven by thin-film Si tandem solar cells.

Leibniz Institute for New Materials develops efficiency-enhancing CIGS PV barrier layer

A team of scientists at the Leibniz Institute for New Materials (INM) has developed a glass-like barrier layer that separates the metal carrier from the absorber film. The new material is said to increase the efficiency of metal-based CIGS thin-film solar cells by as much as 13%.

The diffusion barrier – which is transparent, flexible, and only a few microns thick – is applied on the metal carrier by means of a sol-gel process, according to the INM group. The scientists said they have produced DIN A3 size foils using a combination of dip coating and slot coating. By employing a traditional roll-to-roll printing process, continuously layered foils could be produced at lengths up to 50m and widths of about half a metre.

Source: INM

The Leibniz INM building in Saarbrücken, Germany.

DyeTec Solar secures US$1-million grant for technology development

DyeTec Solar has secured a US$1 million Ohio Third Frontier Commission grant to help it develop technology for the mass manufacture of glass-based BIPV (building-integrated photovoltaic), BAPV (building-applied photovoltaic) and AIPV (automotive-integrated photovoltaic) products. The technology, which will be produced alongside glassmaker Pilkington North America at DyeTec's Toledo facility, is aimed to cater for both commercial and residential users.

Before developing its technology for mass consumption, DyeTec plans to create prototype DSC-based BIPV glass panels and equipment sets; the final product will be created with transparent conductive oxide (TCO) glass and DSC materials, and allow downstream suppliers in the glass market to mass produce high-performance DSC-TCO products for use in BIPV, BAPV and AIPV systems.

Japanese scientists develop 'moth eye' cell film

The PV industry's latest innovation in cell design owes as much to Mother Nature as it does to time spent in any laboratory. It is the water-repellent, antireflective coating of a moth's eye that has provided the inspiration behind this latest advance in thin-film technology.

A Japanese research team has published a paper in the bimonthly Energy Express unveiling its next-generation cell protection film, which mimics eye microstructure of a moth to significantly cut down on the amount of sunlight reflected by the cell, thus enabling it to harness more of the sun's solar energy.

The paper found that the 'moth eye' films improved the annual efficiency of solar cells in their two testing regions of Phoenix and Tokyo by around 6% and 5%, respectively. The team is currently working on improving the film's durability and tailoring it for a range of solar cells.

The antireflective properties of a moth's eye was the inspiration behind the new cell film.

Product Reviews

Honda Soltec

Honda Soltec's more compact CIGS module claims 13% efficiency

Product Outline: Honda Soltec Co., Ltd. will this year release a new thin-film solar cell with an even more compact design than the current model to allow efficient installation on a wide range of roof shapes. The module conversion efficiency of the new solar cell module is expected to exceed 13.0%, ranking it among the world's most efficient CIGS-based thin-film solar cells.

Problem: The new model is more compact, with only approximately two-thirds the module surface area of the current model, allowing it to be installed in limited space on a wide range of roof shapes.

Solution: The performance of the photosensitive CIGS layer has been improved and the surface area of the surrounding frame and other non-photosensitive portions reduced, resulting in approximately a 10% increase in module conversion efficiency compared to the current model. Nominal maximum output per module is 89W compared with the previous module's rating of 130W.

Applications: Residential, commercial and utility-scale applications.

Platform: The prototype manufactured using existing Honda Soltec equipment achieved a module conversion efficiency of 13.0%. Honda is working to further improve module conversion efficiency as it brings the product to market. External dimensions (W × L × H) 926mm × 738mm × 37mm. Weight is now 8.7kg compared with 14.4kg for the previous model. Nominal open circuit voltage (V_{oc}) is 190V, compared with 280V.

Availability: Unspecified date in 2011.

TRUMPF

TRUMPF's TruMicro Series ultra-short pulse lasers offer improves thin-film edge ablation

Product Outline: TRUMPF's TruMicro Series of ultra-short pulse lasers are claimed to lower the manufacturing cost of photovoltaic cells while also enhancing their performance. The small and compact TRUMPF TruMicro Series 3000 with wavelengths of 1064 and 532nm are designed for P1, P2 and P3 patterning.

Problem: The patterning of thin-film cells made from $Cu(In,Ga)(S,Se)_2$ or CI(G)S is particularly challenging for the laser process. For application of molybdenum on a glass substrate, nanosecond lasers are still used but picosecond lasers are claimed to offer a far better solution. To protect thin-film solar modules against unfavourable environmental influences – especially against moisture – a width of approximately 10mm of the layer system is ablated along the edge and covered with laminated film. The traditional method employed is sandblasting, but TRUMPF TruMicro lasers are claimed to provide a far more suitable process.

Solution: In the production of solar modules from amorphous silicon (a-Si) or cadmium telluride (CdTe), conductive and photoactive films are deposited on large substrate areas such as glass. After every deposition, the laser subdivides the surface so that the cells created are automatically switched in series by the process sequence. With these lasers, the material is ablated with ultra-short pulses but without significant heating of the process edge zone.

Applications: P1, P2 and P3 patterning, edge deletion and other process steps.

Platform: TRUMPF's TruMicro picosecond lasers have output power up to 50W, which can significantly reduce process costs.

Availability: Currently available.

DuPont PV Solutions

DuPont's PV5400 series encapsulants are available in roll form for easy handling and fast laminating

Product Outline: DuPont Photovoltaic Solutions has introduced the PV5400 series thin ionomer-based encapsulant sheets designed to protect sensitive thin-film solar modules, while offering manufacturers new ways to cut costs, speed throughput and deliver more power over the life of each unit.

Problem: Material innovation is particularly critical to increasing the lifetime and efficiency of solar modules and reducing total system costs. A key challenge is how best to protect thin-film PV modules from air and water vapour in the long term, and how to continue to lower manufacturing costs. Choosing the right encapsulant material not only increases module durability and production efficiency, but can significantly enhance long-term power generating efficiency.

Solution: Because the new DuPont 5400 series encapsulants are resistant to moisture intrusion, it is possible to achieve strong, lasting edge integrity without the need for caulking or additional edge sealing, saving costs in manufacturing. The added moisture resistance of assembled modules results in longer service life from each thin-film module installation. Compared with traditional photovoltaic encapsulants such as EVA and PVB, this new offering is claimed to have up to 100 times more electrical resistivity, improving electrical insulation and thereby minimizing current leakage.

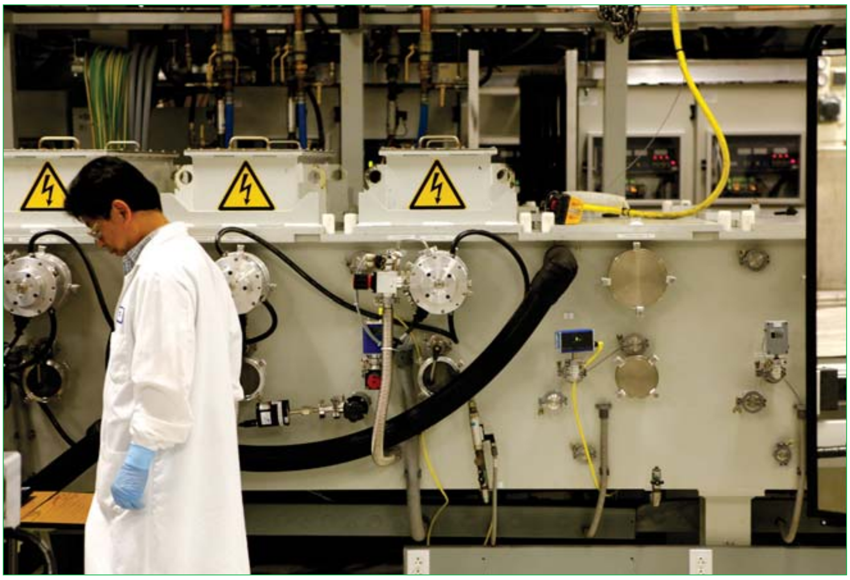
Applications: Thin-film module encapsulation.

Platform: The PV5400 series encapsulant is DuPont's first ionomer sheet to be made available in convenient roll form, easing storage and handling for large-volume, high-speed manufacturing. Available sheet thicknesses include 400 and 500µm.

Availability: Currently available.

Eye on Stion: Moduling in Mississippi makes sense for upstart CIGSSe 'layer cake' manufacturer

By **Tom Cheyney**



Source: Stion

When Stion started looking for sites to establish its first volume production plant, Mississippi was not even on its radar. After vetting some "100 different opportunities, state and local flavors and locations," the San Jose-based thin-film PV module company had "narrowed the list down to a half-dozen or so pretty quickly," including Texas, Virginia, Michigan, and California, according to CEO Chet Farris.

But then Pierre Lamond of Khosla Ventures (a VC investor in Stion) provided an introduction for Farris with the current governor of the Magnolia state and former chairman of the Republican National Committee, Haley Barbour. Less than five months after an initial meeting between the two chief execs, Stion has agreed to – and the Mississippi state legislature approved – an incentive-laden deal for the CIGSSe firm to build its factory in Hattiesburg.

During the late August meeting, "we discussed where we were at, told him [Barbour] that we were pretty far along in our process, and that they would have to do something fairly quickly," recalled Farris during a phone interview. "They jumped right on it."

The Stion CEO has nothing but praise for the efforts of the Mississippi group. "They worked very hard. It's just a whole different environment than many other places. They put together a consolidated team at the state, county, and local levels. They brought in the university [Southern Mississippi] and junior college on the workforce training programs. They put it all together and worked as a team to come to an agreement that made a lot of sense for both the state and Stion, whereas in other states, that can be a much more difficult challenge to get all those people together on one sheet of music with one common goal."

Incentives were arranged, leading to the low-interest loan of US$75 million, a sales tax exemption worth about US$10 million offered for the tools to be bought and brought in, and other perks presented as part of the package for the company. According to published reports, the company also plans an IPO in 2012 to raise US$100 million to US$150 million.

Five or six locations were scrutinized, although Hattiesburg was not initially considered. "We started closer to the proximity of the Memphis airport, for example," said Farris. Because of the "combination of the worker demographics, the local incentives from the city and county coupled with what the state was willing to do, the proximity to the university and the junior college, we found that it is the right place for us, the right city, the right infrastructure."

The actual site location is a former Sunbeam factory, about 725,000 sq ft in size, that is "very well-suited [for us] and doesn't require a major investment to use," according to Farris. "It was a manufacturing building and has a fair amount of power and infrastructure available on the site. It's a very large, open building, which is ideal for our footprint, with very high ceilings, thick concrete, a lot of basic stuff…the load ratings, the amount of water, power, and sewer that are available at the site, just happen to be a real good fit for us."

The building also "would give us the ability to continue to grow and expand for the next five or six years." Initially, Stion will occupy roughly half the space, with options to utilize more space in the future and even build additional facilities on the overall property, which is about 180 acres.

The news also means that the original major expansion plans for Stion's south San Jose base of operations – where the company has a couple hundred thousand square feet of additional space available to it – will be put on hold.

"We have the [10MW] pilot line, which we'd already started to build up, to add automation and improve the economics and our ability to produce on that line…we'll finish the work we started on the pilot," explained Farris. "The corporate headquarters, the research and development, the general and administrative functions will all stay in San Jose."

While it won't benefit from the hundreds of additional jobs now promised for the Hattiesburg facility, the home site will still hang out the "help wanted" sign for prospective new hires. More hands on deck are needed to help ramp up and operate "the pilot line to get it to be very stable and able to run four full shifts, 24 hours a day. But as we expand further, Mississippi is going to move in advance of any major expansion that we would have in California."

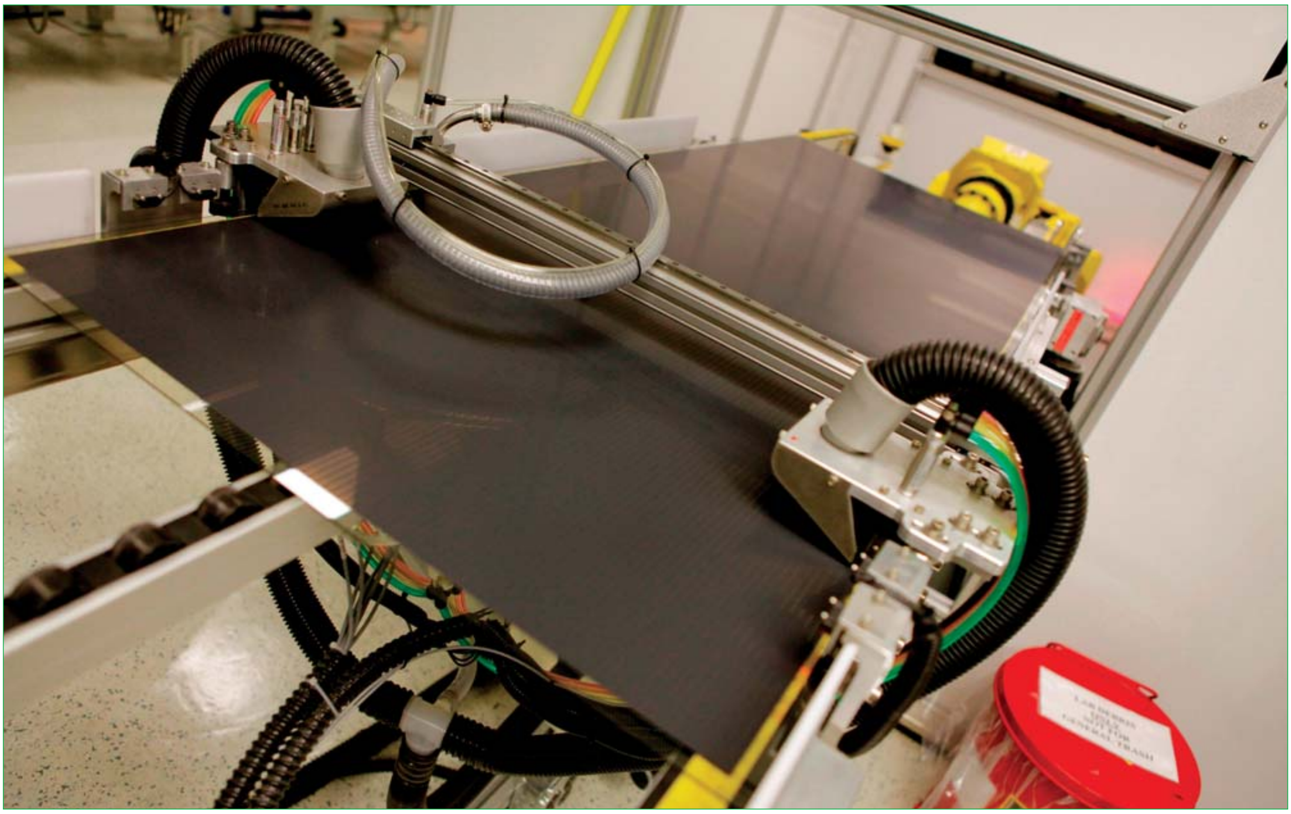
The pilot line will feature the same toolset as the planned volume production facilities. Farris said it will be used as a "training vehicle, so that when the new equipment starts arriving in Mississippi in the late May/June time-frame – we ordered all the long lead tools in the third and fourth quarters of 2010 – people will be able to hit the ground running as it comes up, so we'll have a much quicker ramp-up as a result."

Assuming no major tool shipment delays, with deliveries continuing throughout the third quarter, the company plans to be at "a full 100MW rate by the end of 2011," according to the company exec.

Since the Stion manufacturing scheme features both single- and multiple-use equipment – one sputter tool can handle molybdenum back-contact and absorber-formation duties, for example – the company can "incrementally scale" and not "have to wait for all 100 megawatts to be on the floor before you can produce."

Before manufacturing multimegawatts monthly in Mississippi, Stion will make and ship its Gen 1 65cm × 165cm panels from San Jose. The company has received the requisite UL and IEC certifications, which means that customers will start receiving more monolithically integrated modules soon.

He acknowledged that previous shipments have been "fairly modest," not only because of the size of the pilot line, but also since the company is "still doing a lot of technical work in San Jose to improve efficiency (currently



Source: Stion

averaging ~12%) and support the technology transfer with TSMC."

"But the balance of the allocation of time on tools will shift more to the production side in the second quarter," and the production volume will be in the "hundreds of kilowatts range over the next few months, and that will continue," said Farris. "By the third quarter, we'll definitely start to see output from Mississippi, and it'll just dovetail right in."

"Making CIGS is kind of like baking a cake; they all have flour, eggs, and milk. But we don't tell you everything in the recipe," quipped Farris. In his company's case, the cinnamon and nutmeg can be found in the constituent ratios, molybdenum back-contact secret ingredients, a nontraditional approach to depositing the transparent conductive oxide, and other ways of sweetening its copper-indium-gallium-sulfur-(di)selenide thin-film photovoltaic confection. The pastry analogy doesn't end there: the upstart's roadmap calls for a tandem-junction CIGSSe device, a veritable high-efficiency layer cake.

Stion may be the only CIGS player that has been pursuing a tandem-junction architecture from day one. As I learned during a visit to the company in early December, its first-generation product is actually the bottom device of what will ultimately be a mechanically stacked dual structure.

Farris has been pleasantly surprised that the initial product, given its low bandgap (about 1.05eV), has performed "better than we had actually anticipated," with the Elevation Series modules coming off the company's 10MW pilot production line regularly hitting 12–13% conversion efficiencies.

He believes that a "rational endpoint for single-junction efficiencies from a reproducibility point of view" is about 14–15%. Not champion cells, which Farris has little use for, but "consistent, center-line, tightly distributed" +/-0.5% module efficiencies. "We have a little different strategy: first we tighten the distribution, then work on moving up the efficiency numbers."

Admitting that the "interconnect structure is pretty loose today, especially on the first rollout of the product," he explained that the design "set the P1 to P3 [scribe] spacing pretty wide, and about half of that space can be recovered, which is worth about three-tenths of an [efficiency] point all by itself."

Throw in the elimination of the interconnect card and improved doping, selenization, and sulfurization, as well as other optimization of the film stack, and the efficiency could be boosted a whole point or more. "We were being very, very conservative in that design, so we're going back and looking for ways to recoup some of that."

Although the Gen 1 and eventually Gen 1.5 single-junction modules represent the vanguard of Stion's first commercial push, the key strategic piece of the longer-term game plan hinges on the development and rollout of the tandem-junction CIGSSe panels, which will push efficiency numbers into the mid- to high teens.

"It's a mechanically stacked tandem; the device structures are built completely independent of each other," Ferris explained. "This has some advantages, like not needing tunnel junctions. It allows you to optimize the diodes independent of each other."

"The bottom circuit is built in the substrate configuration, and the top circuit is built in the superstrate configuration. This allows us to exploit and not complicate the bill of materials. We have the semiconductor layers but we don't change any [other] materials.

"We already have two sheets of glass, so we exploit the second sheet of glass for the tandem, and the EVA acts as the dielectric between the two pieces of glass. It's a four-terminal device that gets converted to a two-terminal device in the box, and the way you match currents is by physical cell dimensions rather than to try and suboptimize the diodes.

"The high-bandgap devices (about 1.6eV) will be higher voltage, lower current than the low bandgap devices, which will be lower voltage, higher current, so you have a current-matched diode, and the best way to do that is simply to do it mechanically," he said.

Work on full-size tandem modules has recently begun at Stion. Farris told me that the final tool had arrived a few weeks before. Up to that point, development efforts used 5 × 5cm^2 and 20 × 20cm^2 test devices, on which efficiencies of 15.7% and 15.5%, respectively, had been achieved.

The "tool performed flawlessly, the very first [full-size] panel was good that came off of it. We did the absorber formation on that particular tool; it's an RTP [rapid thermal processing] tool. I'm very happy


Source: Stion

with the performance and uniformity--it did what we expected."

"We'll continue to work on that, to make sure we perfect that recipe in 2011 and get it qualified," Farris continued. "I would anticipate that the Gen 2 product would be available in early to mid 2012."

Speaking of those ubiquitous recipes, the firm's cooking process doesn't deviate that much from the standard combination of back electrode/contact–absorber–buffer (which is called the emitter in Stionese)–top contact flow and requisite isolation and interconnect scribe steps seen on other CIGS lines, but the cake does have its differentiated flavors.

Farris took me through the company's existing facility in San Jose, where he described the circuit process and module assembly flow. About US$8 million was spent on the production and R&D gear, an indication of another factor that Farris believes makes Stion "a bit different from other thin-film companies" – they don't design, develop and build their own equipment.

"We use industry standard equipment, optimized for each individual process step," he pointed out. "For virtually all the tools, there are second and third sources available. There is nothing really proprietary in the mass production line from an equipment point of view." Capital expenditures for the volume production facility are projected to be well under a dollar a watt, he added.

The manufacturing line starts with washing/drying the incoming glass and tagging each plate with a barcode. The molybdenum back electrode (along with some proprietary additives) is then sputtered on the glass, followed by a laser-scribe isolation/patterning step.

From there, the absorber layer begins to take shape, the first step consisting of copper, indium, and gallium precursor metals being sputtered (in elemental form, not as compound semiconductors, he pointed out), followed by a reactive thermal anneal process and introduction of the hydride gases to convert the stack to a semiconductor.

A "pretty standard cadmium sulfide dip" takes place next to create the buffer or emitter layer, with the wet process followed by a mechanical interconnect scribing step.

At this point, the Stion process takes a road less traveled in the CIGS community. The company has concocted its own aluminum-zinc-oxide TCO cocktail, which in and of itself is not an eyebrow raiser, but the method it uses to deposit that film does grab one's attention – metalorganic chemical vapor deposition.

MOCVD is cheaper than the usual sputtering processes used to deposit the top contacts, Farris claimed. "More importantly, the film quality on our TCO is unique in that it has a scattering effect to it…which improves the diffusion length of the junction slightly."

Although Stion uses this approach because of its lower cost and improved current characteristics, there's also what the chief exec called a "serendipitous" benefit in terms of the "superior aesthetics" of the module, since its appearance is more uniform compared to some other thin-film panels.

Eventually, because of what Farris vaguely described as "intrinsic aspects of using MOCVD for TCO," the scheme may help with another process innovation: the *elimination*, not the replacement, of the buffer step altogether. "We've already demonstrated a completely cadmium-free process, and we're doing reliability studies," he said, adding that modules made with the improved process should be released to the market in the first part of 2012.

Back on the production floor, once the P3 isolation scribe is lasered in and the leads attached, the manufacturing flow continues into a pretty standard layup/lamination/edge-seal/etc. module assembly sequence, which is semi-automated on the current pilot line but will be highly automated when the volume lines are installed and qualified in the Mississippi facility.

While walking through the line, we encountered groups of TSMC employees being trained in the Stion process. The semiconductor giant plays a major role in the young company's life, as major investor (to the tune of 21%), licensor of the single-junction technology, joint developer, and eventual supplier of modules to Stion to help fulfill its backlog of orders, which "saved us a fair amount of capital investment in order to gain access to that capacity sooner," according to Farris.

The partners are on similar production ramp paths, with both saying they should be getting their volume lines rolling by the second half of 2011. "I think the timeline we have is pretty much the same, and it's dictated by tool delivery schedule and nothing else. TSMC is also buying the same tools from the same vendor(s)," he revealed.

Stion is "very happy with the relationship with TSMC," Farris said. "Obviously, you have different cultures, different styles, that's always a little bit of a challenge to make sure you integrate with them effectively. I think the partnership is working as planned.

"They've helped us get these tools released and our procedures released, and work on maintenance procedures—they're a very good manufacturing company so we've exploited that resource. I think it's been a real win-win relationship, and I'm looking forward to continuing it."

With a reported 500MW of sales deals valued at US$700 million, the CIGSSe company and its low-cost, measured approach and differentiated technology, as well as its strategic alliance with that certain four-letter acronymed chip foundry, may make it a serious player in the photovoltaics cake-baking market in 2011 and beyond.

This article is a revised version of a two-part blog that originally appeared on PV-Tech.org.

Light trapping in nanotextured thin-film silicon solar cells

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ABSTRACT
Conversion efficiencies of thin-film silicon solar cells can be increased by nanotexturing of the cells. This nanotexturing step allows for a larger fraction of the incoming light to scatter and diffract, so that both the total absorption of light in the solar cell and the short circuit current is enhanced. In this study, we investigate the optics of thin-film silicon solar cells by numerically simulating Maxwell's equations by a finite-difference time-domain algorithm. Starting with periodically textured solar cells, the influence of the texture period and height on the quantum efficiency and short circuit current were investigated. With this understanding of the optimized surface texture for periodically textured solar cells, the possibility of interpreting the optics of randomly textured solar cells will be discussed.

Introduction
Reducing the cost and increasing the conversion efficiency is a major objective of research and development on solar cells. An approach that simultaneously achieves these two objectives is the use of light trapping or photon management. Light trapping facilitates the absorption of sunlight by a thin-film solar cell that is much thinner than the absorption length of the material. Thsi study will focus on the analysis of thin-film solar cells based on hydrogenated microcrystalline silicon. Thin-film microcrystalline silicon solar cells have a typical thickness of 0.8–1.5µm, which is significantly less than the thickness of conventional wafer-based silicon solar cells (180–250µm) [1].

Over the last decade, several concepts have been proposed to enhance the absorption of light in thin-film silicon solar cells. Most of these concepts are based on random nanotexturing of the contact layers of the solar cells [2,3]. Conversion efficiencies higher than 10% have been demonstrated for amorphous and thin-film microcrystalline silicon solar cells by introducing randomly textured interfaces in the solar cell [3–5]. For micromorph tandem solar cells, stable efficiencies of up to 11.9% have been demonstrated using textured interfaces [5–6]. A schematic sketch of a single-junction thin-film silicon solar cell on a smooth glass substrate and with textured contact layers is shown in Fig. 1(a) and 1(b), respectively. The yellow arrows indicate the transmitted and reflected light within the thin diode. The optics of solar cells on smooth substrates (Fig. 1(a)) are characterized by the forward and backward propagating waves. By introducing nanotextured interfaces to the solar cell (Fig. 1(b)), the rough surface leads to enhanced scattering and diffraction of light in the device.

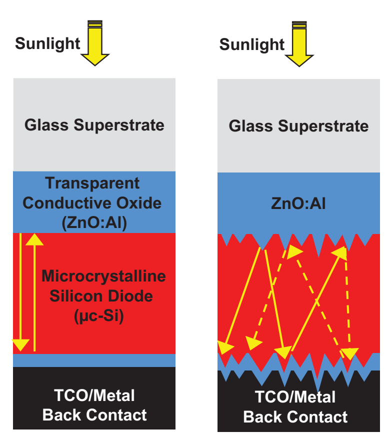

Figure 1. Schematic sketch of a thin-film microcrystalline silicon solar cell (a) on a smooth substrate and (b) on a randomly textured substrate.

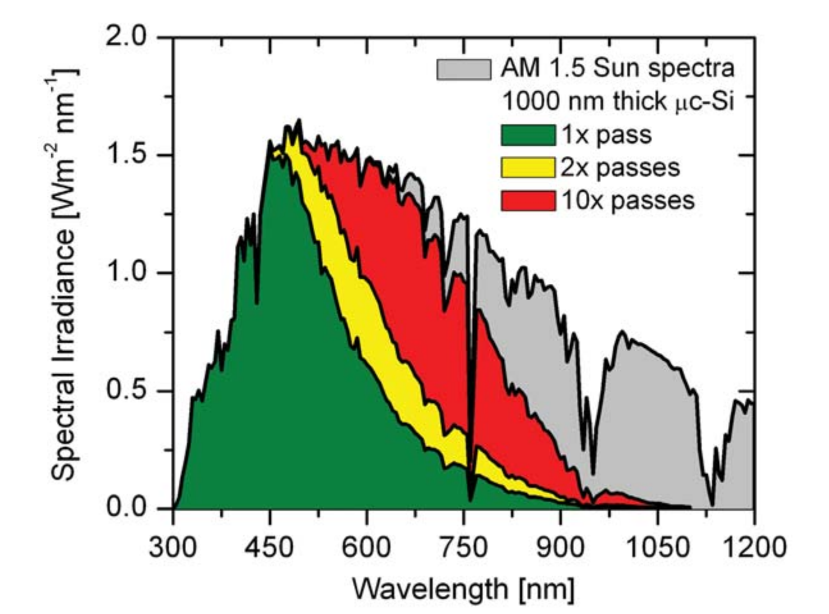

Figure 2. Absorbance of the incident AM 1.5 sun spectra in a 1000nm-thick microcrystalline silicon solar cell for single and multiple passes.

Due to multiple reflections within the silicon layer, the optical path length of the incident light is greatly enhanced. This leads to a distinctly enhanced short-circuit current and quantum efficiency in the red and infrared part of the optical spectrum. The influence of an enhanced optical path length on the incident sun spectrum is shown in Fig. 2.

In order to understand the optical propagation within such thin-film devices, it is imperative to use numerical methods and solve the Maxwell's equations rigorously. By considering the near-field optics, the nanotexturing process for efficient solar cells can be understood and optimized. Maxwell's equations have to be solved rigorously to calculate the wave propagation in such nanotextured devices. The finite-difference time-domain (FDTD) method, finite-element method (FEM), or finite-integration technique (FIT) are commonly used to determine the absorption, quantum efficiency, and short-circuit current of these solar cells.

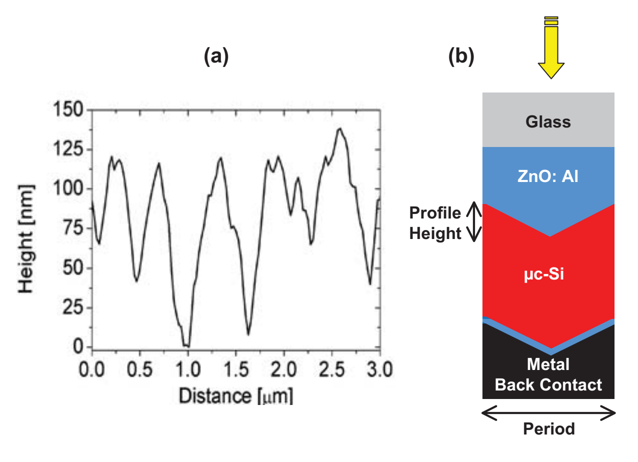

Figure 3. Line scan from the surface of a randomly textured aluminum doped zinc oxide (ZnO:Al) film (a). Schematic sketch of the unit cell of the periodically textured solar cell with an integrated triangular surface texture (b).

For this study, we investigated the wave propagation of nanotextured microcrystalline silicon solar cells using an FDTD simulation tool.

Optical simulation model

Many different concepts have been proposed in an effort to increase the effective thickness of thin-film silicon solar cells. The different approaches encompass wet etching of sputtered transparent conductive oxides (TCOs) [2], direct growth of textured oxides by low pressure chemical vapour deposition (LPCVD) [7], or using textured back reflectors [8]. In the case of thin-film silicon solar cells, randomly textured contact layers – realized by direct deposition of zinc oxide films or etching of sputtered zinc oxide – have resulted in the most efficient solar cells [2–4]. A line scan of the surface profile of such an etched aluminium-doped zinc oxide (ZnO:Al) film is shown in Fig. 3(a). The sputtered zinc oxide film was etched in a dilute hydrochloric acid (HCl) solution for several seconds. The triangular texture of the film exhibits an almost periodic arrangement with a period of around 500nm. Based on these observations, we investigated a solar cell with a periodic triangular surface texture.

A schematic cross-section of the investigated unit cell is shown in Fig. 3(b). It is assumed that the solar cell on a textured substrate can be described by a unit cell, which provides all information on the behaviour of the entire cell. Key parameters of the unit cell are the period and the profile height. The microcrystalline silicon solar cell investigated in this study consists of a 500nm-thick ZnO:Al front contact, followed by a (p-i-n) hydrogenated microcrystalline silicon diode (µc-Si:H) with a total thickness of 1,000nm and a back reflector consisting of an 80nm-thick ZnO:Al layer and a metal reflector. The device structure is consistent with the standard microcrystalline silicon solar cell process used by several research groups such as the Jülich Research Centre and the University of Neuchâtel [2,7]. In order to study the influence of the dimensions of the texture on the optical performance of the solar cell, the period of the unit cell was varied from 50nm up to 6,000nm, while the height was varied from 0nm up to 500nm. The unit cell was illuminated under normal incidence for the entire spectrum of wavelength from 300–1,100nm.

Results and discussion

In order to compare the different surface textures, power loss profiles within the solar cell, quantum efficiency and short-circuit current were utilized. The power loss profile for thin-film solar cells with integrated triangular structures under blue and red illumination are shown in Fig. 4. The period of the triangular profile for all cases was 900nm with heights of 100nm (Fig. 4(a) and 4(c)) and 400nm (Fig. 4(b) and 4(d)), respectively. The respective incident lights have wavelengths of 400nm and 700nm with amplitude of 1V/m. In the

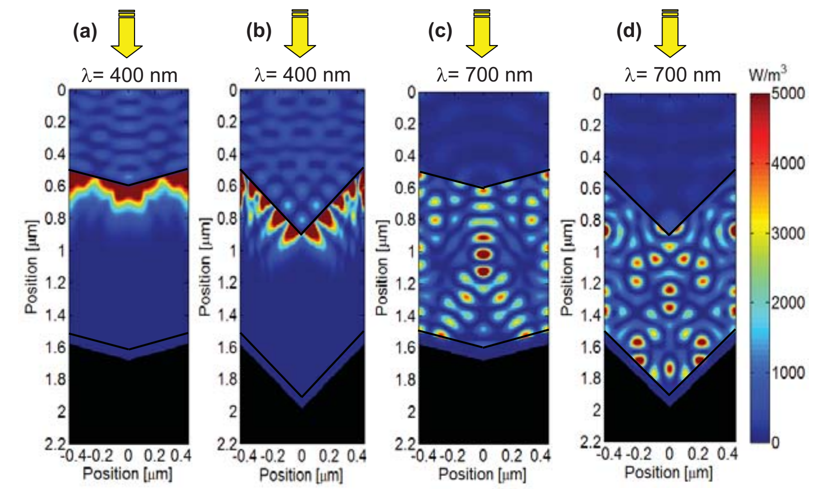

Figure 4. Simulated power loss profile for a textured unit cell with a period of 900nm and profile heights of (a, c) 100nm and (b, d) 400nm under monochromatic illumination of (a, b) wavelength 400nm and (c, d) wavelength 700nm.

case of short wavelength illumination (λ=400nm), the photons get absorbed within the first 200nm of the silicon absorber layer. By having a small period height, as shown in Fig. 4(a), the opening angle of the triangular texture approaches 180°, the short-circuit current being comparable to the current of a solar cell on a smooth substrate. By having an opening angle close to 90°, a 'flame-like' power loss pattern occurs, as shown in Fig. 4(b). The power loss pattern is caused by the formation of evanescent fields at the boundary between the zinc oxide texture and the p-i-n solar cell. This power loss pattern disappears for longer wavelengths of the incident light and smaller periods of the texture.

Due to a low absorption coefficient of silicon for longer wavelengths, the incident light has to be confined in the solar cell. The light can be completely absorbed only if the light completes multiple passes inside the silicon layer. The power loss profile for a structure under monochromatic illumination of wavelength 700nm is shown in Fig. 4(c) and 4(d). Light diffracted by the front and back grating constructively interferes, which leads to a higher absorption of the incident light. For opening angles close to 90°, the power loss in the solar cell is maximized as shown in Fig. 4(d).

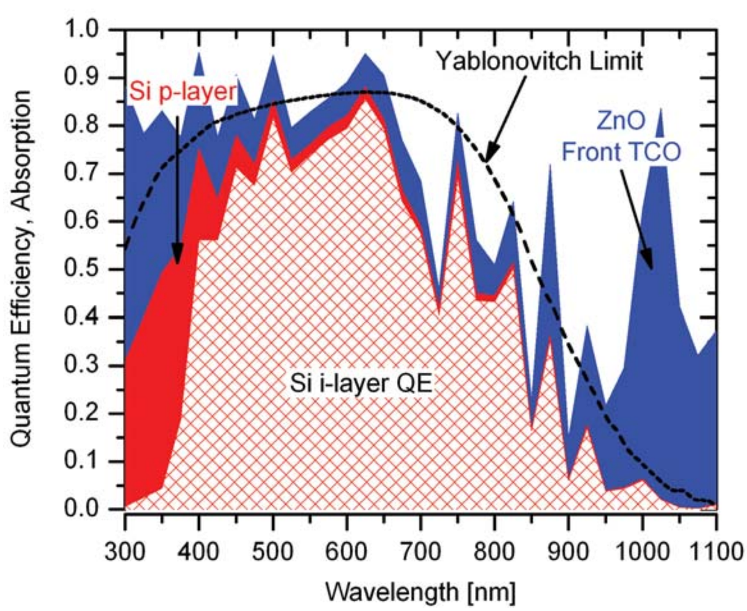

Figure 5. External quantum efficiency of the p-i-n microcrystalline silicon solar cell and parasitic absorptions in the silicon p-layer and front zinc oxide layer. The absorptions in the n-layer silicon and back zinc oxide are not shown since they are almost negligible. The Yablonovitch limit is shown with dashed lines. The thickness of the silicon diode was 1.0µm.

Based on the power loss calculations, the quantum efficiency for the solar cell can be determined. The quantum efficiency is defined as the ratio of the power absorbed in the silicon layer with respect to the total power incident on the unit cell. Details on how to calculate the quantum efficiency are given in [9]. The collection efficiency, taking the electronic properties of the material into account, is assumed to be 100%; in other words, the internal quantum efficiency is assumed to be 100%. Therefore, the determined quantum efficiency defines an upper limit of the achievable external quantum efficiency. Fig. 5 shows the absorption in different regions of the solar cell with a period of 700nm and triangular groove height of 400nm. The quantum efficiency in the i-layer of the silicon diode, along with the parasitic absorptions in the p-layer of silicon and the transparent conductive oxide front contact are also depicted in Fig. 5. The absorption in the microcrystalline silicon n-layer and the zinc oxide layer in the back is very low, accounting for a loss of less than 2–3%. Moreover, since a perfect back reflector was assumed in this case, the loss in the back contact is zero, and therefore these losses are not shown in the image. The thickness of the p-layer silicon was assumed to be 30nm.

The dashed line in Fig. 5 represents the maximum achievable quantum efficiency (Yablonovitch limit) for a silicon solar cell with a thickness of 1µm. Yablonovitch and Cody determined the absorption for a perfectly textured solar cell. However, they did not describe how to realize such a structure. The absorption enhancement compared to a solar cell on a smooth substrate can be $2n^2$ fold (where n is the refractive index of the diode material; for silicon this corresponds to $2n^2 \sim 25$). By considering the unavoidable reflection losses in the front air/ZnO interface and parasitic absorption in the front ZnO layer, the upper limit for the absorption in the 2D textured silicon layer was calculated and plotted in Fig. 5.

> "Due to multiple reflections within the silicon layer, the optical path length of the incident light is greatly enhanced."

Taking the weighted sun spectra AM 1.5, the short circuit current can be calculated from the quantum efficiency. For the case shown in Fig. 5, the total short circuit current was calculated to be 20mA/cm² compared to a short circuit current of 12.4mA/cm² for a smooth substrate. In terms of the parasitic absorptions, the p-layer and the front zinc oxide layer, both absorb 10% and 30% respectively of

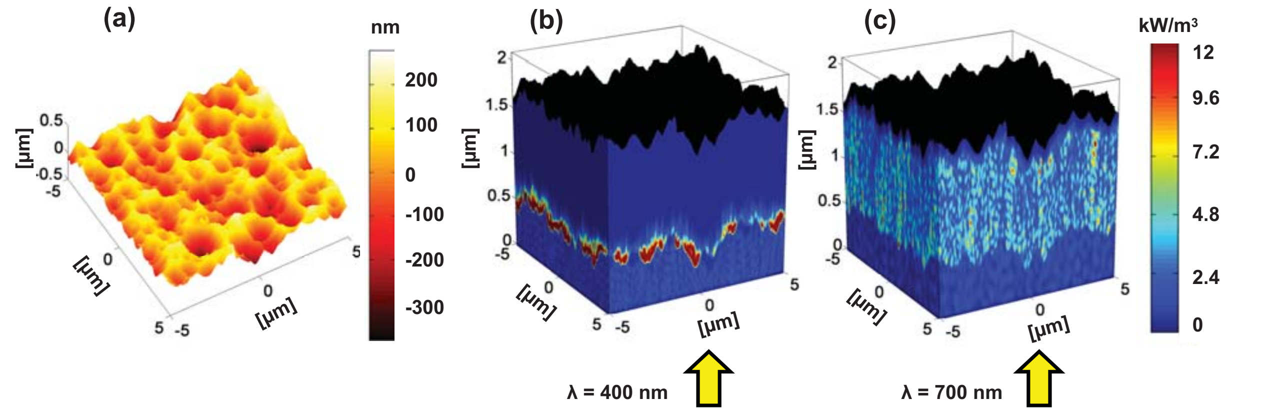

Figure 6. Surface profile of a randomly textured aluminium-doped zinc-oxide substrate (a), showing simulated power loss profiles of the corresponding randomly textured thin-film silicon solar cells under monochromatic illumination of wavelength (b) 400nm and (c) 700nm.

the total absorbed light in the entire solar cell stack. The largest loss in the p-layer is observed for the shorter wavelengths (from 300nm to 500nm), while the layer is almost transparent for the longer wavelengths. Absorption loss in the front zinc oxide layer for shorter wavelengths accounts for almost 50%. For wavelengths ranging from 500nm to 750nm, the absorption in the front zinc oxide is minimized. Optical loss in the aluminium-doped front zinc oxide layer for longer wavelengths increases as a result of the free carrier absorption. When compared to the theoretical absorption limit, more than 30% of the incident light is lost via reflection, and these losses increase as the absorber layer gets thinner. Therefore, a reduction of the reflection should be a key point for the design of ultra-thin solar cells, where the absorber is significantly thinner than the absorption length for longer wavelengths.

The 2D triangular textured solar cells discussed in this study have yielded results that suggest that the optimal period of the texture is in the range of 500–900nm with texture height of 400–500nm [10]. Compared to a solar cell on a smooth substrate, the degree of enhancement in the short-circuit current depends greatly on the period of the triangular profile unit cell. When periods of the texture are smaller than the incident wavelength, enhancement in the shorter wavelengths (300–500nm) of the spectrum is brought about by the improved incoupling of the light into the absorber layer. Longer wavelengths (700–1,100nm) can result in the short-circuit current being distinctly enhanced if the period of the triangular profile unit cell is in the range of the incident wavelength. The latter case exhibits the highest short-circuit current because it best utilizes the diffraction and scattering of light. This enhancement comes from light trapping of the longer wavelengths.

Towards simulations of randomly textured substrates

The simulation of periodic structures provides an understanding of light trapping and allows for optimization of the surface texture. It has recently been shown that the behaviour of quasi random surfaces can be described by the weighted superposition of solar cells with periodic surface texture [11]. Whether or not it can also be applied to random surfaces still remains an open question.

The power loss profile obtained from a simulation of the solar cells on a randomly textured substrate is shown in Fig. 6 for a substrate area of 10 × 10µm^2. Fig. 6(a) shows the surface profile of a randomly textured zinc-oxide substrate patterned by wet etching in an acid solution. In Fig. 6(b) and 6(c), the power loss profiles of the randomly textured solar cells for incident wavelengths of 400nm and 700nm, respectively, are shown. The dimensions of the device structure were kept the same as before; the randomly textured substrate was integrated into the solar cell in lieu of the triangular grating as was described in this study. Similar to the periodic surface texture, the shorter wavelength (λ = 400nm) gets absorbed within the first few hundred nanometers of the silicon layer. For longer wavelengths (λ = 700nm), the light is scattered and diffracted by the front- and the back-surface texture. Systematic studies of the crater distribution together with optical simulations of textured solar cells are pivotal in order to better understand the optical propagation in such devices.

Summary

As thin-film silicon solar cells get thinner, the necessity for efficiently trapping the incident light within the absorber layer becomes more vital. Surface-textured microcrystalline silicon solar cells with texture periods in the range of 500–900nm offer the most effective conversion of incident light into short-circuit current. For amorphous silicon, the highest short-circuit currents are achieved for periods of 150–250nm, resulting from an enhanced diffraction and scattering of longer wavelengths within the solar cell. In order to understand the complex optical propagation in randomly textured solar cells and maximize the short-circuit current, systematic studies of randomly textured cells together with periodic solar cells will be indispensable.

Acknowledgment

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References

[1] Beaucarne, G. 2007, "Silicon Thin-Film Solar Cells", *Advances in OptoElectronics*, Vol. 2007, Article ID 3697.

[2] Beyer, W. et al. 2007, "Transparent conducting oxide films for thin film silicon photovoltaics", *Thin Solid Films*, Vol. 516, pp. 147–154.

[3] Yamamoto, K. et al. 1999, "Thin-film poly-Si solar cells on glass substrate fabricated at low temperature", *Appl. Phys. A*, Vol. 69, pp. 179–185.

[4] Benagli, S. et al. 2008, "High-efficiency amorphous silicon devices on LPCVD-ZNO TCO prepared in industrial KAI-M R&D reactor", *Proc. 24th EU PVSEC*, Hamburg, Germany, pp. 2293–2298.

[5] Green, M.A. et al. 2011, "Solar cell efficiency tables (version 37)", *Prog. Photovolt: Res. Appl.*, Vol. 19, pp. 84–92.

[6] Bailat, J. et al. 2010, "Recent developments of high-efficiency micromorph® tandem solar cells in Kai-M PECVD reactors", *Proc. 25th EU PVSEC*, Valencia, Spain, pp. 2720–2723.

[7] Meier, J. et al. 2004, "Potential of amorphous and microcrystalline silicon solar cells", *Thin Solid Films*, Vols. 451–452, pp. 518–524.

[8] Sai, H. et al. 2008, "Enhancement of light trapping in thin-film hydrogenated microcrystalline Si solar cells using back reflectors with self-ordered dimple pattern", *Appl. Phys. Lett.*, Vol. 93, p 143501.

[9] Dewan, R. et al. 2009, "Light trapping in thin-film silicon solar cells with integrated diffraction grating", *J. Appl. Phys.*, Vol. 106, p. 074901.

[10] Dewan, R. et al. 2009, "Light trapping in thin-film silicon solar cells with submicron surface texture", *Opt. Express*, Vol. 17, pp. 23058–23065.

[11] Haase, C. et al. 2008, "Efficient light trapping scheme by periodic and quasi-random nanostructures", *Proc. 33rd IEEE PVSC, San Diego*, California, USA, p. 171.

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Oerlikon Solar proudly announces the new **THIN**FAB which reduces the manufacturing cost of thin film silicon modules to a record breaking €0.50/Wp, with 10 percent stabilized efficiency and 143 Wp module performance. Beyond that we introduce our new world record breaking cell efficiency of stabilized 11,9 percent on Micromorph® technology. Find out more about our non-toxic, environmentally friendly solar technology at **www.oerlikon.com/solar/thinfab**

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Market Watch

The thin-film PV equipment market

John West, VLSI Research, Bedford, UK

ABSTRACT

As recently as a couple of years ago, solar panels based on thin-film manufacturing technology were being promoted as the low-cost alternative to crystalline silicon. Not only was it cheaper, but thin film also had a convincing roadmap which guaranteed this cost advantage for the foreseeable future. That was 2008, when persistently high polysilicon prices seemed inevitable as demand for solar electricity boomed. We now know that assumption to be false, and although we all knew polysilicon prices would fall eventually, no one predicted the speed and magnitude with which they crashed: in the space of several months, prices reached the point where any advantage associated with the lower materials costs of thin-film manufacturing were completely blown away.

Unsurprisingly, this has taken its toll on the market for thin-film PV equipment. Sales fell by 18% in 2010 against an overall PV equipment market which grew by 30%. It is tempting to conclude that crystalline silicon has won the battle and that thin-film technology will have to be satisfied with serving niche markets from now on, but a closer look at what happened in 2010 shows that the market for thin-film PV equipment is on a recovery track, much of which is being driven by innovations from the equipment suppliers.

The good news is that polysilicon prices are stabilizing and the free ride that everyone in the crystalline silicon cell and module market enjoyed from falling materials costs is over. This brings the focus firmly back onto improvements in manufacturing technology and getting cell efficiencies up. Thin-film manufacturing has the advantage in that it potentially has the greater upside to improve cell efficiency, but the downside is this sector does not have access to the same level of resources as crystalline silicon.

> "Thin-film manufacturing has the advantage in that it potentially has the greater upside to improve cell efficiency."

Putting this into perspective, revenues from sales of crystalline silicon-based modules were 10 times higher than sales of thin-film panels in 2010. Likewise, sales of crystalline silicon-based equipment – excluding polysilicon, ingot and wafering equipment – were double the size of the market for thin-film PV equipment. Ultimately, it could be the lack of access to the same levels of research and development cash that decides just how much of the market thin film can address competitively. However, a lot of work has been done towards getting back on terms and the early signs for 2011 are good: the market for thin-film PV equipment is already recovering strongly, albeit from a low base.

To quantify the situation, the market for thin-film PV equipment reached US$1.4 billion in 2010, down 18% from US$1.7 billion in 2009. This contrasts with a market

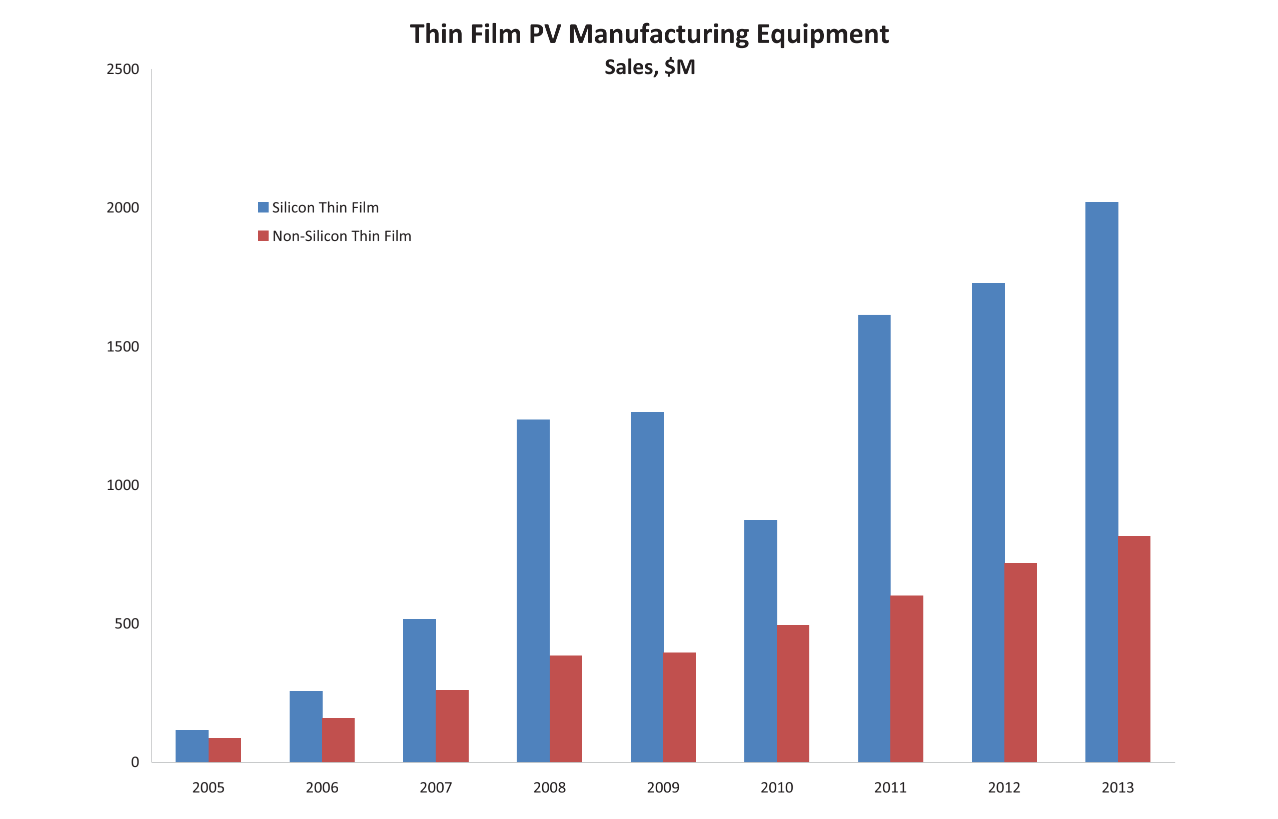

Figure 1. Sales of PV manufacturing equipment (projection to 2013) comparing silicon thin film with non-silicon thin film.

for crystalline silicon equipment which grew 41% from US$5.9 billion in 2009 to US$8.3 billion in 2010, and an overall market for PV equipment, including all PV cell technologies, which grew 30% from US$7.7 billion in 2009 to US$9.9 billion in 2010.

Orders for thin-film PV equipment in the first quarter of this year are already significantly up from last year and capital expenditure announcements made by thin-film panel manufacturers indicate that demand for thin-film PV equipment could grow in excess of 60% and reach record levels in 2011. This increased level of activity is being confirmed by suppliers of materials, components and subsystems who are reporting shipments of large volumes to thin-film equipment vendors. Clearly, the recovery in this sector is underway.

The market for thin-film PV equipment breaks down into two major segments: silicon thin film on glass and non-silicon thin film on glass, and each of these markets has very different dynamics.

Silicon thin film on glass

The market for amorphous silicon thin-film PV equipment suffered the most in 2010 as polysilicon prices collapsed. Sales of silicon thin-film PV equipment fell from US$1.3 billion in 2009 to US$0.9 billion in 2010, or a 31% fall in demand. To make matters worse, around a quarter of the 2010 revenues were for equipment already shipped in 2009, so in terms of shipments, the market actually fell by 60%.

Inevitably there were consequences and the most high-profile casualty was Applied Materials which announced it was withdrawing from the thin-film turnkey business. Essentially, the SunFab turnkey line was canned, although it is important to note they are still offering individual pieces of thin-film PV equipment and remain hugely successful in the market for crystalline silicon equipment. It is a measure of their success in crystalline silicon that they were still the number one PV equipment supplier in 2010 by a long margin, despite dropping most of their silicon thin-film business earlier in the year.

> "The market for amorphous silicon thin-film PV equipment suffered the most in 2010 as polysilicon prices collapsed."

Oerlikon Solar, on the other hand, without the distractions of serving multiple markets, has made something of a comeback with their new THINFAB solution. They claim production costs of €0.50 per Watt peak (Wp), which puts them right back in contention. Furthermore, they can roll out some of this new manufacturing technology to their existing customers. It cannot be stressed strongly enough how important this is, as much of the technology for silicon thin-film manufacturing is being supplied by the equipment vendors. As a result, if they want to attract new customers, they have to prove they can provide ongoing support.

While the silicon thin-film industry's two biggest hitters, Applied Materials and Oerlikon Solar, struggled to make headway in 2010, it is surprising to see that there is no shortage of companies actively addressing this market. In particular, Ulvac and Shimazu in Japan continue to do well and the list of Chinese and Korean PV equipment companies is getting longer, many of them going from strength to strength. Companies to look out for in 2011 are China's GS Solar and Korea's IPS/Atto and Jusung Engineering.

Non-silicon thin film on glass (CdTe & CIGS)

In contrast to the silicon thin-film PV equipment market, sales of non-silicon thin-film PV equipment grew in 2010 by 25% from US$0.4 billion to US$0.5 billion. First Solar continues to dominate this sector and while their capital expenditures grew by over 50% in 2010, a large portion of this money was spent on building new factories with the majority of equipment slated to ship in 2011. First Solar's success and, until recently, the inability of its competitors to make serious inroads into the market meant that sales of this type of equipment were mostly tied to how much First Solar decided to spend on capacity. This is a situation which will change in 2011 as Solar Frontier ramp up their 900MW CIGS facility.

> "The real challenge for thin film going forward is staying competitive against crystalline silicon in markets where they compete head-to-head."

Despite the lack of big customers for non-silicon thin-film PV equipment, there is no shortage of companies offering individual pieces of equipment and turnkey solutions. The established non-silicon PV equipment suppliers are mostly German companies, such as centrotherm photovoltaics, Leybold Optics, Manz Automation, Pfeiffer, Roth & Rau, Singulus, and Von Ardenne Anlagentechnik. With Solar Frontier making a big push in 2011, we should see Japanese equipment suppliers gaining market share as well as the emergence of new entrants from Korea and China.

One of the features of the non-silicon thin-film market is that customers are expected to have their own manufacturing process as only a few equipment suppliers are able to offer full turnkey solutions. centrotherm photovoltaics and Roth & Rau have developed their own processes; interestingly, Manz Automation is now offering a turnkey solution which includes a proven manufacturing process licensed from Würth Solar. Although it is still too early to say if Manz Automation's business model is going to work, it does provide another solution for companies looking for access to this market.

Conclusion

The market for thin-film manufacturing equipment is dominated by silicon thin film on glass technology: in 2010 this market was almost double the size of the market for non-silicon thin-film PV equipment. It is clear from Oerlikon Solar's turnaround and the emergence of new entrants, particularly in Korea and China, that silicon thin-film will continue to be the main thin-film technology going forward. The trajectory of the non-silicon equipment market, while assured to be upwards, will depend on the success of Solar Frontier and new entrants. The proliferation of solutions offered by equipment vendors in this sector points to some interesting competition in the years ahead.

The real challenge for thin film going forward is staying competitive against crystalline silicon in markets where they compete head-to-head. Further compounding this challenge is the fact that the initial outlay on thin-film PV equipment is considerably higher than that for crystalline silicon, and to counter this, equipment vendors need to get the message across that capital expenditure on thin-film PV equipment as a percentage of the total expenditure over the lifetime of a factory is insignificant. The most important issue to address for the industry as a whole, however, is getting cell efficiencies up and the cost per watt down. All PV cell technologies have the same problem and have their work cut out for them. Now that polysilicon prices are stabilizing, thin-film PV equipment suppliers are back in contention.

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PV Modules

JinkoSolar joins credit rich list of Chinese PV manufacturers

China's drive to consolidate its leading position in PV manufacturing has been reinforced with a credit facility offered to JinkoSolar from the Bank of China that could be worth approximately US$7.6 billion over a five-year period. According to a recent study by Mercom Capital Group, US$34 billion was provided by Chinese Government Banks to China-based solar companies last year, in which key beneficiaries were LDK Solar, Yingli Green, JA Solar, Suntech and Trina Solar.

JinkoSolar's credit facility is also significant as the PV manufacturer is much smaller by capacity and revenue than the likes of LDK Solar and Yingli Green. The largest single transaction last year was the US$8.9 billion credit facility to LDK Solar, offered by the China Development Bank.

JinkSolar had recently guided that 2010 revenues would be in the range of US$638-US$648 million, as its production capacity reached its targets of 600MW of production capacity in wafers, cells and modules.

However, the company has yet to guide capacity and revenue expectations this year. The signing of an agreement with BOC suggests that JinkoSolar will follow others in expanding capacity aggressively in 2011.

Source: Jinko Solar

Jinko Solar monocrystalline solar module.

Business News Focus

Roth Capital Partners forecast PV demand of 18GW in 2011: bankable products overcapacity at 17%

Global PV demand of 18GW in 2011 is being projected by investment bank Roth Capital Partners. Concerns of major overcapacity in module production exist, but the bank estimates module supply is in the 21GW range and would only exceed demand by approximately 18%. Low-cost bankable module manufacturers are expected to see utilization rates remain in the 90% range. Roth believes ASP declines of as much as 30% are not expected, while ASP declines of approximately 15% are more realistic for this year. Roth Capital Partners noted that it expected global demand for solar modules to be 15.8GW in 2010, a 119% increase compared to the previous year.

Although Roth expects a decline in demand in Germany, the investment bank expects markets such as Italy, U.S. and Japan to show strong growth in 2011. Upside potential also exists in other markets such as China, U.K., and Canada. Roth Capital Partners forecasts German market demand of 6.1GW in 2011, compared to 8.1GW in 2010, a 25% decline.

However, the firm projects demand in Italy will reach 2.5GW in 2011, up 67% over 2010 figures. It is anticipated that the U.S. will be close behind Italy at 2.3GW, a greater increase of approximately 152% over the previous year. Japan is also noted as a fast mover this year. Roth expects demand to reach 1.8GW, an 80% increase over 2010.

Roth calculates a substantial amount of new production capacity coming online in 2011, noting that the 11 U.S-listed Chinese manufacturers alone will expand capacity throughout the supply chain by 60% to 15GW of module supply by year-end 2011, compared with the same period in 2010. The effective 2011 supply from this peer group wihh likely be around 12-13GW.

Tianwei, Sunvalley Solar sign 1.2MW module supply contract

Tianwei SolarFilms has signed a contract to supply 1.2MW of silicon thin-film modules to Sunvalley Solar for its future projects in southeastern California. The contract will not only help Sunvalley complete the US$5 million worth of installations it has lined up in Palm Springs, but also allow TianWei to increase its presence in the U.S. market.

Trina Solar module shipments top 1.06GW in 2010: capacity to reach 1.9GW mid-year

Trina Solar squeezed a few more module shipments out of the factory gate in 2010 than previously guided. Shipments were approximately 351MW for the fourth quarter of 2010, compared to previous guidance of approximately 300MW, resulting in total 2010 module shipments reaching around 1.06GW in 2010. Net revenues in the fourth quarter were US$641.8 million, an increase of 26.3% sequentially and 104.9% year-over-year. Total revenue for 2010 reached US$1.86 billion, a increase of 119.8% from 2009. Gross profit was US$584.4 million, an hike of 146.4% on 2009, while gross margin was 31.5%, compared to 28.1% in 2009.

Source: Trina Solar

Trina Solar multicrystalline module.

Trina guided shipment volumes for PV modules to be slightly higher than that for the fourth quarter of 2010. For the full year of 2011, the company expects total PV module shipments between 1.75GW to 1.80GW, representing an increase of 65.6% to 70.3% from 2010.

Dip in demand generates PV module inventory surge, says IHS iSuppli

Weaker demand in the first quarter of 2011 is expected to generate a significant rise in PV module inventories throughout the supply chain, according to market research firm IHS iSuppli in a new report entitled "PV: Strong Market Has Suppliers' Inventories at Healthy Levels." Days of inventory (DOI) are forecasted to increase by 22.9% for c-Si modules and by 21.4% for thin-film modules.

As the firm was quick to point out, inventory build should be a first-quarter problem only as global solar demand will rebound sharply over the course of 2011, bringing inventory for the entire PV value chain back to relatively low levels. Suppliers should see only a small increase in DOI compared with 2010, which was very low.

Komax invests in Chinese module laminator equipment supplier

Swiss-based PV equipment supplier Komax has signed a cooperation agreement with Yingkou Jinchen that will see Komax acquire a majority stake (51%) in newly formed Komax Jinchen. The move by Komax is to penetrate the Chinese market and add more laminators to its product range.

Yingkou Jinchen was formed in 1994 and is a supplier of lamination equipment and automated production lines. The new company employs around 100 people at its production site in Yingkou City, Liaoning Province, China. Yingkou Jinchen has supplied module production lines to Canadian Solar, Jiangyin Hareon Solar and Jiangsu Sainty International Group in the last 12 months.

Motech becomes a member of PV Cycle

Motech Industries is the latest company to become a member of PV Cycle, membership will ensure that its modules are properly recycled in Europe when they reach their 'end-of-life.'

3S Modultec sells production line to Lithuanian firm

3S Modultec has increased its presence in the Eastern European solar market by selling one of its integrated production lines to Lithuanian firm MG AB Precizika. The 38MW facility will manufacture crystalline panels for projects in Eastern and Southeastern Europe, and will be the first of its kind in Lithuania.

East and Southeastern Europe is an area of huge growth potential for the solar industry and MG AB Precizika's purchase signals its intent to tap into this market. The TÜV Rheinland-certified manufacturing line will be installed in the Baltic state this spring, with production beginning a few months later.

Source: Motech

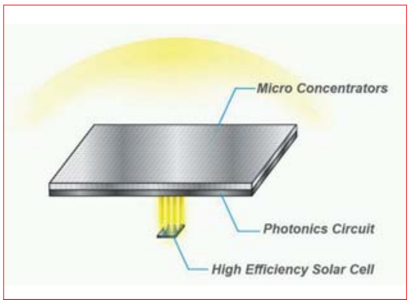
Motech Peak Power 205-220W PV modules.

Testing & Certification News Focus

HyperSolar unveils new micro-concentrator module prototype design model

HyperSolar has finished work on the prototype design model of its new thin micro-concentrator module. The commercial version of the concentrator, which is set to be both smaller and more efficient than the prototype design model, will be released once the photonic and optical characteristics of the test module are validated.

The final module will be approximately 1cm thick and deliver 400% light magnification, thus potentially reducing the number of solar cells in an individual panel by 75% and significantly lowering the cost per watt of solar electricity.



Source: HyperSolar

HyperSolar's concentrator will deliver 400% light magnification.

H.B. Fuller receives UL certification for back-rail adhesive for PV modules

H.B. Fuller has been awarded Underwriters Laboratories (UL) 746C QOQW2 Polymeric Adhesive Systems Electrical

Equipment-Component for its back-rail polymeric bond adhesive used in the production of solar panels. The company's PV-RH75 is a patent-pending adhesive that is formulated to attach back-rails to solar modules.

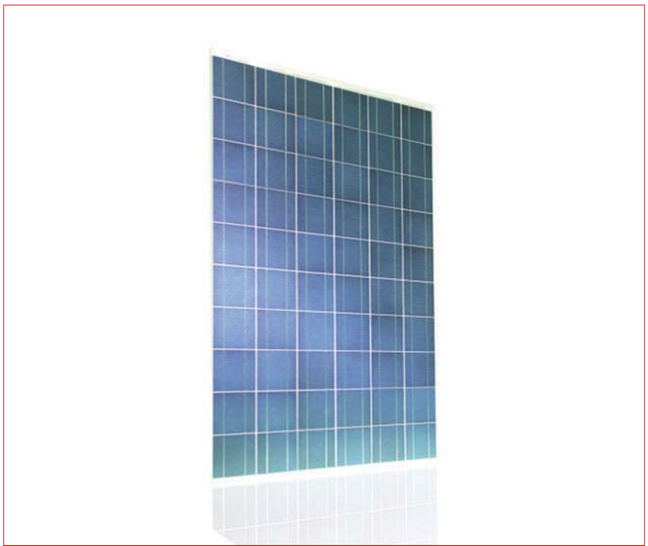
H.B. Fuller comments that it manufactured this adhesive specifically to meet the need of high temperature performance and lean manufacturing customers that need to affix back-rails to their solar modules. Apart from receiving UL certification, the material also passed performance and long-term durability tests to achieve IEC 61646 standards.

Upsolar gains CSTB certification in partnership with Soleos Solar, Oxysoleil

Upsolar has obtained certification – in partnership with mounting structure manufacturers Soleos Solar and Oxysoleil – from the Centre Scientifique et Technique du Bâtiment (CSTB), which ensures the quality and safety of sustainable construction through research, assessment and evaluation. Additional certifications are also in process with Mecosun and Renusol.

The company was required to submit a complete description of its components and manufacturing processes, as well as information on its online quality controls and test reports from third-party laboratories before being considered for CSTB approval. Soleos Solar and Oxysoleil were also required to present detailed calculations and technical product renderings to demonstrate adherence to national building codes, including waterproofing capabilities and resistance to mechanical loads and corrosion.

Upsolar's latest certifications cover the company's monocrystalline and polycrystalline modules as well as its building-integrated and rack-mounted systems. Additional product and system certifications are expected during 2011.



Source: Upsolar

Upsolar's polycrystalline PV module

Spire modules receive UL1703 standards certification

Spire Corporation has received the 'Listing Mark of Underwriters Laboratories' (UL) for its PV modules and panels. UL1703 standards testing involved a thorough investigation into the safety, performance, and overall quality of Spire's PV module design.

Schott Solar's Poly 290 module tops TÜV Rheinland testing

Schott Solar's latest offering, the double-glass Poly 290 module, has come through TÜV Rheinland's PV+ testing process with a final assessment of 'very good.' The process examines modules' performance, resistance to ageing, documentation, electrical safety, manufacturing

JinkoSolar signs 35MW module supply contract with Payom Solar

Vertically-integrated Chinese manufacturer JinkoSolar has signed a contract to supply 35MW of its modules to Payom Solar in 2011. The modules are to be used on a range of Payom's rooftop and ground-mounted projects across the U.S.

China Sunergy wins 1.1MW Swiss module supply contract

China Sunergy has won a contract to supply one of the largest solar facilities in Switzerland with its PV modules. The contract is with Swiss system integrator Sunergic, which will equip the Services Industriel de Geneve (SIG) solar facility with 1.1MW worth of Sunergy modules.

S.A.G. Solarstrom secures module supply agreement with Canadian Solar

S.A.G. Solarstrom has secured a 60MW polycrystalline module supply deal with Canadian Solar. The modules are intended for planned projects in both Germany and Italy during 2011. S.A.G. Solarstrom noted that it undertook intensive assessments of the technology and quality before signing the supply contract with Canadian Solar. Financial terms were not disclosed.

Spire wins turnkey module line business with Rahimafrooz Renewable Energy

Bangladesh firm Rahimafrooz Renewable Energy has ordered an advanced module manufacturing line with a capacity of 20MW from Spire Corporation. The modules made at the new facility will be used for rural applications. Rahimafrooz has installed PV on more than 100,000 homes directly and has supported the provision of solar energy in another 600,000 homes in Bangladesh since 2003. Financial and shipment/installation details were not disclosed.

JA Solar enters 400MW module supply deal with European firm

An unidentified company, described as 'leading European specialists in photovoltaic systems,' has struck a new deal with JA Solar. Under a signed agreement, JA Solar is to provide 400MW of solar modules to the firm beginning in 2011 and running through the end of 2013. Under the terms of the supply agreement, 100MW of solar modules will be supplied in 2011, 125MW in 2012, and 175MW in 2013. Financial details or module specifications were not disclosed.

Celestica signs 180MW supply agreement for Recurrent's Ontario solar power plants

Recurrent Energy entered into a 180MW supply agreement with Celestica for the delivery of its crystalline-silicon PV modules to 19 of Recurrent's Ontario-based solar power projects. The solar projects are part of the Ontario FiT program and will have the Celestica-manufactured solar panels delivered under a multiyear agreement. No financial details were revealed, although full production is expected by summer 2011.

Siemens enters agreement with Suntech for PV modules on European projects

Siemens Energy and Suntech Power Holdings have entered into a framework agreement where by Suntech will provide solar PV modules for various European solar installations. Siemens notes that over the past seven months, the company has received orders for PV plants that have a combined capacity of over 80MW in six countries.

JA Solar signs 29MW supply contract with Italian renewable energy company

JA Solar Holdings has signed a module supply agreement with an unidentified Italian renewable energy company. The contract between the two companies will see JA Solar provide 29MW of its solar PV modules in 2011 to the Italian renewable company.

ET Solar to supply 40MW of modules to Umwelt Sonne Energie

In its fourth year of supplying to German-based distributor and system integrator Umwelt Sonne Energie, a new 40MW supply deal including both mono- and multicrystalline modules has been signed with ET Solar for 2011. USE continues to deliver Asola and Solar Fabrik modules on the crystalline side, while it also has deals with Solyndra and First Solar in the thin-film segment.

DelSolar to supply modules to North American customer

DelSolar has signed a supply contract with an undisclosed North American PV market provider, in which DelSolar will supply solar modules worth around 22MW of generating capacity in 2011 to its customer. The price of the supply contract was not disclosed, but DelSolar did note that the signed contract accounted for supply terms for product quantities and prices.

Volthaus signs supply contract with module manufacturer EGing

German systems integrator Volthaus has signed a strategic supply contract with the module manufacturer EGing Photovoltaic Technology. The agreement will see EGing supply 20MW of its monocrystalline modules to be used on a range of Volthaus projects in the first half of 2011.

Yingli, Borrego Solar ink new 20MW PV module supply deal

Yingli Green Energy's Americas unit has signed a new PV module supply agreement with Borrego Solar Systems. Under the terms of the deal, 20MW of Yingli Solar crystalline-silicon modules will be provided to the San Diego-based PV systems installer in 2011. Borrego plans to use the panels for commercial projects across the U.S.

The agreement represents a doubling of Borrego's 2010 purchase order, when the company bought 10MW of Yingli Solar modules, deployed in projects such as the San Diego Community College District (2.8MW), City of Ridgecrest, CA (500kW), and San Diego County Water Authority (1.8MW). These projects created approximately 400 green jobs and are expected to deliver enough clean solar energy to power approximately 8,500 homes.

quality, guarantee and assembly characteristics, and after the first round of testing the Poly 290 was the highest-ranked of the eight modules under examination.

Sanyo HIT modules receive MCS accreditation

Sanyo Component Europe has become the latest solar module manufacturer to receive the British government's Microgeneration Certification Scheme (MCS) accreditation. The certification, which is a prerequisite in order to sell PV systems in the UK under the feed-in tariff (FiT), has been awarded to Sanyo's HIT range, including the new N series 240W crystalline-based silicon module – the most efficient of its kind in the world.

All of Sanyo's HIT modules will be produced at its manufacturing facility in Hungary, which is currently expanding its capacity from 165MW to 315MW; the redevelopment is scheduled to be completed in March. This month will also see the launch of the HD edition of Sanyo's N series module.

Product Reviews

2BG

2BG offers complete automation of string bussing soldering process

Product Outline: 2BG Srl has extended its product line with the complete automation of the bussing soldering process in order to meet the high demand of quality production and throughput. The IC200AR is an in-line system that operates as a robotic workstation which solders bus ribbons to solar cell strings for completion of the electrical interconnection of the module prior to lamination. Positioned after the string layup enables a high degree of automation in the panel assembling line.

Problem: Bussing process is a very critical step in the assembling and is closely related to the final product quality and efficiency of the panel. For this reason, it is important to choose very skilled operators of the soldering iron in the manual bussing station. The manual process cannot guarantee repeatability and stable results with fixed cycle time.

Solution: With 2BG's solution, wire preparation and placement are carried out with high accuracy by robots with special tools and devices. Particular attention has been paid with the choice and integration of soldering technology and vision cameras with the purpose of assuring the best combination of performance and reliability, reaching cycle times of 80 seconds for each 72-cell module. The workstation prepares and welds ribbon bussing strings to complete the electrical circuit before the module lamination and ensures that solar cells are not subjected to mechanical stress.

Applications: Automation of the string bussing soldering process.

Platform: The IC200AR is an in-line system based around a robotic workstation, using advanced soldering technology and vision systems.

Availability: Currently available.

Avago

Isolation amplifier from Avago offers greater accuracy

Product Outline: Avago Technologies has introduced a new precision optical isolation amplifier for motor control and current sensing applications. The ACPL-790B, ACPL-790A and ACPL-7900 devices improve the accuracy and response times of the Avago isolation amplifier portfolio, while addressing compact applications with a smaller footprint package design for solar module power systems and general analog isolation.

Problem: Competing solutions based on Hall Effect technology and current transformer technology suffer electrical parameter variation over temperature fluctuations and require a larger footprint in a design.

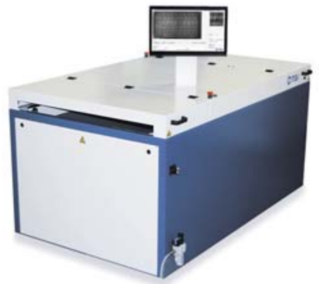
Solution: As current flows through the external resistor in a motor drive implementation, the resulting analog voltage drop is sensed by an ACPL-790B/790A/7900 isolation amplifier, and it allows a proportional output voltage to be safely created on the other side of the optical isolation barrier. The ACPL-790B precise isolation amplifier provides up to 0.5% high gain accuracy, and offer 200kHz bandwidth and 1.6μs fast response time to enable capture of transient signals in short-circuit and overload conditions. The devices operate from a single 5V supply that is compatible with 3.3V outputs and provides improved linearity and dynamic performance of 60dB SNR.

Applications: Solar module power systems.

Platform: For general applications, the ACPL-790A (±1% gain tolerance) and the ACPL-7900 (±3% gain tolerance) are recommended. For high-precision applications, the ACPL-790B (±0.5% gain tolerance) can be used. Compliant to UL 1577 5000V_{rms}/1 minute rating, IEC/EN/DIN EN 60747-5-5 and CSA industrial safety standards.

Availability: Samples and production quantities are currently available.

MBJ Solutions



MBJ Solutions offers low-cost fast electroluminescence inspection system

Product Outline: MBJ Solutions is expanding its product portfolio with the new SolarModule EL-quickline system. The SolarModule EL-quickcheck is designed as an alternative to the company's high-resolution product platform, the SolarModule EL-basic / EL-lab. The system uses two fixed installed, cooled CCD-NIR cameras to attain a very high testing speed. The resolution is low in comparison with the high-resolution models, but the system is considerably more cost-effective in part due to the simple mechanical concept.

Problem: Micro-cracks on solar modules are mostly invisible to the human eye, yet present a significant risk of decreasing the module's performance. Micro-cracks can happen anywhere and anytime, during production, transportation or installation.

Solution: The SolarModule EL-quickcheck has a simpler mechanical design with two fast-action fixed cameras, providing a reasonable image quality at a significant lower price. Moreover, using this technology provides valuable information about the overall quality of the solar module under test.

Applications: The system is designed for mono- and multicrystalline silicon solar modules; sizes of min. 400 × 600mm, max. 1050 × 2000mm (W x H).

Platform: The compact mechanical design with its multiple camera approach ensures short tact times @7.8MPixel. The short side leading system allows inspecting framed and non-laminated modules combined with an automatic contact unit. The images captured by the cooled NIR-CCD cameras are displayed on the user interface in a matrix view and the operator can grade the module as either 'good' or 'reject' depending on the defects visible in the images. The SolarModule EL-quickline has a cycle time of less than 25s including automatic loading and unloading of the module.

Availability: Currently available.

Luminescent encapsulation layers for multicrystalline silicon PV modules

Bryce S. Richards & **Efthymios Klampaftis**, Heriot-Watt University, Edinburgh, Scotland

ABSTRACT

This article highlights an alternative method for increasing short-wavelength external quantum efficiency (EQE) and hence overall conversion efficiency of mc-Si PV modules via luminescent down-shifting (LDS), a technique originally proposed by Hovel et al. [1] in 1979. The potential for efficiency enhancement via LDS has been either predicted or measured for a wide range of PV technologies (see [2] for a review). However, in this article, we will highlight how LDS can be incorporated into the existing encapsulation layer, avoiding any modification to well-established solar cell manufacturing processes and thus offering the potential of a production-ready technology.

Introduction

The performance of many PV modules manufactured in large-scale production exhibit a poor response to short-wavelength (λ = 300–450nm) light, thereby reducing the amount of photocurrent that can be generated from this part of the solar spectrum. In a study of the mechanisms limiting the short-wavelength response of a multicrystalline silicon (mc-Si) PV module, it was found that absorption in the ethylene vinyl acetate (EVA) encapsulant played the largest role, while absorption in and reflection from the anti-reflective coating (ARC) also contributed significantly [3]. The traditional approach to solving these problems has been to constantly improve the opto-electronic design of the PV device, particularly with regard to texturing, ARCs, and the potential of selective emitters. However, design trade-offs often exist and a balance between optical and electrical performance – as well as the potential for implementation into large-scale production – must be achieved.

Luminescent down-shifting (LDS)

The optically active materials in the LDS layer are designed to absorb ultraviolet and blue light before it strikes the solar cell, and then emit luminescence at longer wavelengths where the underlying PV device exhibits a significantly higher EQE. In this article, the focus is on the opportunity to dope the luminescent species in the pre-existing EVA layer – as shown in Fig. 1 [4] – given that the majority of mc-Si module manufacturers use EVA encapsulation, which affords the exciting possibility of achieving LDS with no added production processes or layers to the device. In addition, the same approach can be applied to other PV technologies that rely on front-surface encapsulation, like copper indium (gallium) diselenide-based thin-film devices or indeed alternate front-surface encapsulation materials [5].

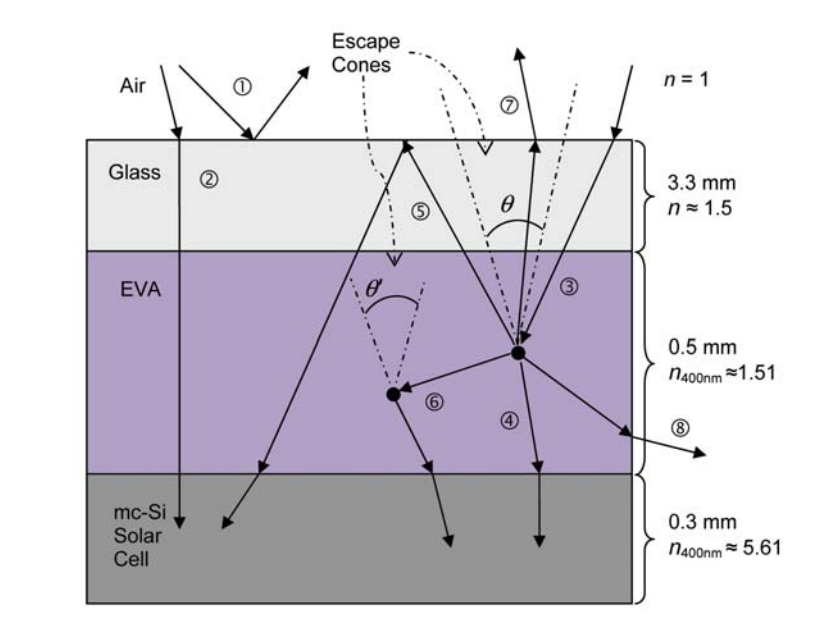


Figure 1. Possible light paths in a mc-Si PV module encapsulated with LDS EVA, with incident light ① being partially reflected by the front surface of the cover glass. Longer-wavelength light entering the module ② is transmitted to the cell without any dye interaction, while short-wavelength can be absorbed by the luminescent material ③ and re-emitted at longer wavelengths. The majority of the emitted light will reach the cell, either directly ④ or after internal reflection at the air:glass interface ⑤, or via re-absorption and re-emission by another luminescent species ⑥. A small fraction of the light can leave the module via the top plane escape cones ⑦ or through the sides ⑧, although the latter is negligible for full-size modules [4].

It has been shown that LDS EVA layers can alleviate the following loss mechanisms [1,4,6]:

- Parasitic absorption in the EVA layer is reduced as a large fraction of short-wavelength photons are now down-shifted to regions where the EVA is less absorbing.
- Absorption and reflection by the ARC can also be reduced, since the resulting red-shifted incident spectrum better matches the properties of this layer, while it is also easier to design a better ARC for the narrower spectrum that is now incident upon the solar cell.
- Recombination at the front surface can also be reduced because the down-shifted photons are more likely to be absorbed deeper into the device.

However, a trade-off remains as the implementation of LDS into a PV module also introduces certain optical losses: firstly, due to a fraction (>12.5%) of the emitted photons escaping back out of the front surface of the module; and, secondly, if the luminescent material(s) used exhibit a photoluminescence quantum yield (PLQY) of less than 100%, i.e. one photon is emitted for each photon absorbed.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that powers a PV module
can also
destroy it.
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Fabrication of LDS EVA

EVA pellets (PV1650, DuPont) were used as the starting material for all experiments described in this article. The authors have produced LDS EVA layers by adding fluorescent organic dyes via two methods: mechanical mixing and sheet extrusion [4]; and dissolving the dyes in a suitable solvent (e.g. toluene), then adding to EVA, followed by baking off the solvent and using a hydraulic press to form sheets [7]. Both clear and doped EVA sheets were created, the latter containing up to four commercially-available dyes (BASF Lumogen Violet 570 [8], Yellow 083, Yellow 170 and Orange 240) as well as a europium (Eu^{3+})-based rare-earth complex [7,9]. The Lumogen dyes were chosen because of their high absorption coefficients and PLQYs, as well as for their ease of processing with polymers, while the Eu^{3+} ion in the rare-earth complex exhibits an ideal emission wavelength and a very large Stokes shift (i.e. no overlap between absorption and emission spectra).

This article focuses on the variation of LDS performance as a function of Violet 570 dye concentration, with dye concentrations of 0.0425% w/w, 0.1305% w/w, and 0.2610% w/w being added to EVA to achieve optical densities (OD) of OD = 1, OD = 3, and OD = 6, respectively, at the dye peak absorption wavelength (375nm) and a final sheet thickness of d = 0.5mm.

"The majority of mc-Si module manufacturers use EVA encapsulation, which affords the exciting possibility of achieving LDS with no added production processes or layers to the device."

The excitation and emission spectrum of each dye concentration in EVA as well as the PLQY was determined using a spectrofluorometer (Edinburgh Instruments FS920) equipped with an integrating sphere [10,11]. Quarters of full-size mc-Si solar cells were cut (59cm^2 active area) and laminated in a symmetrical sandwich of EVA (doped on front, clear on rear) and borosilicate float glass. The lamination cycle was 155°C for five minutes under vacuum followed by five minutes under atmospheric pressure in air. Glass-glass modules were fabricated, rather than the more common glass-Tedlar construction, so that the transmittance of the PV laminate could be measured (Perkin Elmer Lambda 950 spectrophotometer). The electrical performance of the samples both before and after encapsulation was tested using a continuous solar simulator (ABET model 11044) and four current-voltage (I–V) curves were taken in each case. The EQE of these mini-modules was measured using a monochromator-based spectral response system (Bentham). Images of three different mc-Si laminates are shown in Fig. 2, one using clear EVA and two fabricated with luminescent EVA. Thus, another benefit of luminescent EVA is that it becomes a simple and cost-effective method for altering the colour of PV modules.

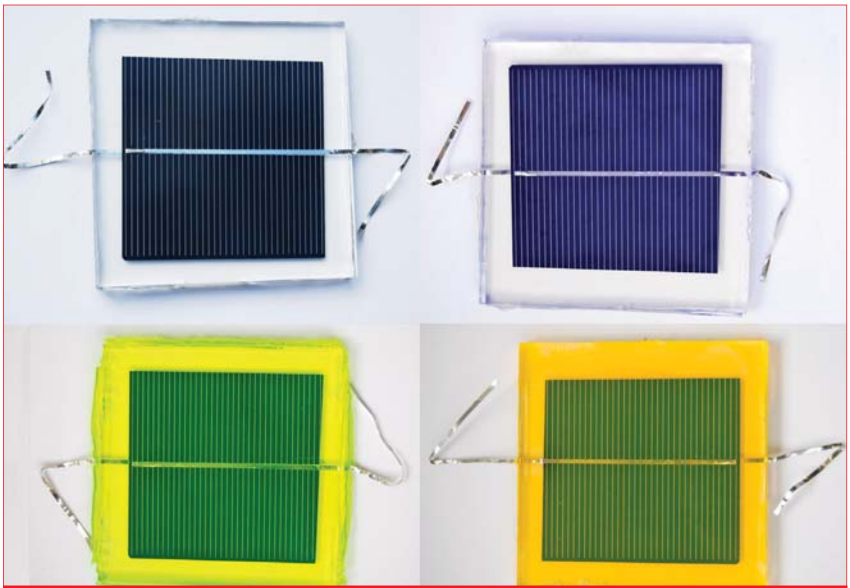

Figure 2. Four mc-Si PV mini-modules (cell area 59cm2) fabricated with either clear EVA (top left) or luminescent EVA based on thee BASF Lumogen dyes: Violet 570 (top right); Yellow 083 (bottom left) and Orange 240 (bottom right).

Results and discussion

The absorption and emission spectra of a violet-doped EVA sheet (OD = 3) are plotted in Fig. 3, along with the EQE of the clear-EVA mini-module. The Violet 570 dye absorbs photons in the range of λ = 300–400nm, where the mini-module's EQE is in the range of 23–58% and emits in the range λ = 400–570nm, where the mini-module's EQE is significantly higher in the range of 58–88%. The PLQY of the violet dye in EVA was determined to be 100 ±10% [4], which agrees with the same value measured in polymethylmethacrylate (PMMA) [10].

Comparing the transmission data for luminescent samples against the control samples (see Fig. 4) indicates that no significant scattering occurs due to the addition of the dyes to the EVA encapsulant. Fig. 4 also shows that using the solvent-based method (solid curves) to dope the sheets resulted in slightly more transparent (less scattering) material than mechanical mixing (dashed curves).

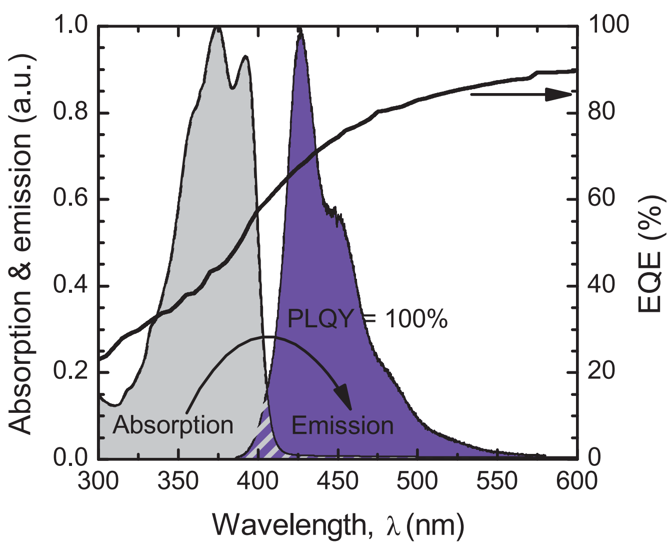

Figure 3. Normalized absorption and emission spectra of the Violet 570 dye (OD = 3) in EVA, along with the EQE of the clear-EVA mini-module to give an indication of the potential gains to be made by employing LDS in a mc-Si PV module (adapted from [4]). Note that the emission spectrum is considerably red-shifted compared to the datasheet [8] due to the high dye concentration used here.

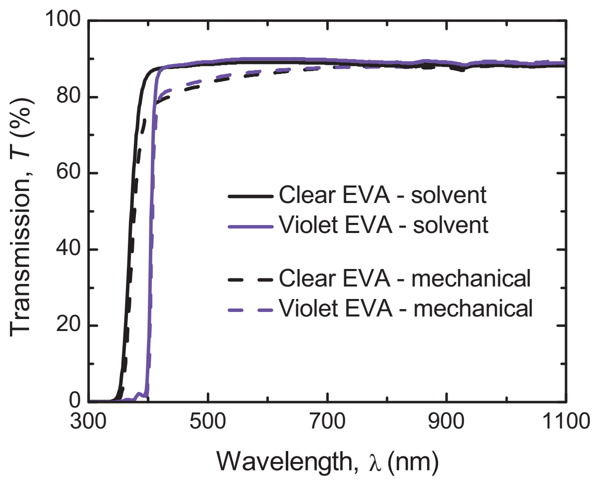

Figure 4. Transmission measurements through four of the mini-module laminates fabricated. The violet dye is seen to absorb a significant fraction of light from 350–400nm, while the use of solvent for doping the EVA resulted in a superior EVA sheet than that achieved via mechanical mixing and extruding.

The EQE curves of the four encapsulated mc-Si mini-modules are shown in Figure 5. The violet-doped-EVA laminates exhibits an increase of 10 – 20 % in EQE in the range λ = 300–400nm. With increasing dye concentration, a greater fraction of light is absorbed, which has the effect of broadening the width of the absorption peak centred at 375nm, while the resulting EQE increases at wavelengths less than this value.

> "If this can be achieved, then increasing mc-Si module efficiencies by 0.5% (absolute) would become possible."

However, at longer wavelengths, the performance is slightly worse at higher OD since there is an increased probability of re-absorption in layers with higher dye concentrations. Hence, there is an increased possibility of the emitted photons undergoing a second absorption event and being re-emitted possibly before being collected by the underlying mc-Si solar cell. However, as mentioned previously, for each emission event (assuming isotropic emission) there is a 12.5% chance of losing the emitted photons back out the front surface. These losses are compounded further during subsequent re-absorption/emission events, and for this reason luminescent materials with large Stokes shifts are of interest.

Table 1 compares the efficiency enhancement achieved via the application of LDS EVA for the series of violet-doped samples. Whilst the concentration that corresponds to OD = 3 seems to be the optimum for maximum efficiency enhancement, the OD = 1 sample yields a very similar improvement, but only using one third of the quantity of the dye. This can be important to cost analysis considerations for the technology in case of application to production scale; it is generally better to use lower concentrations if possible to avoid any risk of dye aggregation. This best result achieved to date, using the violet dye at OD = 3, translates to a 0.2% absolute gain in module efficiency.

Cost estimate and photostability considerations

The cost of implementing an LDS layer (of OD = 3) into a mc-Si module has been presented previously [3,4]; however, the example of Violet OD = 1 is presented here to illustrate the point. To manufacture a 1m^2 EVA sheet of 0.5mm thickness doped with OD = 1, approximately 208mg of violet dye is required. Lumogen dyes are

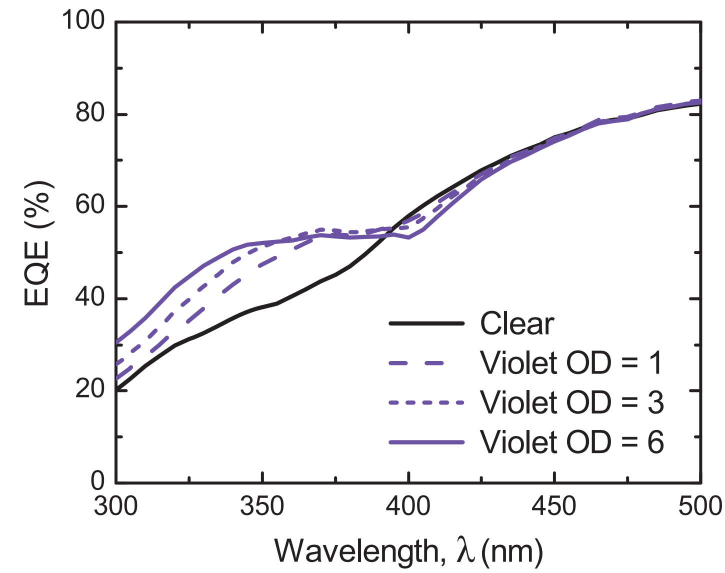

Figure 5. Impact of violet dye concentration on the EQE of a mc-Si mini-module.

EVA Type	Initial(cell) η (% ab.)	Final (module) η (% ab.)	$\Delta\eta$ (% rel.)	Improvement due to LDS(% rel.)
Clear	14.32	14.26	-0.39	n/a
Violet OD = 1	14.63	14.78	+1.07	+1.46
Violet OD = 3	14.26	14.42	+1.09	+1.48
Violet OD = 6	14.15	14.18	+0.24	+0.63

Table 1. Efficiency results for samples encapsulated in violet-doped EVA sheets at different concentrations. The mini-modules' efficiencies are compared to the corresponding cell efficiencies prior to encapsulation, rather than directly to each other, because the mc-Si cells had slightly different initial efficiencies. The difference between the initial and final efficiencies of the same device describes the effect $\Delta\eta$ of the encapsulation in each case. The benefit directly attributed to LDS is calculated by subtracting from the effect of encapsulation calculated for each sample, the effect of encapsulation for the corresponding control sample.

commercially available in bulk quantities, priced at about €7,000–9,000/kg [12]. Thus, the additional cost for a 1m^2 module is in the range of €1.50–2.00, which is very small compared to the factory-gate price of ~ €360/m^2 for European manufacturers of mc-Si modules [13].

Using the efficiency results presented in Table 1 and the above cost considerations, a reduction from €2.40/Wp to €2.38/Wp is estimated to be the benefit of LDS in terms of cost of photovoltaic power. Naturally, the €/Wp benefit will increase with optimized luminescent materials that exhibit a large Stokes shift and emit at $\lambda > 600$nm. In addition, technologies the exhibit a poorer short-wavelength performance than mc-Si, such as CI(G)S, also stand to benefit more.

For the above calculation to be really useful, this additional electricity needs to be generated over the lifetime of the mc-Si PV module. PV manufacturers typically guarantee a minimum performance over an extended period of 20–25 years and every component should meet this requirement. For example, pure EVA exhibits inadequate photostability to UV light and requires the addition of UV-absorbers to protect the copolymer [14]. The violet dye is characterized by the manufacturer as long-term photostable, despite exhibiting UV-induced photodegradation under irradiation with light of $\lambda < 345$nm [15]. In experiments using acrylic (PMMA) doped with Lumogen violet dye, a 50% reduction in emission was measured after exposure to sunlight for ~ two years [15]. However, in the case of LDS EVA, the doped encapsulant is beneath the glass coversheet of a PV module, which strongly absorbs light of $\lambda < 340$nm [3]. This, along with the presence of the UV-absorber in the EVA, will afford some additional UV protection. It is clear that extensive accelerated weathering and outdoor testing is required to adequately address this issue.

Conclusion and future direction

This study has shown that an enhancement in the performance of mc-Si devices can be achieved without any modification to the well-established manufacturing process of these devices and any addition to the cost of power generation. This can be done by dissolving a suitable luminescent species in the EVA encapsulation layer that is commonly used for the manufacturing of mc-Si devices. The Lumogen Violet 570 dye is reported to offer an increase of over 10% in EQE for the region of 300–400nm, which results in 0.2% higher module efficiency. Future R&D in this area needs to focus on the development of photostable luminescent materials that are able to strongly absorb light in the 300–450nm range and emit this at about 600nm with a near-unity PLQY. If this can be achieved, then increasing mc-Si module efficiencies by 0.5% (absolute) would become possible.

References

1. Hovel, H.J., Hodgson, R.T. & Woodall, J.M. 1979, "The effect of fluorescent wavelength shifting on solar cell spectral response", *Solar Energy Materials & Solar Cells*, Vol. 2, pp. 19–29.
2. Klampaftis, E. et al. 2009, "Enhancing the performance of solar cells via luminescent down-shifting of the incident spectrum: A review", *Solar Energy Materials & Solar Cells*, Vol. 93, pp. 1182–1194.
3. McIntosh, K.R. & Richards, B.S. 2006, "Increased mc-Si module efficiency using fluorescent organic dyes: a ray-tracing study", *Proc. 4th World Conf. on Photovoltaic Energy Conversion*, Waikoloa, Hawaii, USA, pp. 2108–2111.
4. Klampaftis, E. & Richards, B.S. 2010, "Improvement in multi-crystalline silicon solar cell efficiency via addition of luminescent material to EVA encapsulation layer", *Prog. Photovolt: Res. Appl.*, DOI: 10.1002/pip.1019.
5. Böhm, A., Grimm, A. & Richards, B.S. 2008, International Patent Publication Number: WO / 2008 / 110567 (patent rights held by ColorFlex G.m.b.H., Germany).
6. McIntosh, K.R. et al. 2009, "Increase in external quantum efficiency of encapsulated silicon solar cells from a luminescent down-shifting layer", *Prog. Photovolt: Res. Appl.*, Vol. 17, pp. 191–197.
7. Klampaftis, E. et al. 2011, "Luminescent EVA encapsulation layers for enhancing the short wavelength spectral response and the efficiency of silicon PV modules", *Solar Energy Materials & Solar Cells* (submitted).
8. BASF Corporation, Technical information [available online at http://www2.basf.us/additives/pdfs/lumvio570.pdf].

9. Moudam, O. et al. 2009, "Europium complexes with high total photoluminescence quantum yields in solution and in PMMA", *Chem. Commun.*, Vol. 43, pp. 6649–6651.
10. Wilson, L.R. & Richards, B.S. 2009, "Measurement method for photoluminescent quantum yields of fluorescent organic dyes in polymethyl methacrylate for luminescent solar concentrators", *Applied Optics*, Vol. 48, Issue 2, pp. 212–220.
11. Porres, L. et al. 2006, "Absolute measurements of photoluminescence quantum yields of solutions using an integrating sphere", *Journal of Fluorescence*, Vol. 16, pp. 267–272.
12. Böhm, A. (personal communication 2008), ColorFlex GmbH & Co KG, Kirchwaldstrasse 75, Mannheim 68305, Germany.
13. MarketBuzz: Annual World Photovoltaic Market Review, *SolarBuzz LLC* 2009; 301.
14. Czanderna, A.W. & Pern, F.J. 1996, "Encapsulation of PV modules using ethylene vinyl acetate copolymer as a pottant: A critical review", *Solar Energy Materials & Solar Cells*, Vol. 43, pp. 101–181.
15. Seybold, G. & Wagenblast, G. 1989, "New perylene and violanthrone dyestuffs for fluorescent collectors", *Dyes and Pigments*, Vol. 11, pp. 303–317.

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Snapshot of spot market for PV modules – quarterly report Q4 2010

pvXchange, Berlin, Germany

ABSTRACT

Solar enterprises will each be faced with the occasional surplus or lack of solar modules in their lifetimes. In these instances, it is useful to adjust these stock levels at short notice, thus creating a spot market. Spot markets serve the short-term trade of different products, where the seller is able to permanently or temporarily offset surplus, while buyers are able to access attractive offers on surplus stocks and supplement existing supply arrangements as a last resort.

Introduction

2010 – what a year! The global PV market has seen growth rates and prospects the likes of which other industries can only imagine. Highly-developed capacity in the module and inverter production sectors has been sufficient in the past year; enough goods were available and they are becoming cheaper and cheaper on the market. Only the presence of those coveted 'bestseller' products from known brands has prevented prices from falling even more than they already have. At the same time, the spot market has grown strong, delivering pvXchange its strongest year since its foundation. Approximately 180MW of solar modules and inverters with a capacity of 85MW/AC were traded by thousands of registered participants. The statistical basis for the analysis of the fourth quarter's trading activities is thus based on more records than ever before.

Before we look at the entire year, let's take a more in-depth look at Q4 of 2010. The expected decline on the spot market was not as severe as anticipated at the end of the third quarter. This was particularly true for high-power modules that were available in Europe. By the end of the year, demand was steady as a result of ongoing projects in Italy and the Czech Republic. However, modules purchased from Asian manufacturers at the end of November that were scheduled to arrive at their European destinations in mid-December have been more favourably priced at an average of €0.05 per watt.

What is striking is the rapid decline in prices of CdTe modules. This was the most likely factor at play in the declining demand in Germany – the biggest market for this thin-film technology. By comparison, while prices for crystalline modules fell in November compared to October by about 1%, CdTe module prices fell by over 5%.

Considering, therefore, that the data regarding regions and technologies being produced is more accurate, several interesting developments have occurred in the past year. In December 2010, Chinese module prices were only about 1% lower than prices in January 2010. Japanese manufacturers reduced their prices by about 10.5% during the year. The region that saw the greatest decline was Europe, with a price decrease of about 13.8% by the end of Q4. Among the manufacturing regions, this also reduces the overall price difference in crystalline solar modules. While Chinese modules in January were between 30% and 22% cheaper than those from Europe and Japan, they are now only between 12% and 10% cheaper. The price advantage in the European markets seems to be shrinking for Chinese producers.

Over the course of the year, thin-film producers have adjusted their prices. Prices for a-Si and microcrystalline modules have fallen by 11.8% on average. Even First Solar's CdTe modules had to cope with a price cut of 14.3% on the PV market.

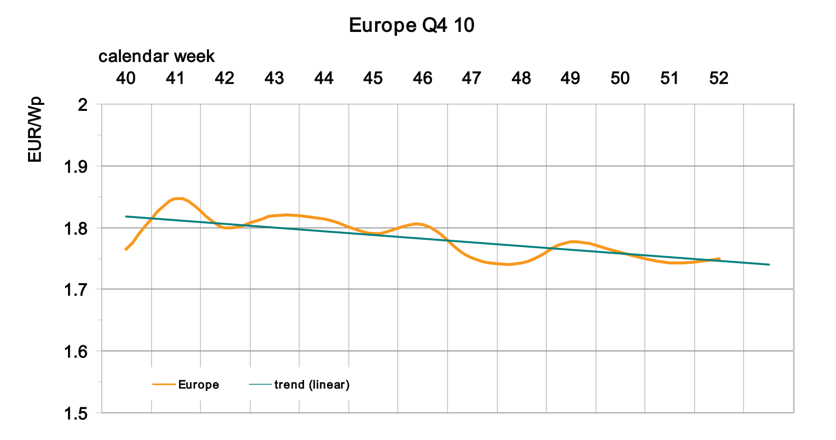

Figure 1. Development of module prices for modules produced by European manufacturers from October 2010 to beginning of January 2011.

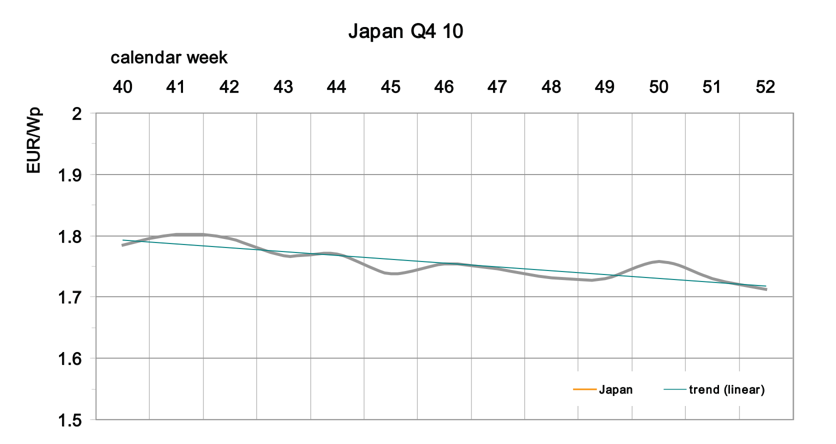

Figure 2. Development of module prices for modules produced by Japanese manufacturers from October 2010 to beginning of January 2011.

Crystalline manufacturers from Asia have been clear-distance winners on the spot market in 2010. They have clearly benefitted more than their competitors from the increased demand from Germany following the introduction of the new feed-in tariff in July. The same can also be said of Chinese manufacturers as a result of developments in the Czech and Italian markets in the second half of the year.

There are many reasons for the worldwide price decline. In addition to growing over-capacity in the crystalline solar module sector, there are falling cellular prices on the spot market. The price for solar cells as at the end of Q4 was US$1.42 per watt compared to US$1.20–1.25 per watt in November. Furthermore, the seasonal cooling of the solar industry coupled with political decisions in Germany and France are certainly not beneficial to the turnover of the manufacturers in the coming months. The new year is uncertain; 2011 is expected to diversify demand in favour of new, non-European markets. Nevertheless, the expected peak positions will feature the same countries – with the exception of the Czech Republic – as 2010.

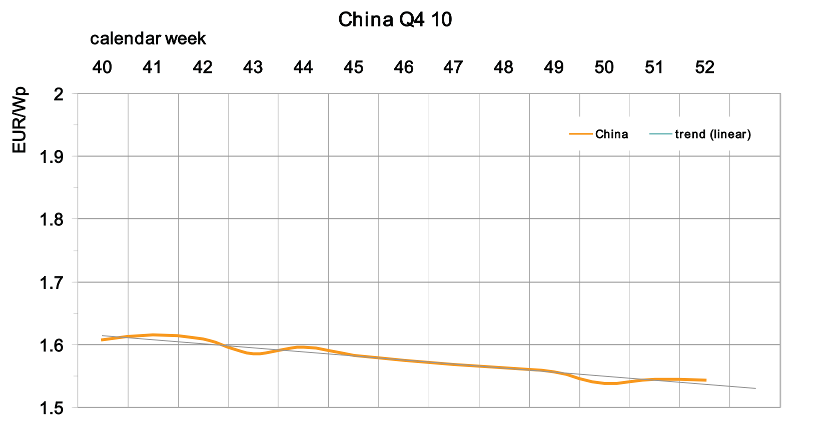

Figure 3. Development of module prices for modules produced by Chinese manufacturers from October 2010 to beginning of January 2011.

About the Authors

Founded in Berlin in 2004, **pvXchange GmbH** has established itself as the global market leader in the procurement of photovoltaic products for business customers. In 2010, the company procured solar modules with an output of around 180MW. 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.

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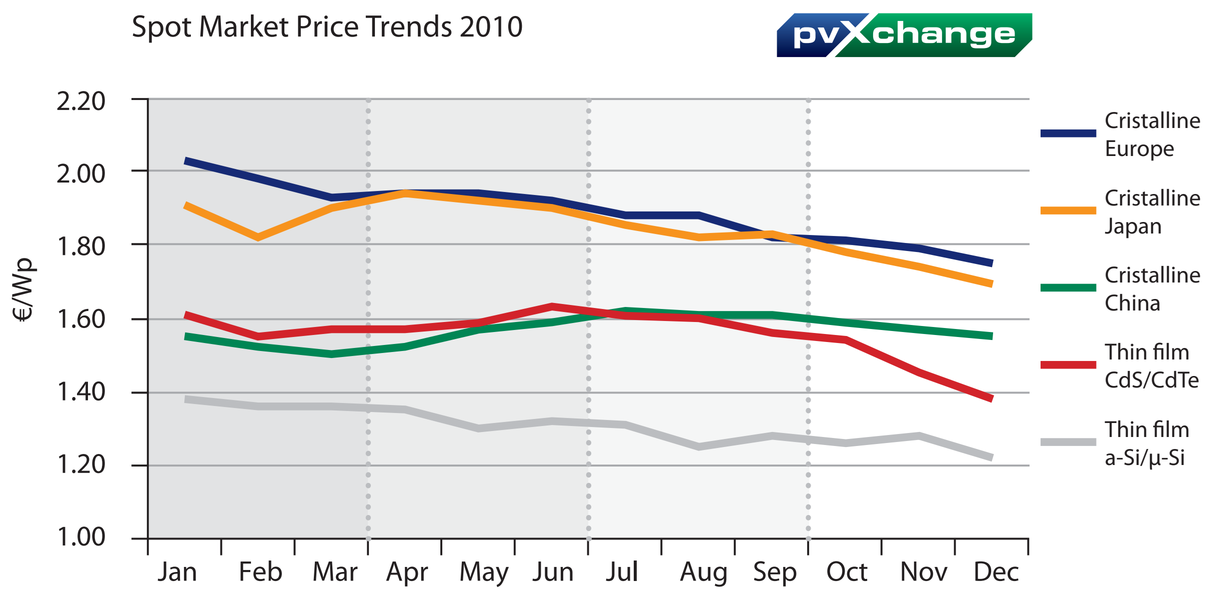

Figure 4. Spot market price trends (by technology type and region) for 2010.

Corrosive effects of ammonia on PV modules and their evaluation

Urban Weber, **Ralf Eiden**, **Thorsten Soegding** & **Kurt Nattermann**, SCHOTT AG; & **Harry Engelmann**, SCHOTT Solar AG, Mainz, Germany

ABSTRACT

Ammonia, a gas which has its roots in livestock farming, can have potentially detrimental effects on the lifetime and reliability of PV modules. Research into the degree of corrosive effects of this gas on modules is of utmost importance for any module manufacturer guaranteeing a certain specific lifetime for their product. Researchers from SCHOTT and SCHOTT Solar together with the DLG (Deutsche Landwirtschafts-Gesellschaft/German agricultural society) developed a test design involving humidity, temperature and ammonia gas. This design is based on permeation testing and microscopic analysis of samples aged under a controlled atmosphere or from outdoor exposure. Additionally, a highly accelerated test is presented which allows screening materials for use in PV modules within 84 hours. An Arrhenius type of model is used to calculate the acceleration factors involved. Based on this model, the proposed test design is equivalent to more than 20 years of outdoor exposure in the rural environment (in Central Europe).

Introduction

The agricultural environment in Central Europe represents a substantial market segment for the application of PV modules (e.g. 19% of all investors for PV systems in 2009 in Germany [1]). Although this has been threatened of late as a result of the German government's cutting of the feed-in tariff for free-standing PV applications on agricultural land, the assessment of the specific risks for reliability and lifetime expectancy of PV modules in the agricultural environment is still crucial. A variety of potentially harmful gases – such as ammonia, carbon dioxide, methane, hydrogen sulphide and nitrous oxide – can emanate from livestock farming (e.g. pigs, cows or chickens) [2]. Two of these gases are potentially corrosive (ammonia and hydrogen sulphide); the others are what have become known as greenhouse gases.

"For a valid correlation of test conditions with outdoor exposure, knowledge of the temperature dependence is required."

Ammonia can be identified as being more relevant than hydrogen sulphide with respect to degrees of corrosive damage inflicted. The maximum workplace concentration value of ammonia is higher (20ppm vs. 5ppm) and it forms strong bases, whereas hydrogen sulphide forms a relatively weak acid (comparable to carbon dioxide, whose atmospheric concentration is 350–400ppm).

In other environments, different gases may need to be considered – for example, in the vicinity of volcanoes, gases like CO_2, SO_2, H_2S, HCl or even HF may result in a more significant corrosive attack [3]. Similarly, near fossil fuel burning sites (including motorways and railway trails), other potentially corrosive gases prevail (e.g. SO_2, NO_x, CO_2). For each of these environments, a corresponding approach – as for ammonia in this paper – would need to be taken if identified as a significant area of PV application.

Regarding field data, not much is known of specific damages occurring to PV modules in the rural environment; however, one severe case of the loss of adhesion of a junction box and a subsequent arcing is reported by Althaus et al. [4], which can most likely be attributed to the system's being installed above a pig pen exhaust outlet. The same publication reports the browning of an adhesive and the corrosive attack of the aluminium frame due to ammonia exposure [4]. Ammonia is known to induce minor damage in metals such as silver and aluminium, and to severely attack several polymer materials such as PET, PBT and PC [5]. Therefore, the loss of adhesion of a polymer is likely to be attributed to the influence of ammonia gas. These data highlight the importance of assessing ammonia resistance for PV modules, both as a prerequisite for warranting stability of power output as well as for security reasons.

Experimental approach

In order to assess the influence of ammonia on photovoltaic modules, a systematic approach is needed to describe the diffusion behaviour of ammonia within a PV module while outlining the main damage mechanisms that result from the presence of ammonia in combination with humidity. For a valid correlation of test conditions with outdoor exposure, knowledge of the temperature dependence of both aspects is required.

Figure 1. Setup for highly accelerated ammonia life test. The desiccator was filled with an ammonia solution designed to produce an ammonia concentration of 50,000ppm at 85°C, as well as various materials used in PV modules, such as glass/EVA laminates, cables etc. that do not come into contact with the liquid ammonia solution.

This study proceeded to determine the permeation of ammonia through a major encapsulant material (ethyl vinyl acetate, EVA) as well as a major back sheet material (Tedlar®/PET/Tedlar® (TPT)), allowing the evaluation of the temperature dependence. In order to identify the main damage mechanisms, PV modules were mounted in a test chamber with ammonia concentrations up to 2,000ppm in 70°C/70% relative humidity for a total duration of 840 hours. These PV modules were characterized together with a module from the roof of a pig pen which had been operating outdoors without problems for four years. Additionally, module components such as glass and encapsulation materials were stored in a highly accelerated ammonia life test, which consisted of ammonia concentrations of 50,000ppm at a temperature of 85°C and 100% relative humidity for a time of 84 hours (see Fig. 1).

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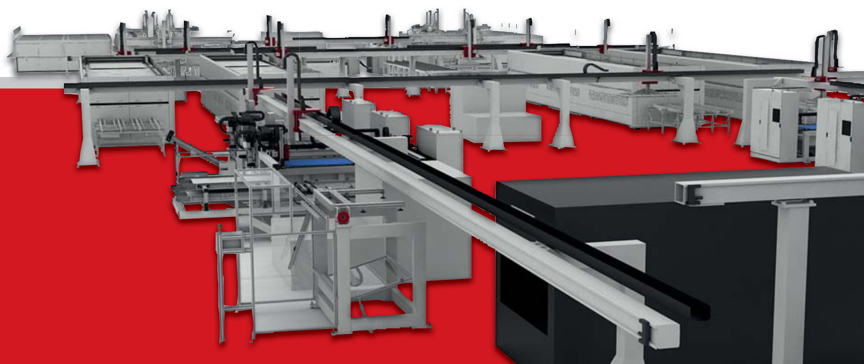

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Ammonia diffusion

The transmission rates of ammonia gas through EVA and TPT were evaluated at different temperatures. The transient data were analyzed according to the approach proposed by Kempe [6], from which diffusion and solubility constants can be extracted. The TPT laminate was considered as a homogeneous material, since the Tedlar layers are comparably thin and it can be assumed that the obtained values reflect the properties of the central PET layer. The aim of this analysis was to estimate the times for ammonia ingress into a photovoltaic module.

Results of the diffusion and solubility constants of the two relevant polymer components are shown in the graph in Fig. 2. The solubility constants are similar for the two materials and depend only weakly on temperature. The diffusion constants are two orders of magnitude higher for EVA than for TPT. The ammonia ingress times into a PV module can be estimated from these data, according to the formula for the average range x_{av} of the entering gas:

$$x_{av} = \sqrt{Dt} \qquad (1)$$

when D is the diffusion constant and t the time. Fig. 3 displays times for ingress into a typical PV module, where 1mm is representative of a typical EVA thickness, and 76mm is half the size of a 6" cell.

These data imply that in the field, ammonia penetrates the outer skin of an EVA/TPT PV module within a few days. Although it can take several years to reach the centre of the cells at the front side, corrosive effects – if present – can begin immediately after deployment near the rims of the cells. On the other hand, a test design for ammonia resistance should take the time lag into account (typically a few days) which can retard the ammonia action within the PV module.

The situation is different for 'double glass' modules that have a back-side glass slide instead of a polymer foil or laminate. Ammonia is unlikely to penetrate at all within these modules; if it does so, it would be from the rim. In such a scenario, a comparably thick polymer sealing (at least several millimetres) and a certain distance of the cells from the rim (again, several millimetres) must be ensured, thus delaying any corrosive attack until much later in these modules' lifetimes.

Damage mechanism: glass corrosion

The modules were extracted from preliminary ammonia tests and outdoor exposure and inspected by light microscopy and scanning electron microscopy (SEM) and energy-dispersive x-ray detection, paying particular attention to the metallization features of the solar cells (bus bars, fingers and back contacts) and interconnectors. No signs of degradation were observed. Therefore, more detailed investigations concentrated on the front glass and the polymer components of the module.

After ammonia tests with the modules, light microscopy and white-light interference microscopy of the front glass showed locally minor damage to the glass surface in the nm range (see Fig. 4). Modules that had undergone four years of outdoor exposure showed no such signs (see Fig. 4). The signs of glass corrosion were not unambiguous, however. The front glass was subjected to high ammonia load conditions (50,000ppm) which led to severe glass damage in the form of an extreme surface roughness and the formation of a film of crystallite-like particles which could not be wiped away using either water or ethanol (for details see [7]). These are typical signs of severe glass corrosion [8], which strongly suggests that this is an area of potential damage as a result of the presence of ammonia.

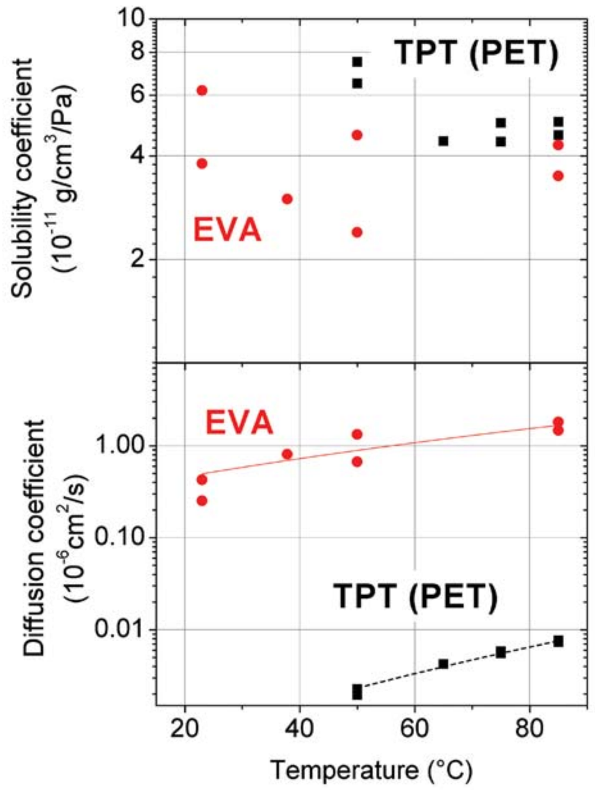

Figure 2. Diffusion and solubility coefficients of ammonia in EVA and TPT, with the latter evaluated as a single material. Graph lines are Arrhenius fits to the data (activation energies E_A = 17.2kJ/mol for the diffusion coefficient of EVA and E_A = 32.5kJ/mol for TPT (PET)).

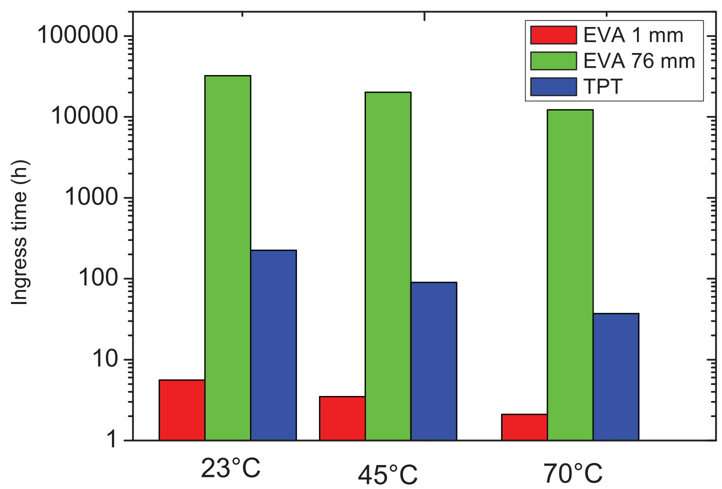

Figure 3. Ammonia ingress times for different distances in materials, extrapolating the value for TPT/PET at 23°C.

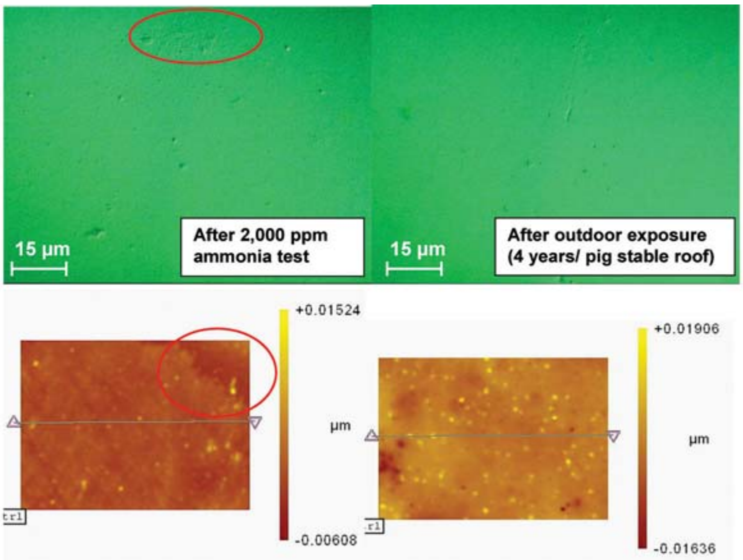

Figure 4. Light microscopic and white-light interference microscopy images (63µm × 47µm) of PV module front glass after preliminary module tests (up to 2,000ppm ammonia at 70% humidity and 70°C for 840 hours) and outdoor exposure (four years on top of a pig stable roof).

As the outdoor-exposed module from the pig stable did not show any signs of front-glass corrosion, realistic field conditions do not seem to implicate a significant damage of the module front glass. The situation is, however, very different in the case of antireflective-layer-coated (ARC) front glasses, as the visual appearance of such modules could degrade much more severely due to glass corrosion.

Glass corrosion results from the fact that ammonia forms a base according to the following reaction:

$$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^- \qquad (2)$$

The degree of degradation is related to the concentration of hydroxyl ions, $c(OH^-)$, which may be assumed to be proportional to:

$$c(OH^-) \propto \sqrt{c(NH_3)c(H_2O)} \qquad (3)$$

where $c(H_2O)$ and $c(NH_3)$ are the water (vapour) and the ammonia concentrations, respectively.

Soda-lime glass is currently being used as the front glass material by the vast majority of PV module manufacturers (as is the case for ARC glasses). Therefore, glass corrosion is expected to be a prevalent feature. Glass corrosion of soda-lime glass in an alkaline environment is mediated by the hydroxyl ion through the disruption of siloxane bonds [9]. In order to model glass corrosion depending on ambient conditions, the corrosion rate r_{glass} may be assumed proportional to the hydroxyl ion concentration with an Arrhenius dependence on temperature:

$$r_{glass} \propto exp(E_A^{gl} / K_B T)\cdot\sqrt{c(NH_3)c(H_2O)} \qquad (4)$$

For the activation energy E_A^{gl} of glass corrosion in alkaline solutions, a value of 158kJ/mol has been determined [10]. However, the temperature dependence of ammonia-induced glass corrosion of glass-lined steels may be described by an activation energy closer to that observed in the acid-driven corrosion of soda-lime glasses, namely 79kJ/mol [11,12]. Both values are quite high and implicate a large acceleration in terms of increasing the temperature for an accelerated lifetime test.

PV Modules

"Glass corrosion of soda-lime glass in an alkaline environment is mediated by the hydroxyl ion through the disruption of siloxane bonds."

Therefore, any accelerated test will increase the glass-corrosion damage much more significantly than other mechanisms with lower activation energy. As a result, it becomes clear why samples from accelerated ammonia tests (as that discussed above) show signs of glass corrosion whereas outdoor-exposed samples do not (as in Fig. 4). The same applies, incidentally, to the classic damp heat test, where a disproportionate acceleration of front glass corrosion should also be expected (however, an acid-driven leaching of the surface is more likely in this case).

Damage mechanism: polymer degradation

Several polymer components of PV modules as used by SCHOTT Solar were subjected to highly accelerated ammonia life test (50,000ppm/85°C/100% relative humidity/84 hours). Attenuated-total-reflection infrared (ATR-IR) analysis of the respective materials did not show major degradation of any material investigated, which included cables, the junction box, adhesives and back-sheet materials. Minor modifications were noticed in the ethylene vinyl acetate copolymer used for encapsulation. As shown in Fig. 4, although the main peaks do not change, a small peak around 1,795cm^{-1} disappears upon ammonia treatment, both for cured and for uncured material.

This peak is very likely a signature of the C=O double bond as it is shifted versus the main C=O peak of vinyl acetate (1,735cm^{-1}). As a result, the peak is assumed to be associated with an additive, possibly a peroxy esther which may be

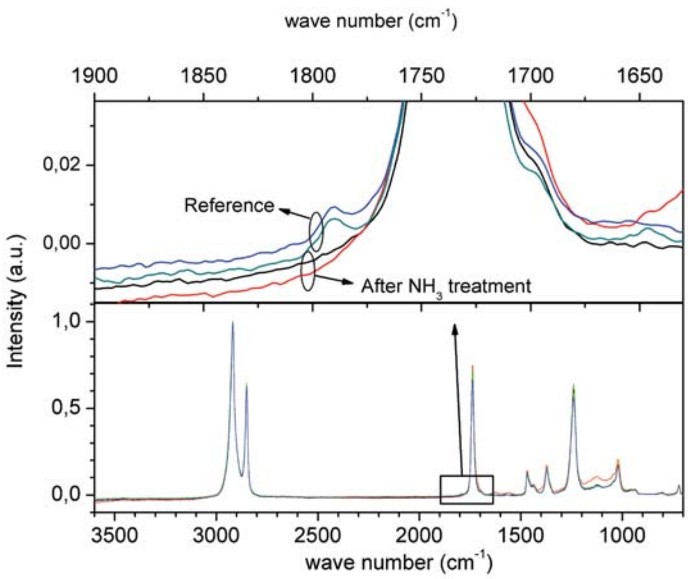

Figure 5. ATR-IR spectra of ethylene vinyl acetate copolymer cured and uncured with and without a highly accelerated ammonia life test (50,000ppm ammonia).

used as a curing agent. The respective chemical compound degrades in the highly accelerated ammonia life test.

From the experimental findings, degradation of polymer components may be identified as additional potential failure mechanisms brought about by the presence of ammonia. The environment most likely to result in the activation of the degradation mechanism of polymers in ammonia (i.e. alkaline) is the saponification reaction, i.e. the hydrolysis of an ester to form an alcohol and the anion of a carboxylic acid. This can occur in ethylene vinyl acetate copolymers and their additives as well as in other polymer components of the module. The disappearance of the 1,795cm^{-1} peak in the IR spectrum of the encapsulant material (see Fig. 4) might be a signature of this type of reaction – presumably only for an additive and not for the polymer backbone. Similar to glass corrosion, the saponification reaction is mediated through hydroxyl ions. Therefore, the dependence of the respective degradation rate r_{polym} may be assumed to be similar to equation (4):

$$r_{polym} \propto exp(E_A^{po} / K_B T) \cdot \sqrt{c(NH_3)c(H_2O)} \quad (5)$$

The activation energies of different types of saponification reactions range between 40 and 42kJ/mol [13].

Test designs

Various norms can be found for corrosion testing of products by corrosive gases like H_2S, NO_2, Cl_2, and SO_2 (DIN EN 60068-2-60), or by SO_2 with a cyclic temperature program (DIN EN ISO 3231, ISO 6988-1985 and DIN 50018). DIN 50916:1985 is presumably the only norm referring to a test with ammonia (generated by an NH_4Cl-NaOH solution with defined pH); it is designed to test stress-corrosion cracking of parts made of copper alloys. No explicit norm is available for the corrosion testing of PV modules subjected to ammonia; however, an international standard is currently under development (Ammonia corrosion testing of photovoltaic (PV) modules, 82/600/NP). Some module manufacturers claim to pass an ammonia test according to DIN 50916:1985.

Various designs for testing the impact of ammonia atmosphere on PV modules have been proposed of late, some of which are listed in Table 1. In the DLG test centre, a test design was proposed for best comparison with a reference scenario taking the ammonia ingress times and the different degradation mechanisms into account. Other proposed tests involve cycling conditions between elevated temperatures (40°C as in ISO 6988-1985 or 45°C) and room temperature. Table 1 outlines details of these test conditions. The highly accelerated ammonia life test developed at SCHOTT (HAALT) is also included (Test design no. 4); the respective conditions can, however, only be applied to small components (cells, polymers...) because the duration required for ammonia ingress into a complete PV module would introduce a too long a time lag.

These different test designs may be compared to a reference scenario of 20 years of outdoor exposure. The following conditions were assumed as typical of Central Europe: an average temperature of 12°C, an average relative humidity of 80%, 1,000 hours of direct sunshine with an assumed module temperature of 60°C [14], and, as a 'worst case' scenario, an ammonia concentration of 50ppm. This ammonia concentration is the maximum value occurring in livestock stables [15]; a similar value (46ppm) was reported by Althaus et al. [4]. In Germany, 20ppm is the maximum value permitted by the official regulatory bodies [16].

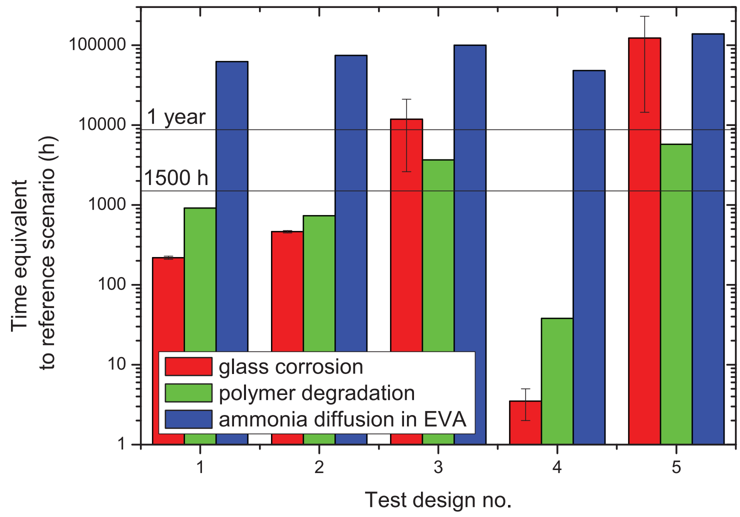

Figure 6. Times equivalent to reference scenario for different test designs (see Table 1).

"Test designs #3 and #5 clearly fail to reach equivalence to the reference scenario within a reasonable test time."

Fig. 6 depicts calculated times for which the different test designs have reached an equivalent degradation status to the reference outdoor scenario. The three values reflect the equivalence with respect to glass corrosion (Equation 4), polymer degradation (Equation 5, cf. Figs. 2 and 3) and diffusion within EVA, respectively. The DLG test design (#1) with a duration of 1,500 hours therefore relates to realistic outdoor conditions and exceeds the 20-year reference scenario regarding the two relevant damage mechanisms.

Test designs #3 and #5 clearly fail to reach equivalence to the reference scenario within a reasonable test time. This is owing to the fact that the temperatures chosen are (too) low (30–45°C) in comparison to the real module temperatures achieved in the field during solar irradiation. For test design #2, whether or not an equivalence to 20 years of outdoor exposure can be reached depends on the chosen time span; for example, 160 hours is too short a time span for correct comparison.

All test designs (including the DLG test) failed to reach equivalence regarding the ammonia diffusion in EVA, which may be relevant at the front side of embedded cells. This is due to the fairly low activation energy for ammonia diffusion within EVA. As a consequence, after any of the proposed tests, the possible damage mechanisms at the front side of the solar cells will not be distributed locally as was the case after the reference scenario. However, this is not a huge drawback: if damage mechanisms are indeed present, they would still be visible or otherwise discernable through their action near the rims of the cells.

Ammonia ingress times through the back sheet, however, do need to be considered. With respect to inner module components, a time lag of around 40 hours (DLG), 50–90 hours (test designs #2 and #3), or 170 hours (DIN 50916) has to be taken into account (cf. Fig. 3). For test design #5 (DIN 50916) in particular, this is a substantial fraction of the total test time, so a correct evaluation of degradation within the module is additionally impeded. As a consequence, the DIN 50916 test is clearly unsuitable for assessing the ammonia resistance of PV modules. In the DLG test design, sufficient time is given for ammonia to reach inner module components and to correctly assess their ammonia resistance.

Some uncertainties are associated with the reported activation energies, such as measurement errors (as in the

	$[NH_3]$	humidity	Temp.	time
1.	DLG test (750ppm)	70%	70°C	1,500 h
2.	6,667ppm	100%	60°C	160 h
3.	1,200ppm	85%	45°C	?
4.	HAALT (50,000ppm)	100%	85°C	84 h
5.	DIN 50916 (7,250ppm)	100%	30°C	672 h

Table 1. Different proposed test designs. For some cyclic tests, only the maximum temperature is reported; for test design #2, see [4,17].

determination of the diffusion coefficients) and the identification of the correct damage mechanisms. Therefore, for any test design, it is safest to choose conditions not too far from the estimated maximum temperature in the field (i.e. ~60°C [14]) and, for acceleration, slightly higher – this was the reasoning behind choosing a temperature of 70°C for the DLG test design.

A cyclic test (as in the proposed variants #2 and #3) may amplify the degradation due to condensation phenomena and may thus be closer to the realistic conditions. However, even under non-cyclic test conditions, capillary condensation occurs within gaps and cavities of a PV module such that the basic difference in the occurrence of damages due to the condensation phenomena is not assumed to be large for PV modules.

Conclusions

Reactive gases introduce a new challenge for the life testing of PV modules. Ammonia gas is the first in line for consideration due to the prevalence of this gas in a major area of the application of PV modules: the agricultural environment, where ammonia gas evolves in substantial amounts in livestock farming. More and more module manufacturers have been reacting to this trend and have been ensuring that their modules are being qualified with respect to ammonia resistance. The most relevant damage mechanism seems to be polymer degradation which affects encapsulant, back sheets, junction boxes, cable sheathing and adhesives, etc. A number of different test designs have been proposed and applied to modules from different manufacturers, some of which fail to reach equivalence with a 20-year reference scenario.

Interestingly, it turns out that double glass PV modules (e.g. with both front-side and rear-side glass) bring certain advantages in a corrosive gas environment versus modules with a polymer (laminate) back side. Not only is a polymer-based module more susceptible to damage from ammonia, but they tend to be basically 'open' to permeation by volatile substances. This advantage of double glass modules could very well be transferable to other corrosive environments such as volcanic sites or in the vicinity of exhaust pipes of fossil fuel burning sites, including motor highways or railway trails. In the future, the prevailing areas of deployment of PV modules will dictate whether the damage caused by other corrosive gases will need to be taken into the consideration for module lifetime estimation.

References

[1] pwc.de, January 2011, "Germany's photovoltaic industry at the crossroads", [available online at http://www.pwc.de/en/energiewirtschaft/die-deutsche-photovoltaik-branche-am-scheideweg.jhtml].

[2] Hensmann, L. 2005, Master's thesis, Georg-August-Universität Göttingen, Germany.

[3] Symonds, R.B. et al. 1994, "Volcanic gas studies: methods, results, and applications", *Volatiles in Magmas: Mineralogical Society of America Reviews in Mineralogy*, Vol. 30, pp. 1–66.

[4] Althaus, J. & Mooslechner, J. 2010, *Proc. 25th EU PVSEC*, pp. 4011–14.

[5] DECHEMA e.V. 2008, *Corrosion Handbook Online*, DOI: 10.1002/9783527610433.

[6] Kempe, M.D. 2006, *Solar Energy Materials & Solar Cells*, Vol. 90, pp. 2720–2738.

[7] Weber, U. et al. 2010, *Proc. 25th EU PVSEC*, pp. 4007–4010.

[8] Bange, K. et al. 2002, *Glass Sci. Technol.*, Vol. 75, pp. 20–33.

[9] Paul, A. 1977, *J. Mat. Sci.*, Vol. 12, pp. 2246–2268.

[10] Molchanov, V.S. & Prikhidko, N.E. 1957, *Russian Chemical Bulletin 6*, pp. 1170–1184.

[11] Lanford, W.A. et al. 1979, J. *Non-Cryst. Solids*, Vol. 33, pp. 249–266.

[12] Viscus Group [available online at http://www.viscusoil.com/glassline/others_glasslinedcorrosionresistance.htm].

[13] Smith, H.A. & Levenson, H.S. 1939, *J. Am. Chem. Soc.*, Vol. 61, pp. 1172–1175.

[14] Auer, R. & Schmidt, U. 2007, *Proc. 22nd EU PVSEC*, p. 2779.

[15] KTBL-Schrift 406: Emissionen der Tierhaltung, Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL), Darmstadt (2006).

[16] KTBL-Schrift 447: Handhabung der TA Luft bei Tierhaltungsanlagen, Kuratorium f. Technik u. Bauwesen in der Landwirtschaft (KTBL), Darmstadt (2006).

[17] Althaus, J. 2010, *ep Photovoltaik*, Vol. 67.

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Market Watch

Encapsulation polymers – a key issue in module reliability

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ABSTRACT

The majority of solar module manufacturers use ethylene-vinyl acetate (EVA) copolymer foils as the encapsulant material for solar cells and thin-film modules. Because EVA needs long processing times for curing, thermoplastic process materials that do not employ chemical cross-linking have been coming more and more into focus in the encapsulation sector. This paper takes a look at the mechanical temperature-dependent properties of a variety of such materials.

Introduction

From a processing point of view the advantage of a thermoplastic polymer without chemical cross linking is that the material just needs to be molten up, flow around the inner module components and cooled down. Thus, a repeated lamination cycle is possible whereby the polymer is again made molten and imperfections could be removed. Depending on the viscosity of the polymer melt, holding and pressing times during vacuum lamination can be reduced significantly.

"Polymers show a strong dependancy over temperature in their mechanical properties such as Young's modulus."

Putting aside the advantages and disadvantages of their specific aging behaviour, different encapsulant materials show a variety of mechanical properties that directly affect the reliability of module components. During operation or certification procedures modules are exposed to constant or cycling mechanical or thermo-mechanical loads resulting in stress in module components, such as glass, solar cells or copper ribbons, as well as interfaces. Polymers show a strong dependancy over temperature in their mechanical properties such as Young's modulus. Since solar modules can be defined as laminate structures from a mechanical point of view, the shear-taking polymeric interlayer mainly influences the deflection of a solar module under load. Numerical simulation techniques can be applied to estimate the influence of the interlayer properties on the mechanical response of the module and its components.

In combination with adequate characterization techniques such as Dynamic-Mechanical Analysis (DMA), material parameters can be determined easily for a wide temperature range. In this work, the mechanical temperature-dependent properties of Polyvinyl-butyral (PVB) Trosifol Solar R40 (Kuraray), Thermoplastic Silicon Elastomer (TPSE) Tectosil 185 (Wacker Chemie) and EVA Vistasolar 496.10 (Etimex) will be discussed.

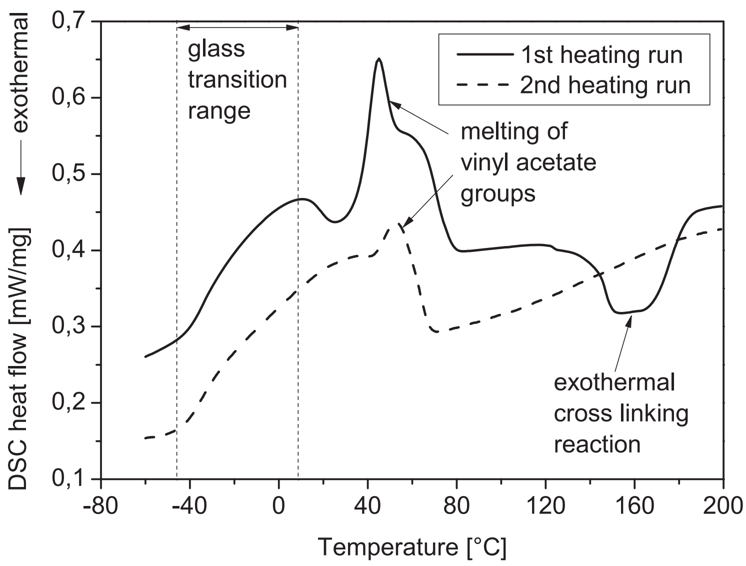

Figure 1. Heat flow diagram of an EVA encapsulant at a heating rate of 10K per minute.

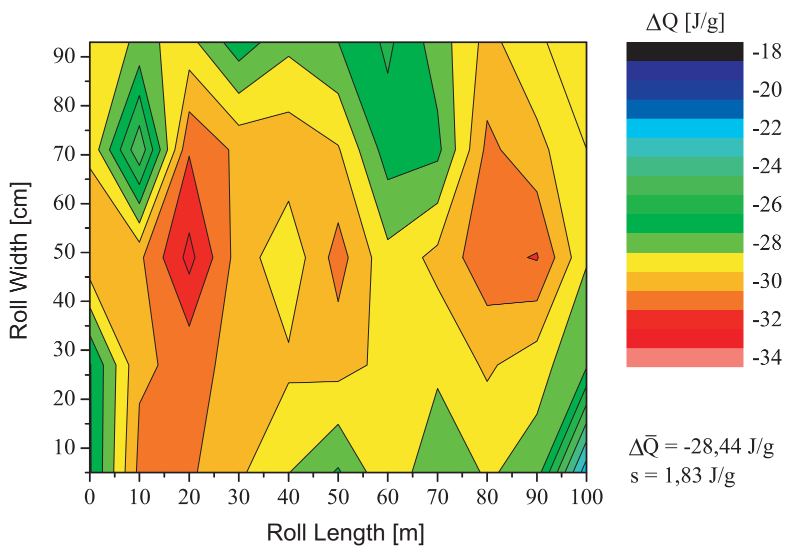

Figure 2. Total heat released during exothermal curing reaction ΔQ for an EVA encapsulant along foil dimensions (standard EVA, no Etimex material).

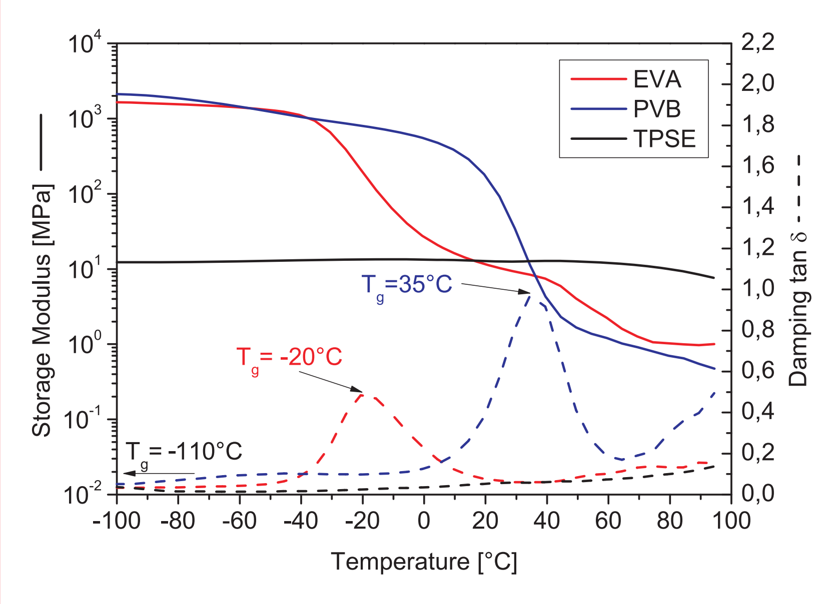

Figure 3. Storage modulus over temperature for different laminated encapsulate foils.

EVA curing at a glance

Differential scanning calorimetry (DSC) can be used to characterize the curing of EVA. This method is well established in polymer science and can give results of the onset of temperature-induced cross-linking. Covalent cross-linking of EVA is achieved by activation of cross-linking agents that are incorporated into the polymer foil and results in a non-meltable elastomeric molecule network. The principal operating mode of DSC is the measurement of heat that is taken or released by the analyzed material during physical or chemical transitions or reactions [1].

A typical heat flow diagram the first and second heating runs for a typical EVA encapsulant is shown in Fig. 1. For the first heating run of the uncured material, the area of glass transition can be found in the temperature range from -40°C to 10°C as a strong change in specific heat capacity. Between 40°C and 80°C, the melting of vinyl acetate groups occurs, followed by the exothermal reaction of the cross-linking. Given that this reaction peak is not present in a second heating run, it is clear that the cross-linking agent becomes totally consumed at the end of the first heating run.

The initial phase of the exothermal reaction can be found at around 120°C as a deviation of the base line. This point represents the minimum temperature required to start a measurable reaction. Additionally, the total heat that is released can be an integral of the heat flow, representing the peak area above 120°C. Taking into account that the total amount of heat which is released during the curing process directly corresponds to the concentration of cross-linking agent in the sample, an estimation of EVA polymer foil quality is possible.

For example, the results of DSC measurements along the length and width of an EVA foil are shown in Fig. 2. It is clear from this schematic that the cross-linking agent does not disperse well in these types of foils. The reason for this is the method in which the additives are incorporated into the melt during foil manufacturing, details of which shall not be discussed here. The degree of cross-linking, which is a function of the amount of cross-linking agent, directly affects polymer properties; therefore, lamination of solar modules can result in locally distributed properties. It was found that the stiffness of the laminated foil, which was determined by tensile testing, did not change after varying holding times during lamination between 5 minutes and 60 minutes. So it can thus be assumed that the distribution of stiffness over the dimensions of an EVA foil can be assumed as statistically homogeneous. The effect of the remaining cross-linking agent – if not totally consumed – on the local chemical aging in solar modules is still uncertain and is a current topic of research and discussion.

Polymer stiffness

One of the most important parameters for characterizing the elastic load-deflection behaviour of solar modules under distributed load is the Young's modulus, or stiffness, of the polymeric interlayer. Several characterization techniques, such as tensile, shear or bending test, can deliver information regarding elastic load-deformation behaviour. One disadvantage of these static tests is that determination of temperature-dependent properties is very time-consuming. In response to this, DMA measurements were carried out in tensile mode using a frequency of 1Hz on rectangular laminated polymer stripes. The temperature was swept between -100°C and 100°C and the glass transition temperature T_g could be determined using the maximum in damping. One resulting parameter of these tests is the storage modulus E' representing the elastic part of the deformation. For low frequencies, this modulus can be equalized with the static modulus E, which is a result of standard tensile-tests and is used as an engineering parameter for calculation of solar module mechanics.

Fig. 3 shows the storage modulus over temperature for all three polymer types tested. A strong temperature-dependence of stiffness was found for PVB and EVA. The glass transition or softening temperature, as the peak maximum in tan δ, was determined at -20°C for EVA and 35°C for PVB. For TPSE, this characteristic temperature is below -100°C and therefore was not detectable during this test. While a rise in temperature results in a significant loss in mechanical properties for PVB and EVA, especially in the region of glass transition, TPSE shows nearly constant mechanical properties over the relevant temperature region of -40°C to 85°C.

Module mechanics under load

From a mechanical point of view, a thin-film module is essentially a laminated piece of glass. The encapsulant acts as an adhesive that establishes a so-called shear bond between the glass panes and therefore the mechanical properties of the

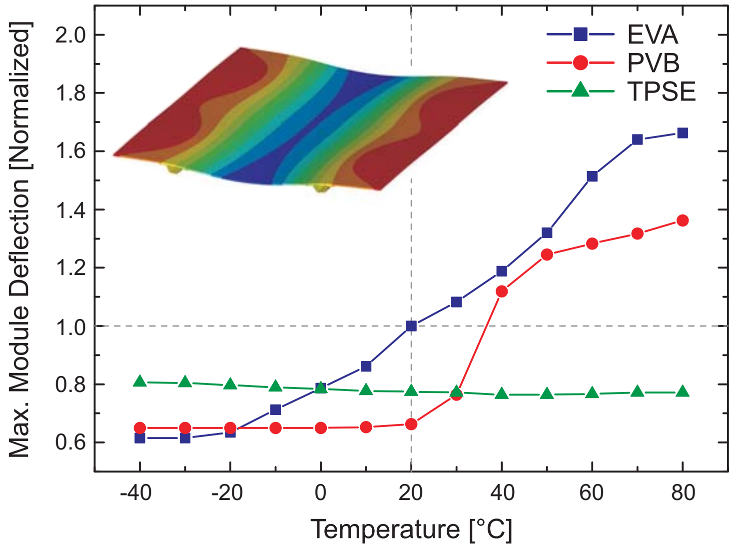

Figure 4. Maximum module deflection for different encapsulants at various temperatures of a common thin-film module with back rail support, normalized for an EVA at 20°C.

Figure 5. Large climate chambers conform to IEC standards at Fraunhofer CSP.

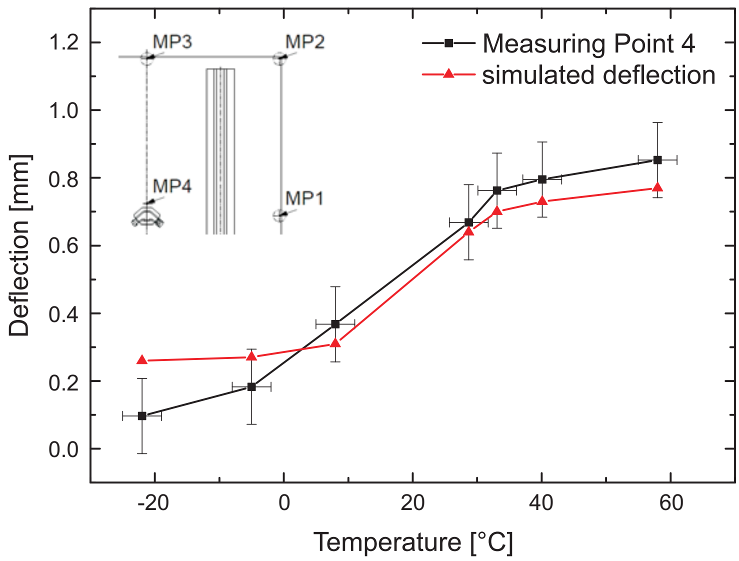

Figure 6. Measured maximum deflection of a thin-film module with PVB encapsulant and back rail support (load: 760Pa).

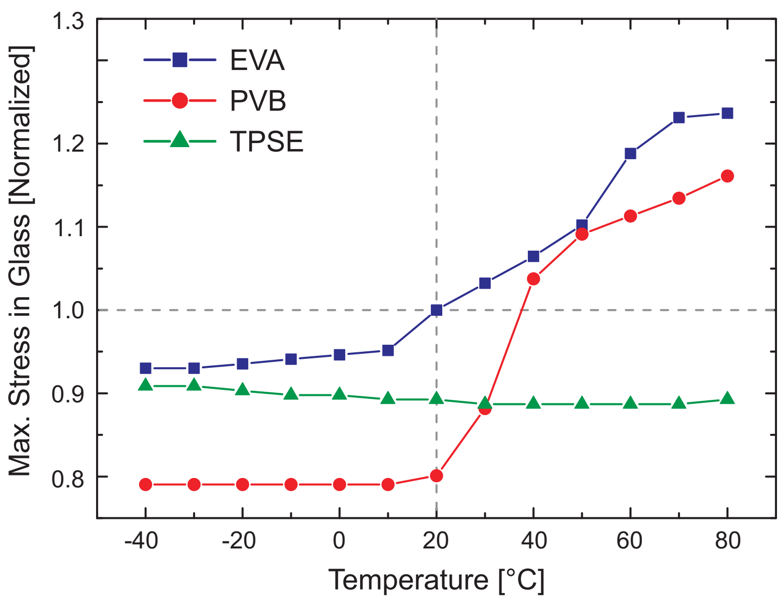

Figure 7. Variation of the normalized maximum tensile stress in glass of a thin-film module with back rail support, normalized for EVA and a temperature of 20°C.

encapsulant directly affects the behaviour of the mechanical system [2]. In order to mechanically qualify a module, it has to withstand a distributed load of 2.4kPa in compression as well as suction in three cycles for one hour according to the IEC 61646 standard. This represents a wind speed of 130km/h with a factor of three. Higher requirements involve the testing of a snow load of 5.4kPa. These tests

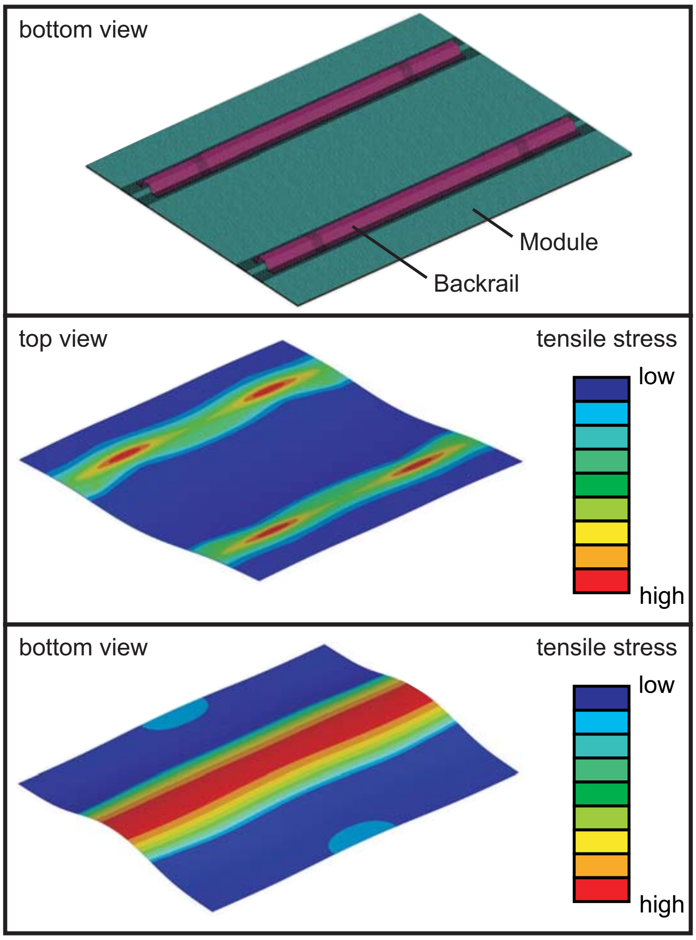

Figure 8. Generic first-principle stress-contour plot of a back rail-supported layered glass module under distributed load.

are performed at room temperature. A solar module experiences a wide range of temperatures during operation. High temperatures above 80°C are possible under intensive solar radiation [3], while snow actually is present below 0°C. This means that the only attention that is paid to the temperature dependence of the encapsulate stiffness is covered by the security factor.

> "With the help of the finite element method (FEM), the deflection and mechanical stresses in the module can be simulated for different load situations and temperatures."

For this reason, the mechanical system is actually very sensitive in the range of the material properties of the encapsulant. With the help of the finite element method (FEM), the deflection and mechanical stresses in the module can be simulated for different load situations and temperatures. Since the absolute numerical results are dependant on various parameters such as module size and mounting, the following results are normalized to room temperature values of EVA for a standard 3D-FE-model developed at Fraunhofer CSP.

Fig. 4 shows the normalized maximum deflection of a thin-film module (2.2 × 2.6m) with back rail support for different interlayer materials. At low temperatures, most polymers show high stiffness values, resulting in a small maximum deflection of the module.

On the other hand, the low stiffness at elevated temperatures leads to an increased deformation, since it is easier for the glass panes to act against each other and cause higher interlayer shearing. Comparing PVB and EVA with TPSE interlayer modules, the deflection stays nearly constant for the whole temperature range, which corresponds to the results in Fig. 3.

A special experiment was performed with a view to verifying these results. This approach involved the mechanical load testing of a thin-film module in a climate chamber (Fig. 5). The measured deflection for the measurement point in the centre of the module along with the corresponding simulated deflection is in Fig. 6, showing that the results of the simulation and experiments corresponded well in the temperature range between -20°C and 60°C.

The dependency of module deformation from temperature is an indicator that the stresses in the glass are also affected. This effect can be seen in Fig. 7, which depicts the normalized maximum tensile stress in the glass over temperature. The results of

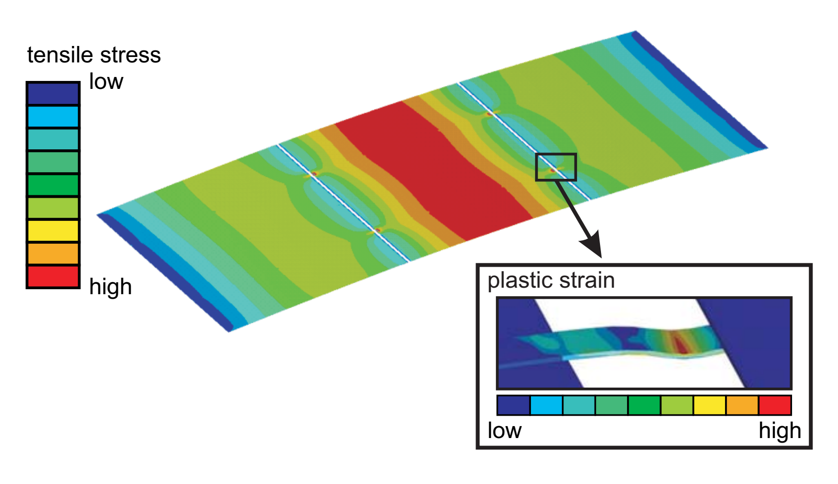

Figure 9. Finite element result of a laminated cell string showing first-principle stress in the silicon. Inset: plastic strain in copper ribbon.

this simulation showed that higher polymer stiffness lowers the stress in the glass, and vice versa. For the analyzed PVB, the glass transition is located at room temperature, which can lead to a wide range of results in the fail/not fail statistics as the temperature interval between 20°C and 60°C results in a glass change of about 31%.

> "TPSE and EVA experience a minor creep deformation due to the physically or chemically cross-linked molecular structure."

Solar-grade EVA shows a broader range of softening but results in similar effects. In this example, the induced stress for an EVA laminate at 60°C is 19% higher than stresses seen at 20°C and -20°C. Stiffer EVA leads to 6% lower stresses. As the stiffness of the TPSE encapsulate is nearly constant over the investigated temperature interval, the maximum stress variation in the glass is relatively low. Fig. 8 illustrates a characteristic stress distribution in the glass for a thin-film module with back rail support under distributed load. In those calculations the back rail support was not allowed to deflect. The highest stresses are located at the end of the back rails on the front side and between the back rails on the bottom side of the module.

Comparing the materials at a standard testing temperature of 20°C, one may assume that the PVB is superior to the other materials in the mechanical load test. This consideration is only valid for short-term behaviour and does not account for the strong time-dependant deformation behaviour of the materials, particularly PVB. The PVB tends to creep intensely above glass transition temperature [3]. In contrast, TPSE and EVA experience a minor creep deformation due to the physically or chemically cross-linked molecular structure.

Mechanical stress in solar cells

An important issue in assessing the long-term reliability of crystalline solar modules in terms of yield is the consideration of the reliability of module components such as copper ribbons and solar cells. Since they are encapsulated into the polymeric matrix, the load, which is applied to those components, is strongly dependant on the mechanical properties of the encapsulant material. Over the past few years, the thickness of solar cells has been decreased rapidly from 300µm to 180µm, while further developments down to 120µm are planned. This, however, increases the tendency of solar cells to form cracks, which in the long term will decrease module efficiency and subsequently yield. Incorporating the specific processing-dependant material properties of the encapsulate polymer and the module structure – including each component and material layer – allows the investigation of loads on solar cells with a mechanical model. These loads are brought about by a range of external conditions such as wind, snow or temperature changes. Recent studies have seen the development of a modelling concept allowing various investigations into the mechanical behaviour of the module systems [4]. The research was focussed on a standard module layout consisting of a front glass sheet, an EVA encapsulant and a polymeric back sheet. In order to gain an understanding of the basic mechanical behaviour, a laminated specimen consisting of a single solar cell string under bending support was investigated under distributed load by finite element analysis. These calculations show that highest mechanical stress occurs in the centre cell (Fig. 9). Moreover, a great deal of attention must be paid to the high strain at the interconnectors, as cyclic loading due to temperature changes, wind or snow loads can result in local hardening and breakage [5,6].

The results of the simulations show that it is important to implement the temperature-dependant mechanical properties of the polymer. As we have shown in [4], the stiffness change of the EVA between -20°C and 40°C and the solar cells themselves have an impact on the module deflection. This effect is comparable to thin-film modules, with the difference that the shear bond partners are now the cell string and the glass. The development of the deflection of the laminate shows a similar behaviour pattern. Incorporating solar cells into a module can lead to a decrease of laminate deflection of more than 20%. Furthermore, the thickness of the solar cells influences the stiffness

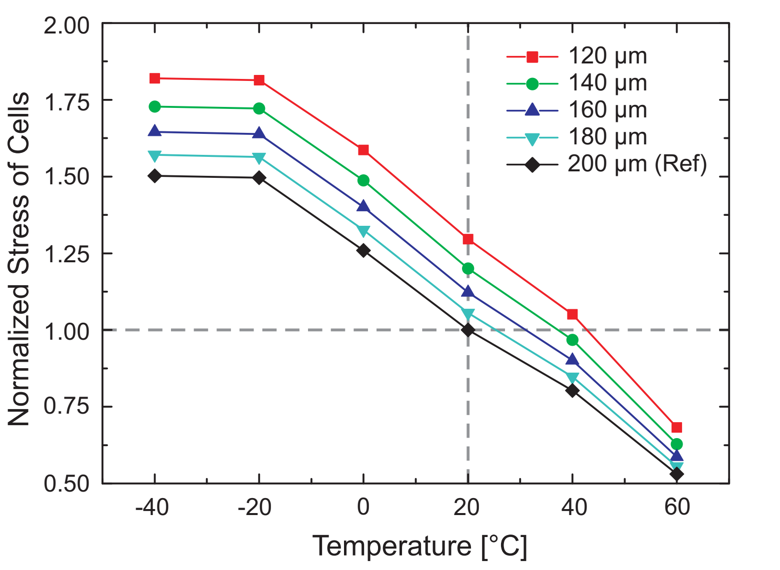

Figure 10. Dependency of the maximum-principle stress in solar cells on temperature and cell thickness, normalized for a cell thickness of 200µm and 20°C [4].

of the laminate. A second study, which focuses on tension stresses in the solar cells, shows an equivalent behaviour over temperature (Fig. 10). At -20°C, the stress in the silicon is increased by 50% compared to room temperature. As the reduction of the thickness of the solar cells lowers laminate stiffness, module deflection increases, leading to higher stresses in the solar cells.

Simple stress-strain diagrams over the cross-section can deliver an insight into this mechanical behaviour. As mentioned, module components like solar cells are coupled by the polymer to the glass front sheet. During mechanical loading, the module glass bends, leading to tension strain at the adverted side of the load. Due to the perfect coupling between polymer and glass, this strain is consequently applied to the polymer/glass interface. Since the stiffness of the encapsulant is usually extremely low, a large amount of this strain can be compensated. Nevertheless, some strain is transferred to the solar cells, setting them under tension load.

Armed with this mechanical understanding, it is obvious that the stiffness of the polymer is crucial to the stress in the solar cells. Reliability studies at room temperature do not apply for other temperatures when using polymers. These materials exhibit a large transition of material properties within the operation temperature range of solar modules that directly influences module mechanics.

References

[1] Ehrenstein, G.W. 2004, *Thermal Analysis of Plastics*, Hanser, Munich.

[2] Dietrich, S. et al. 2008, "Mechanical assessment of large photovoltaic modules by test and finite element analysis", *Proc. 23rd EU PVSEC*, Valencia, Spain.

[3] Miller, D. et al. 2010, "Creep in photovoltaic modules: examining the stability of polymeric materials and components", *Proc. 35th IEEE PVSC*, Honolulu, Hawaii, USA.

[4] Dietrich, S. et al. 2010, "Mechanical and thermo-mechanical assessment of encapsulated solar cells by finite-element-simulation", *Proc. SPIE-Optics and Photonics*.

[5] Meier, R. et al. 2009, "Thermo-mechanical behaviour of copper ribbon materials", *Proc. 24th EU PVSEC*, Hamburg, Germany, pp. 3413–3419.

[6] Meier, R. et al. 2010, "Thermal and mechanical induced loading on cell interconnectors in crystalline photovoltaic modules", *Proc. 25th EU PVSEC*, Valencia, Spain.

About the Authors

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Sascha Dietrich studied mechanical engineering at the Leipzig University of Applied Sciences and University of Paisley/Scotland. His master's thesis at the Fraunhofer Institute for Mechanics of Materials (IWMH) investigated the reliability of silicon structures. Since 2008, he has been working at Fraunhofer CSP in the field of finite element simulations of photovoltaic modules and components and became head of the Module Reliability team in 2010.

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Closing the loop: using production testing and field failure analysis to build high-reliability solar panels

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ABSTRACT
Savvy solar panel manufacturers understand that wringing excess costs from every stage of the value chain is simply the price of admission to today's crowded market. They also know that reliability and quality are not only critical for delivering on a 25-year warranty promise, but also drive the true cost of energy over the lifetime of the system. This factor is becoming increasingly apparent, especially in industrial- and utility-scale solar projects, as they age and the power output of many lower quality systems begins to degrade to unexpected levels. Many of those systems used UL or IEC certifications as a proxy for good reliability. Unfortunately, UL and IEC certifications are primarily concerned with user safety, and are not rigorous enough to ensure trouble-free operation throughout the system lifetime. High reliability and quality require testing and manufacturing methods that go far beyond the certification tests.

Introduction

This article encapsulates what SunPower has learned from six years of producing silicon solar panels and from over a decade of fielding and maintaining systems with solar panels from more than a dozen different manufacturers in rooftop systems and solar farms. The closed-loop learning system described allows a manufacturer to turn the data collected from field failure analysis and each stage of testing into actionable information for improving both its panel design and manufacturing processes.

The closed-loop learning methodology

Today's solar panels are complex assemblies of metal, glass, plastic, semiconductors and adhesives that must deliver a 25-year warranty life (and usually a 30- to 40-year useful service life) in harsh rooftop environments, a task which can challenge even simple asphalt roofing materials. Building photovoltaic panels to this level of reliability requires a disciplined approach to taming the numerous subtle and not-so-subtle failure modes which arise from the thermal, mechanical, chemical, solar and electrical interactions that occur during their exposure to the elements.

The manufacturing environment is another complex factor in the reliability equation. Even subtle changes in a design or its materials and manufacturing processes can produce big changes in the end-product's reliability. In order to capture and correlate these changes with their effects on reliability, a rigorous quality control methodology has been developed that closely couples the design and supply chain management processes with qualification and production testing. In addition, a closed-loop learning process has been implemented that enhances traditional design and manufacturing quality control methodologies with a feedback loop that uses real-world data to constantly retune the quality cycle.

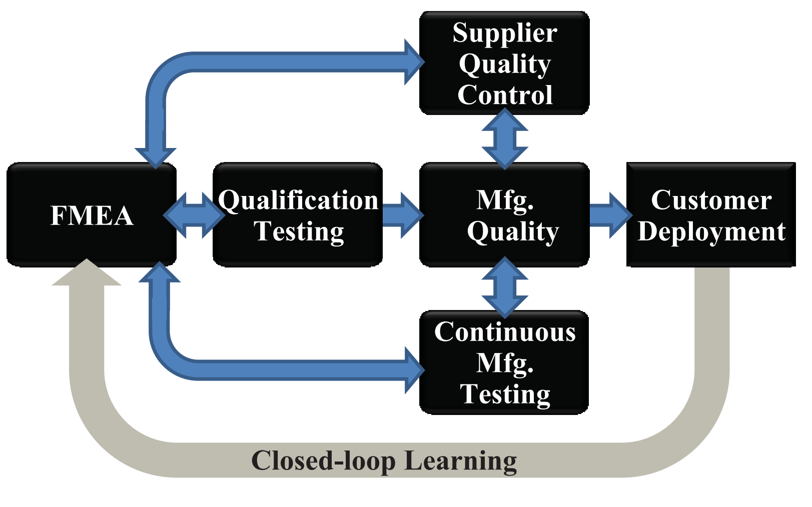

Figure 1. Adding closed-loop learning to the traditional quality control methodology.

The FMEA block

As with most modern QC systems, SunPower's process is built around a failure modes and effects analysis (FMEA) element, illustrated in Fig. 1. FMEA's function is to provide a rank-ordered list of all the known failure modes and their causal stresses that are the foundation of the design for reliability process. It also provides inputs for the qualification tests which will determine if the design of a new product or a product or process modification meets the functional and reliability requirements.

In a traditional FMEA, the failure mode list uses theoretical modeling and design test data (accelerated life and long-term testing) as its primary inputs. Closed-loop learning adds information that includes performance data and failure analysis results collected from operational customer sites. As will be discussed later, this long-term field data provide a critical feedback loop to further improve overall quality.

Constructing the FMEA

Specifications and functional requirements

In order to build an FMEA, one must start with a design concept, as well as a set of clearly articulated functional and reliability specifications. The latter lists all the functions that the product must deliver. For example, the defining functional requirements for a PV module backsheet might include the following:

- The design must provide electrical isolation between the back of the module and solar cells at 1000V.

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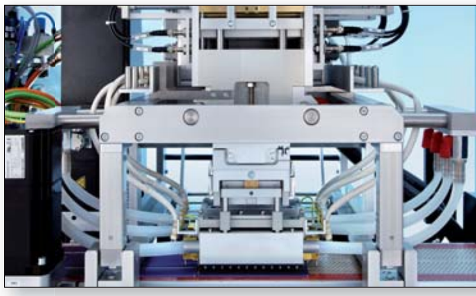

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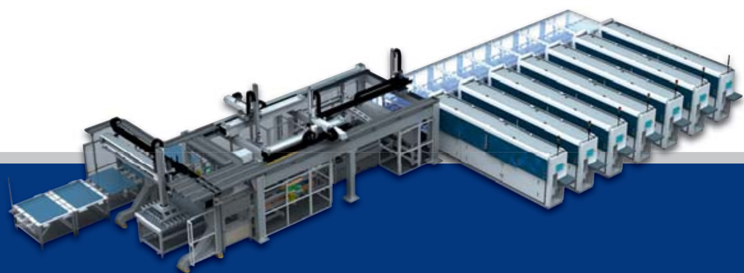

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Functional Requirement	Failure Mode	Effects of failure	Severity	Causes / Mechanisms of failure	Occurrence	Current design: Prevent / Detect	Detectability	RPN
Electrical isolation	J-box detaches from backsheet	Loss in power, increased leakage current, safety issue	10	RTV loses adhesion to backsheet due to surface properties	2	Test j-box and backsheet interlayer adhesion under hot-spot condition on cell on top of j-box with and without weights; test j-box and backsheet adhesion in high-temp and humidity environments	2	40
	Dielectric degradation	Leakage current, safety issue	10	Hot-spot creates burns on backsheet (insufficient temp resistance)	2	Heat soak at various temperatures to determine activation energy	2	40
				Moisture degrades insulating layer (hydrolytic embrittlement)	3	Damp heat testing; check for cracks and increased wet leakage current	1	30
				Growth of pinholes or increased conduction through pinholes	1	Wet leakage current test and optical inspection of backsheet surface as laminated, and post accelerated tests (e.g. DH, HF, TC)	1	10
				Acetic acid from EVA attacks backsheet	1	Test for various acid resistance of backsheet layers	1	10
	Dielectric separation (backsheet layers separate)	Leakage current, safety issue	10	Propagation of slit inside j-box where ribbons exit	2	DH2000, TC200	1	20
				Internal physical puncture	4	Wet leakage current test post various accelerated tests	1	40
				UV attacks individual layers or adhesives	1	Wet leakage current test post UV exposure (equivalent dose for 25 years)	1	10
				Bubbles, loss of interlayer adhesion	5	High-temperature test with and without hanging weight	1	50
Reflectivity	Colour changes	Power loss	3	UV attacks individual layers	3	UV exposure, Combined UV/DH exposure, outdoor exposure	2	18

Table 1. Excerpt of backsheet FMEA.

- The design must reflect more than 80% of irradiance incident on the cell-side surface.
- The design must shrink less than 0.5% during the lamination process along any dimension.

The FMEA also includes reliability specifications, a subset of the functional specifications, with detailed reliability requirements. Continuing with the backsheet example, some typical reliability requirements might include these prerequisites:

- The design must maintain a continuous electrical barrier (no cracks) with 99% likelihood after 25 years in each climate with cells that are at 1000V.
- The design must not bubble or delaminate with 99% likelihood after 25 years in each climate with cells that are at or below 110°C during times of peak irradiance.

It should be noted that the FMEA's effectiveness depends on a clearly defined design concept that allows the requirements to be assessed against a concrete product design. For example, acquiring a good understanding of the interlayer adhesion performance of a backsheet, for example, requires a design that includes precise specifications of the materials, processes and adhesives used to build it.

Once the design and its attendant list of specifications are complete, the FMEA can be developed. Using these inputs, a group of subject matter experts brainstorms to create a prioritized list of all the possible ways a product might fail. This process is captured on a FMEA chart, as illustrated in the excerpt shown in Table 1 that deals with the electrical isolation requirements for the example backsheet that was discussed earlier.

A scoring system is used to create the prioritized list using the following criteria:

- The severity is the economic and safety impact when the failure does occur.
- The frequency is chance that the failure actually occurs.
- The detectability is the chance that the failure mode can be averted by detection and prevention before it reaches the customer (where a low score means high detectability).

The product of these values constitutes the risk priority number (RPN), which is used to prioritize what must be tested to qualify the product.

To enable a thorough qualification test plan (QTP), the FMEA must have thorough coverage over the possible field failure mechanisms and the combinations of stresses that cause them. The three primary approaches used by the subject matter experts are discussed in the following three sections: field experience, highly accelerated life testing, and theoretical understanding.

Field experience

Field experience is a critical element for identifying real design failure modes [1]. Historic failure data are used to set the initial conditions of the FMEA. To be most effective, an analysis must be performed on each type of field failure to determine what combination of stresses caused the failure, so a test can be devised to ensure the new product does not have the same weaknesses. Once in production, the closed-loop learning methodology uses new data from field failures of the current product to adjust the FMEA's risk priorities.

Test data inputs to FMEA – HALT

The second primary input for defining the FMEA is highly accelerated life testing (HALT), which applies combinations of stresses that are related to those seen in field deployment, but considerably beyond the levels anticipated in a normal operating environment. It is not a pass/fail test, but rather a test designed to activate the same failure modes one would encounter after many years in the field, in just a few days or weeks. HALT is a remarkably effective way to reveal unanticipated failure modes, and thus to identify and mend any weak points in the product design.

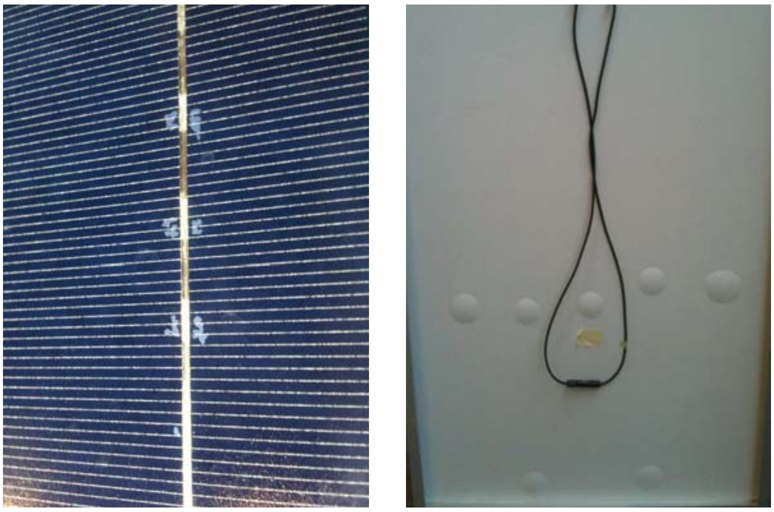

Figure 2. Front-contact-cell modules after a multistress simulator test. Solder flux residue along the interconnect ribbon caused delamination bubbles (left), while lay-up tape outgassing caused backsheet bubbling (right).

A useful example of HALT can be found in the regimen used to qualify other manufacturers' modules for deployment in projects installed by SunPower. This is necessary because the company builds more projects than it can supply with its own back-contact cells, necessitating the use of modules from different manufacturers. HALT and long-term testing both play essential roles in qualifying these modules.

The HALT regimen cited in this paper consists of several mechanical, thermal, and electrical stress sequences:

A five-day exposure in a multistress simulator. The modules under test are placed in a short-circuit configuration and exposed to a 1000W/m^2 of solar spectrum and an additional 150W/m^2 UV spectrum. The exposure is conducted in a controlled environment at 60°C and 55% relative humidity. These tests are especially effective at uncovering any meltdown or discolouration of encapsulants, browning or bubbling in backsheets, adhesive breakdown, and delamination along the front interconnect ribbons [2].

Adding some margin beyond what is strictly necessary often produces a design that is more cost-effective because it is more tolerant of contamination and other process issues. In addition, a robust design's wider tolerances in deviations from target processes are more easily detected before they result in field failure. Multistress

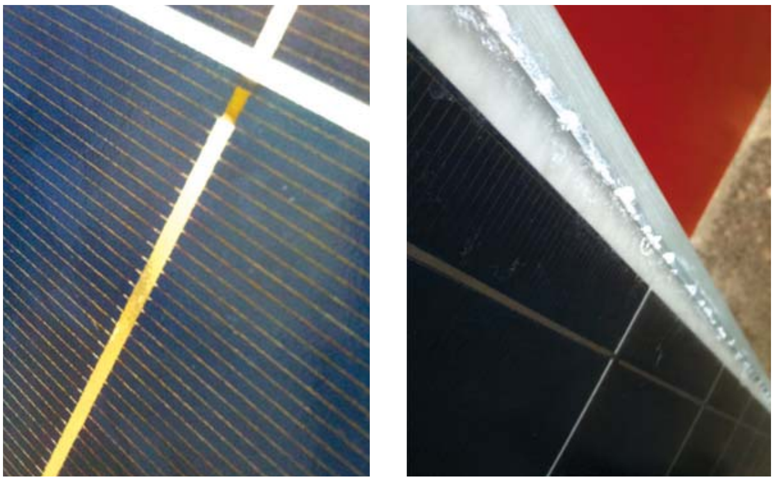

Figure 3. Following 600 hours of damp heat with voltage bias for front-contact-cell modules, corrosion can be seen on the front-contact metal (left). The right-hand picture shows the view looking down the edge of the aluminium frame that surrounds the laminate glass.

simulation testing created the front delamination on the cell shown in Fig. 2, a condition which may be due to solder flux residue. This indicates a manufacturing process control problem or a material compatibility problem and must be solved.

A five-day oven test. In some cases, this is used as an easier and lower-cost test that stimulates similar delamination and bubbling defects as the multistress simulator.

A 600-hour exposure to damp heat and electrical bias. The modules are placed in an 85°C environment at 85% relative humidity with a 1000V bias placed between the cells and the grounded frame. Because the high bias voltage accelerates any electrochemical corrosion or migration effects, this test is excellent for uncovering aging phenomena such as series resistance increases caused by electrolytic corrosion of metal lines or degradation of the Si-metal interface. For example, the corrosion visible on the metal of front-contact cells in Fig. 3 is responsible for causing an increase in series resistance and a decrease in efficiency. The cells' back-contact system appears to be significantly more resistant to electrolytic corrosion because most of the cell's back surface is plated with 40μm-thick copper finger conductors that have a much larger cross-sectional area.

Dynamic load testing combined with temperature cycling. Company protocol calls for 1,000 alternating cycles of mechanical pressure on each surface at ±2400Pa to simulate standard wind load, followed by four temperature cycles between -40°C and 60°C. This is very effective for investigating cell cracking [4], and the interconnect-ribbon-to-silicon wafer solder bond's ability to withstand repeated mechanical stress [5]. For front-contact cells, the copper interconnect ribbons must be soldered onto the silicon wafer at elevated temperatures. Under these conditions, the coefficient of thermal expansion mismatch between the copper and the silicon causes thermal stresses to accumulate at the interface. If not created with well-controlled processes and materials, the solder bond can be too strong, causing a phenomenon known as 'cratering,' where small cracks form in the cell underneath the ribbon or the structure becomes too weak, a condition that causes the ribbon to tear off the cell.

Figure 4. A strain-relieved cell interconnect between two back-contact cells. The three solder bonds on each cell, combined with the plated copper connections between those bonds on the cell, create redundancy.

Sample	Tests
Backsheet sample: 6" × 6"	Moisture vapour transmission rate
	Partial discharge
	Outgassing post heat soak
	Surface morphology analysis (initial and post HF10)
	Shrinkage (at lamination conditions and during accelerated tests)
	Interlayer adhesion (as received, post lamination and HF10)
	UV exposure
Three-cell laminated coupons	Adhesion tests (to encapsulant, interlayers; j-box, labels, framing materials)
	ACL168
	UV
	HF40
	DH2000
	TC200
	Sequence B (UV/TC50/HF10)
	HF/UV combination
	Cut test (pre- and post-HF, checking for crack formation)
	High-temperature voltage stability
	Field tests
	Chemical resistance (various chemicals found in environment)
Full modules	High-temperature heat soak (check for out-gassing due to interaction with other module components)
	J-box with weights tests for creep
	HALT (see Table 2)
	HF40
	DH2000
	TC200
	Field test (in various environments, and some with additional weights on j-box)

Table 2. Backsheet qualification criteria.

Theoretical inputs to FMEA

The final element of a thorough FMEA is a sound theoretical understanding of the product's potential failure mechanisms. This is especially critical for capturing slow-moving failure modes, which may not show up in the field for many years and may not even be encountered during HALT. The only way to capture these failure modes is with lab testing, in order to understand the physics of the breakdown, guided by theoretical modelling.

Good examples of critically important but slow-moving failure modes that are best understood using theoretical analysis occur in the metal interconnect and solder bonds between cells in a module. Fatigue-induced interconnect failures have proven to be one of the two most frequent field failure modes for traditional front-contact-cell modules, information that was used to design the interconnect structure for back-contact cells in 2004. The original design included an in-plane strain relief scheme, which initial validation tests indicated would survive 10,000 mechanical cycles and 20 thermal cycles with no failures and a power degradation of less than 3%.

However, subsequent testing revealed that solder bond failure could occur in

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extended thermal cycling, leading to a loss in fill-factor of ~8% at ~500 cycles. The failure mechanism was found to be cracking, which resulted from heterogeneous coarsening of the solder microstructure.

As a result, the interconnect was redesigned to reduce stress on the solder bonds by increasing the compliance of the interconnect, and work was done to model the failure mechanism.

Production processes were altered to use a higher compliance interconnect (as shown in Fig. 4) and an SnAg solder after testing showed that the combination cut the fill-factor loss to < 2% in 700 thermal cycles [6]. Additional information was then sought to quantify the acceleration factors of the solder joints to be able to predict product life [7,8]. Subsequent testing revealed that there were zero failed joints in 2,300 thermal cycles, significantly more than required for 25 years in a harsh climate.

Qualification testing

Once a solid FMEA is completed, a product test plan is developed. For example, the first line of the backsheet FMEA concerns possible detachment of the junction-box from the backsheet caused by a loss of adhesion of the RTV or backsheet interlayer adhesion. Since its RPN number is high enough to cause concern, a test must be derived to determine whether the product meets the specifications, which involves building a series of modules and coupons that have junction-boxes attached to backsheets with RTV. These are put into field testing with the cells above the j-boxes shaded to induce operating temperatures from hot cells.

These qualification tests can be pass/fail if the relevant acceleration factors are known, or they can require an equivalent or better performance compared to a known high-reliability baseline. In most cases, the tests are extended to produce failures with the aim of learning how this happens.

Long-term testing

Certification-type tests can form the basis for long-term testing, simply by extending the tests to when failure happens. Fig. 5 shows SunPower modules in the extended length versions of the standard certification tests and indicates no runaway failure modes, only slow degradation as a result of the accumulated stresses. Note that these tests are similar to HALT, but the stresses are gentler. For qualification tests to produce meaningful results, it is necessary to run them until failures occur. These extended tests are also repeated periodically as part of the ongoing reliability testing (ORT) for manufacturing.

Field testing

Field testing should always be started immediately and carried out simultaneously in different climates (hot and humid, hot and dry, temperate, urban, rural, coastal, etc.) on full-size modules. These deployments must be monitored and visited regularly to look for any new developments since any significant problem means the product has serious flaws.

An example that highlights of the value of field testing occurred during a failed qualification attempt for a new encapsulant. Coupon-size prototypes had shown no problems in lab tests, so full-sized modules using the same materials were put through field testing for prolonged exposure to various climates. The field tests were the first to show delamination at the encapsulant/glass interface. These defects did not occur during coupon testing, although they also did occur subsequently in damp-heat testing of full-size modules.

This particular example underscores that certification tests are not generally sufficient for qualifying a product design because they are only designed to indicate a reasonable level of initial product quality and safety, and are not meant to indicate product lifetime [9]. Almost all commercial modules that have experienced problems in the field were designs which passed certification testing.

Supplier quality

In order for a product based on a qualified design to perform in a predictable, reliable manner, its input materials must be well-specified and held within those specifications continuously. To accomplish this, supplier qualification and supplier continuous monitoring programs have been employed, which are defined in four stages:

- Stage 1 is internal to the company, in which requirements are clarified and a sourcing strategy is determined. Key requirements are part of the output of the qualification process.
- Stage 2 involves contacting likely suppliers, setting expectations, and developing joint plans.
- Stage 3 is where the primary suppliers go through a 'PSC audit' to evaluate how they are doing along the three most important dimensions:
  - Prevention: extent of employee training, usage of statistical process control, FMEAs, and a formal corrective and preventive actions (CAPA) methodology, as well as their own reliability and supplier quality programs.
  - Standardized/simplified/scalable: evaluation of business processes to make sure they are of high quality, with the change notification process of particular importance.
  - Customer satisfaction: customer surveys, responsiveness to customer issues, etc.
- Stage 4 builds a strong partnership to deliver high-quality products at a large scale. Regular self-assessments with periodic reviews and validation as well as improvement plans are implemented. Such rigor is absolutely necessary for ensuring a consistently high-quality product.

This testing is generally accomplished with a mix of vendor tests (with shared reports) and periodic inspections of incoming material. Table 3 shows a partial list of the incoming materials testing done as part of a regular sampling program. It is critically important to require that absolutely no formulation or design changes be made to the qualified components without requalification.

Material	Measurement
Encapsulant	Gel test, pull test, temperature soak test
Backsheet	Peel test, temperature soak test
Diodes	Leakage current test
Connectors	Production test (wiring fitness, crimping, pull test)
Frame	Mechanical load test, frame pull test
Label	Tape test, IPA test

Table 3. Examples of incoming materials audits.

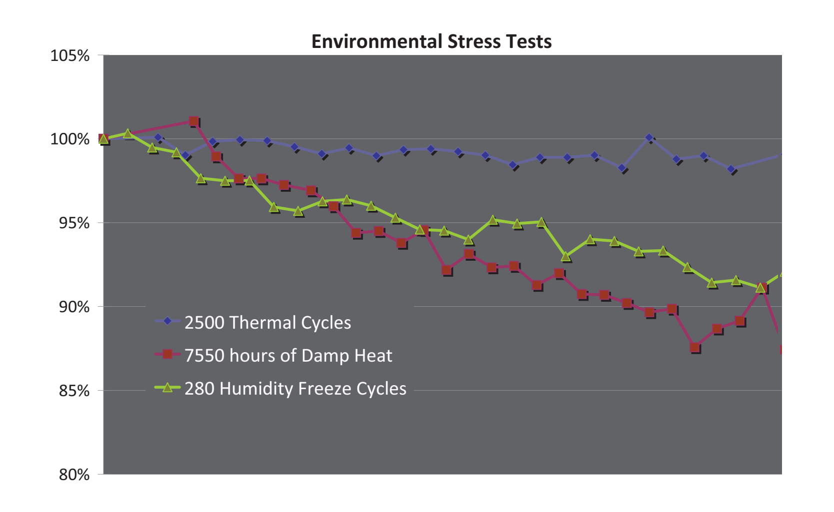

Figure 5. Extended testing of power output for back-contact-cell modules, which pass insulation resistance testing after more than 7× the certification standard in DH, 12× in TC, and 28× in HF.

Separate qualification of each of a vendor's different manufacturing sites is a subtle but critical issue, even when the component being purchased is the same part number. In one instance, a backsheet supplier was bringing up a new manufacturing facility, and the material produced during small pilot runs passed accelerated testing results that exceeded the IEC61215 testing requirements [10] and also passed the customer's internal qualification. This changed when the supplier ramped up to full production, and incoming inspection tests showed the backsheets from the new facility displayed weaker interlayer adhesion than the material received during the qualification testing. This revealed an inconsistency in material quality from the new facility that the supplier then corrected.

Manufacturing quality

The quality system

Consistent manufacturing is an essential part of achieving and maintaining the quality necessary to meet the reliability requirements of PV cells and modules. SPC, total quality management, and six sigma are among the general systems which can help attain and maintain quality in manufacturing. All these methodologies emphasize one main point: quality must be built into the product and cannot be audited into the product.

Since most PV modules must meet the 25-year warranty period as a baseline requirement, minimizing problems that might remain hidden for a decade or more is also essential. This is why SunPower borrowed heavily from the rigorous manufacturing quality procedures developed by the semiconductor industry. The original system was based heavily on the methodology used by Cypress Semiconductor (the majority investor in the company from 2002 to 2008) and later refined to better match the requirements of photovoltaic manufacturing. The key elements of the system include systematized business processes for all developments and changes; coordinated product, process, and equipment development procedures with six levels of control; quality and continuous improvement mentality; and variability and waste reduction.

Quality audits

The quality audit is an important part of achieving and maintaining the consistent manufacture of a high-reliability product. This is most effective if done by people who are outside of a manufacturing unit, such as those working in an independent quality organization.

An audit of workers' adherence to the manufacturing specifications serves both to

Figure 6. Fielded modules with silicone contamination on glass surface show four stripes.

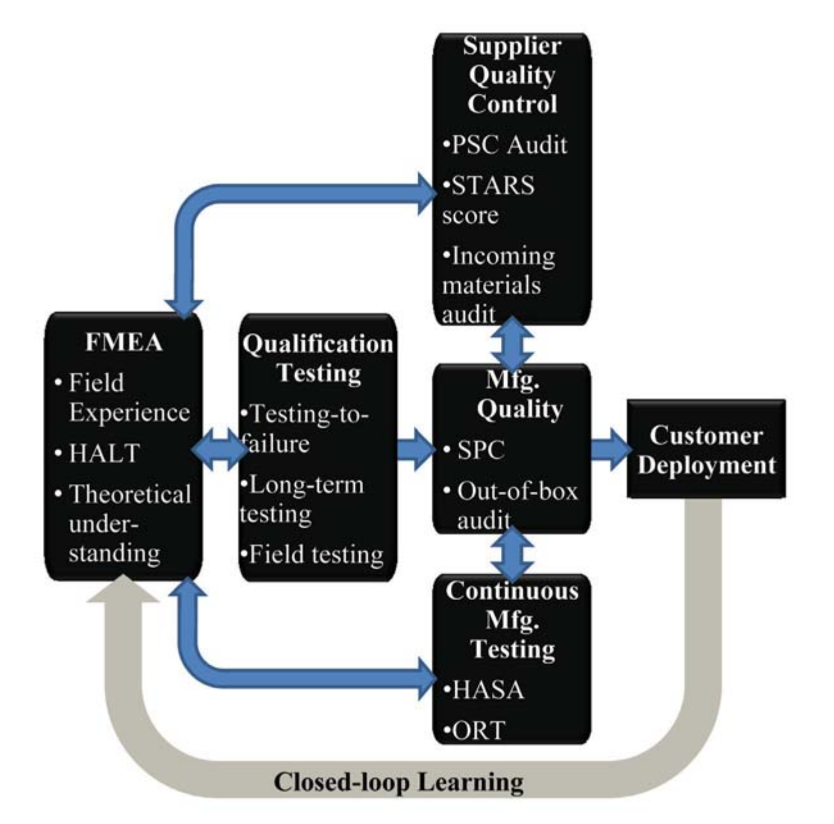

Figure 7. The primary methodologies discussed in each process area.

instil the proper mentality on the line and to catch breeches. The mentality must be to follow the specifications to the letter, or else to change the specifications with any proposed specification change handled only through the structured business process.

As part of the quality audit, an 'out-of-box audit' needs to be regularly performed, using a random sampling of products that have been packed for shipment. In addition to the quality of the packaging, documentation, product cleanliness, and visual defects, the audit compares the panel's actual electrical performance with performance recorded during manufacturing tests.

Continuous manufacturing reliability testing

Continuous testing ensures that the quality of the product does not change over time. The testing plan derives directly from the (regularly updated) FMEA and falls into two categories:

- A highly accelerated stress audit (HASA) detects any material defects or manufacturing problems that have escaped the supplier quality and manufacturing SPC hurdles. The HASA tests exercise important degradation mechanisms determined from the earlier steps in the product design process (HALT, historical data, theoretical understanding, and FMEAs from the product design and the process designs). They must have a fast turnaround time and be well-structured with clear pass/fail criteria that non-experts can interpret.
- An ongoing reliability testing (ORT) continues to validate the baseline

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reliability of the product. These tests are longer with lower stresses, smaller sampling sizes, and provide a general indication that the baseline reliability of the product is not changing.

Closed-loop learning from the field

When used properly, field failures provide invaluable information about the causal stresses a product encounters and how it degrades under real-world conditions. A thorough and thoughtful failure analysis provides critical feedback that can be used to strengthen the FMEA and associated testing of future products. The following incidents illustrate a few of the failure modes caught during field tests that helped improve the test plans currently in use.

An episode involving glass-surface contamination shows how a seemingly insignificant change in manufacturing process can have a surprising effect. For a short period in 2007, a modification was made to the cooling racks for modules coming out of the laminator that used a different insulating cloth to protect the hot modules from being scratched while they cooled. This new cloth, however, turned out to contain silicone oil, which gave the glass a different contact angle with water. While undetected in the factory, it created uneven soiling under field conditions. This problem was discovered fairly quickly but it required significant investment in a nine-step cerium oxide cleaning process to clean all modules deployed at customer installations to the proper specification.

This incident shows the value of fully vetting every process change. Instead of the isopropyl alcohol used in earlier tests, an outgoing water spray inspection for non-washable stains is used, which mimics panel washing practices deployed in the field. Additionally, all manufacturing accessories that have any physical contact with modules are included in the list of materials to be controlled as part of production.

A final problem illustrates how the same closed-loop process uses information from final testing to generate new standard test plans and update FMEAs. In 2009, a new wire/connector pair was undergoing its final qualification test when the humidity-freeze cycling sequence revealed a wet insulation resistance failure. This was traced to a sizing mismatch between the cable and connector that resulted in a broken sealing ring in the connector. Although the original problem was caught and corrected before any products reached the field, it resulted in a continued investigation which revealed that even dimensionally compatible cables are subject to failures. These discoveries led to a new qualification test to compare lifetimes of a population of cable/connector pairs with cycles of humidity-freeze.

Conclusion

A complete design-for-reliability process illustrates a methodology for producing solar modules that meet the dual challenges of the industry-standard 25-year warranty and a highly price-sensitive market. The methodology incorporates QA processes that bridge organizational boundaries and multiple information feedback paths to help it cope with the rapid materials and process changes common to modern manufacturing operations.

As shown in Fig. 7, the FMEA uses inputs from field experience, HALT, and theoretical understanding to generate the criteria for the thorough qualification testing needed to deliver a high-reliability product design. Subsequent feedback from qualification testing, production testing, and supplier quality control testing identify new potential failure modes for possible inclusion in the FMEA and to reweight existing ones.

As part of an ongoing commitment to quality, a closed-loop learning process has been added that channels information from field failures in customer deployments back into the FMEA. The inclusion of closed-loop learning in the quality cycle gives the manufacturing process it supports more intelligence and adaptability to the inevitable changes in design, process, and supply chain, allowing the capability to deliver products that go beyond basic certification to meet or exceed today's stringent reliability requirements in a consistent and cost-effective manner.

Acknowledgment

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References

[1] Quintana, M.A. et al. 2002, "Commonly observed degradation in field-aged photovoltaic modules", *Conference Record of the 29th IEEE PVSC*, Vols. 19–24, pp. 1436–1439.

[2] *UL 1703: Standard for Flat-Plate Photovoltaic Modules and Panels*, 3rd Ed., 2002, ISBN 0-7629-0760-6.

[3] Hacke, P., et al. 2010, "Test-to-failure of crystalline silicon modules", *Proc. 35th IEEE PVSC*, pp. 0–66.

[4] Wohlgemuth, J.H. et al. 2008, "Using accelerated tests and field data to predict module reliability and lifetime", *Proc. 23rd EU PVSEC*, Valencia, Spain, pp. 2663–2669.

[5] Gabor, A.M. et al. 2006, "Soldering induced damage to thin Si solar cells and detection of cracked cells in modules", *Proc. 21st EU PVSEC*, Dresden, Germany, pp. 2042–2047.

[6] Rose, D. & Daroczi, S. 2005, "Development and manufacture of Reliable PV Modules with > 17% Efficiency", *Proc. 20th EU PVSEC*, Barcelona, Spain.

[7] Clech, J.P. 2004, *Proc. SMTA International Conference*, pp. 776–802.

[8] Meydbray, Y. et al. 2007, "Solder joint degradation in high efficiency all back contact solar cells", *Proc. 22nd EU PVSEC*, Milan, Italy.

[9] Osterwald, C.R. & McMahon, T.J. 2009, "History of accelerated and qualification testing of terrestrial photovoltaic modules: A literature review", *Prog. Photovoltaics*, Vol. 17, pp. 11–33.

[10] IEC 61215: "Crystalline silicon terrestrial photovoltaic (PV) modules -Design qualification and type approval"; IEC 61646: "Thin-film terrestrial photovoltaic (PV) modules – Design qualification and approval."

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Power Generation

SolarReserve gets environmental approval for Crossroads solar project from Arizona commission

Utility-scale developer SolarReserve has been awarded its final Certificates of Environmental Compatibility from the Arizona Corporation Commission for its 150MW Crossroads Solar Energy Project to be built near Gila Bend. The approval includes the associated transmission line connecting the CSP project to Arizona Public Service's transmission grid. This final unanimous approval follows December's unanimous decision (11-0) from the Arizona Power Plant and Transmission Line Siting Committee to grant the certificates.

Located on privately owned and actively cultivated land west of the town Maricopa County, the project will supply approximately 450,000MWh annually of electricity to Arizona customers. The system will employ a concentrating solar power approach: the advanced molten salt, power tower technology developed by Pratt & Whitney Rocketdyne, which provides the ability to store 10 hours of solar energy and generate electricity on demand, even after the sun goes down.

Source: Crossroads Solar Energy Project

Artist's rendering of a similar SolarReserve concentrated solar power site.

The developers say that Crossroads will create more than 450 construction jobs during the two-year construction period and up to 5,000 direct and induced jobs, including offsite supplier and supporting activities. The project has a capital cost in excess of US$500 million and is expected to generate economic development in Gila Bend and throughout the region.

It will employ at least 45 full-time, permanent operations staff throughout the 30 year of the project's operating life, and has an annual operating budget of up to US$10 million per year.

Asia News Focus

Kyocera to supply modules for two Japanese plants

Kyocera will supply 3MW of its multicrystalline silicon solar modules for two of Tohoku Electric Power's upcoming developments in central Japan. Construction of the 2MW Shichigahama and 1MW Hachinohe plants is underway and will be completed in January 2012.

The Sendai Solar Power Plant in the Miyagi prefecture town of Shichigahama is expected to generate around 2,100MWh of electricity per annum, while the Hachinohe Solar Power Plant in Hachinohe, Aomori will produce 1,600MWh.

Source: Kyocera

Kyocera's solar module family.

Tohoku's installations are just two of around 30 large-scale solar power plants that are scheduled to be built in Japan by 2020 – adding 140MW to the country's solar capacity; Kyocera will be module supplier for seven of these.

Abengoa, Bharat Heavy Electricals Limited to work together on Indian projects

Abengoa has signed a contract with Bharat Heavy Electricals Limited (BHEL) to work together on a range of concentrating solar power (CSP) projects in India. The agreement will not only see the firms join forces on the engineering, procurement and construction (EPC) of the Indian portfolio but also look to develop projects in other parts of the globe.

Parity Solar installs BIPV system in Zhenjiang, China

Parity Solar has installed a building-integrated photovoltaics (BIPV) system at the New Area Court House complex in Zhenjiang, China. The crystalline and thin-film modules are being installed over the skylight on the complex's roof and will have a power generation capacity of 200kW.

The rooftop array was connected to the grid in December 2010 – meeting the deadline for Jiangsu's 2010 feed-in tariff of 3.0 RMB per kWh – and is fitted with Satcon Solstice inverter technology.

Source: Satcon

Satcon's Solstice inverters will be used for Parity Solar's rooftop installation in Zhenjiang, China.

Europe News Focus

Parabel commissioned to develop 41MW Brandenburg solar park

Parabel has been commissioned to develop one of Europe's largest solar systems, the 41MW park in Brandenburg, Germany. The park, situated on the site of a former military training ground, is currently in the first planning and approval phase, with construction expected to take place between June and August; the final phase will increase output to 90MW and be completed in 2012. The initial development will see around 180,000 modules installed across 94 hectares and at a cost of €90 million.

OPDE starts building 26MW portfolio in northern Italy

OPDE Italia has started building work on six new solar farms in the Piedmont region of Italy. The farms, the combined capacity of which will be 26MW, are to be situated in the cities of Tortona, Alessandria, Pedrosa and Fosano.

More than 91,000 Trina modules, 2,000 SMA inverters and 2,000 single-axis MECASOLAR trackers will be used on the farms, which will create hundreds of direct and indirect jobs in the region. Investment in the portfolio will total around €120 million and construction will be finished by the end of March.

Several investors have already shown an interest in buying not only the six new plants but also the 17MW that OPDE installed in Italy last year. Q2 2011 will also see the Piedmont portfolio complemented by a further 32MW of developments

Source: Satcon

Jose Antonio Mieres, CEO of Grupo OPDE.

across the peninsula, with OPDE currently organising the construction phase of these plants, which have already been legalized with 'Autorizacione Unica.'

TerniEnergia expects to complete 18.3MW of Italian solar power plants by end of March

TerniEnergia is working on 16 industrial-sized PV plants, which will produce 18.3MW of solar electricity in total. The plants are located in the Umbria, Marche, Piemonte, Molise, Lazio and Puglia regions of Italy and are expected to be completed by March 31st.

Two of the 16 plants under construction have full equity finance and will carry a 1.6MW capacity. Five of the solar projects are being constructed for the joint ventures TerniEnergia constructed with EDF EN Italia and hold an 8.2MW capacity. The last nine plants are being built for third-party clients and will have a 6.2MW capacity.

Greece's Public Power sets deadline for Kozani partnership bids

Greece's largest electricity producer, Public Power, has invited prospective strategic partners for its 200MW Kozani solar park to declare their interest by March 31st. The partner will help secure financing for the construction, development and operation of the park, which, when completed, will be the largest solar system in the world.

The Kozani project will cost around €600 million and more than double the capacity the world's current largest PV plant, Canada's 97MW Sarnia site. A decision on who to enlist for the record-breaking project will be made by Public Power during the summer, with construction scheduled to begin before the end of the year and be completed within 18 months.

The international tender stipulates that interested parties must have possessed net assets of more than €500 million for the past three years, have previous experience managing projects in the PV industry and have raised more than €300 million of project funding.

Source: Creative Commons

Servia bridge over Polyfytos lake, Kozani, Greece.

Green Source and Parabel sell 7.4MW portfolio of solar power systems in Czech Republic

Green Source and Parabel recently sold their 7.4MW portfolio of solar systems in the Czech Republic; a project that was developed under their joint subsidiary Vireo Czech and newly connected to the grid. The project portfolio was sold, for an undisclosed amount, to Enercap Power Fund I. Vireo Czech oversaw the management and construction of the PV system.

The solar project is distributed over three sites: Mimon, Lomecek and Tocnik, and will generate 7GWh of electricity per year. First Solar provided the thin-film modules for the installations with Schletter mountings and inverters from Siemens.

Source: REC Systems

REC Peak Enery Series module.

REC Systems, ABB begin construction of 24.2MW Lazio plant

REC Systems and ABB have closed financing and begun construction of a 24.2MW solar power plant in Lazio, Italy. Authorization for the 95-hectare project was granted in March 2010 and, when completed, the system's 100,000 REC modules will generate around 37 million kWh of electricity a year.

Funding for the system, which is Italy's largest lease-financed development, is coming from Unicredit Leasing, Leasint and BNP Paribas Leasing Solutions. And, with 70% and 30% stakes respectively, the BNP Paribas-backed CEF Energia and MedEnergy Group will be the Lazio site's future equity owners.

U.S. & Canada News Focus

Project Navigator PV unit, San Bernardino county sign lease option for 2MW solar landfill project

Project Navigator's PVNavigator solar power projects development group has entered into a lease option agreement with the San Bernardino county to evaluate and explore the development of a 2MW (AC) photovoltaic facility at the closed Big Bear Sanitary Landfill.

The facility's power is expected to be sold to the local Big Bear utility to assist it meet its renewable portfolio goals, according to PVN. When online, the project will likely be the only renewable, commercial-scale solar development in the San Bernardino Mountains. PVN will manage all phases of the Big Bear solar project, including design, permitting, financing, and implementation.

SkyPower begins construction on 10MW Fort William First Nation solar park

SkyPower and Fort William First Nation have signed an agreement that will see SkyPower construct a 10MW solar park on First Nation's land in Thunder Bay, Ontario. This is the first Canadian large-scale solar project to be developed on Fort William First Nation's reserve.

The 10MW project will be built over 100 acres of land and use approximately 45,000 solar panels. Construction work on the solar park began earlier this year and is expected to finish sometime this summer.

Southern California Edison signs PPA with First Solar for Silver State South plant

Southern California Edison (SCE) has signed a power purchase agreement with First Solar for its 250MW (AC) Silver State South plant. First Solar's ground-mounted system, which will be located on 2,500 acres of public land near Primm, Nevada, will start generating electricity in 2014 and be fully operational in May 2017.

Development of Silver State South will create around 300 construction jobs and, when completed, is to be connected to SCE's proposed Eldorado-Ivanpah 220kV transmission line.

PsomasFMG signs PPA with Orange County for 4MW solar portfolio

PsomasFMG has signed a US$20 million Power Purchase Agreement (PPA) to design, engineer, build, operate and maintain a solar portfolio for California's Orange County. The system, which includes both carport and ground-mounted arrays, is to be spread over seven sites and will have a capacity of up to 4MW.

Over the 20-year duration of the PPA, it is estimated that Orange County could make a saving of up to US$5.3 million on its electricity bill; the system will start producing electricity by the fourth quarter of this year.

Source: PsomasFMG

One of PsomasFMG's solar installations.

Campbell's Soup signs PPA with BNB Napoleon Solar to build 9.8MW PV plant

Campbell's Soup has signed power purchase and land lease agreements with BNB Napoleon Solar to build a 9.8MW solar power generation system on 60 acres of the company's largest plant in Napoleon, Ohio. Campbell will lease the land to BNB, which will own the system and be responsible for its financing, construction, operation and maintenance. When completed, it is estimated that the system will produce more than 14.7 million kilowatt hours during the first year of operation.

Under the terms of the 20-year PPA, Campbell will purchase 100% of the electricity generated by the system, which is expected to provide approximately 15% of the Napoleon plant's annual requirement. Over the course of the PPA, Campbell said it will save up to US$4 million based on U.S. Department of Energy projections for the cost of electricity in Northwest Ohio.

The state has shown its support, as the Ohio Enterprise Bond Fund agreed in October to issue US$10.5 million in bonds to finance a portion of the project. Once financing closes and all permits are secured, construction can begin in early June and will create more than 200 construction jobs in Ohio, according to the parties. FirstEnergy Solutions will purchase the solar renewable energy credits from the project.

San Diego Gas & Electric, NRG Solar sign deal for utility to buy power from 26MW PV power plant

San Diego Gas & Electric has entered into a 25-year contract with NRG Solar to buy 26MW of solar energy from a proposed facility in San Diego County, California. The Borrego Springs installation will be deployed on a 300-acre site in the eastern part of the county where there is abundant desert sunlight. Construction is expected to be complete in mid-2012.

This is the fourth solar contract SDG&E has signed in the past nine months, boosting its renewable portfolio by more than 300MW.

Unirac forms new subsidiary, partners with Canadian Solar for 30MW turnkey solar power systems

Unirac and Canadian Solar Solutions have come together to offer its residential and commercial customers 30MW of Canadian Solar's PV systems coupled with Unirac's mounting solutions for rooftop installations in Canada. Canadian Solar will provide the engineering, procurement and construction services for the projects, while Unirac

Source: Unirac

Unirac's Large Arrays range starts at 3kW.

will supply its racking technology. Both companies hope the partnership will help their customers to further take advantage of Ontario's FiT program.

Duke Energy, SunEdison activate 17.2MW solar farm in North Carolina

North Carolina has just activated the final phases of a new 17.2MW solar farm in Davidson County, courtesy of a partnership between Duke Energy and SunEdison. The solar project was built in five phases on over 200 acres of land using more than 63,000 solar panels. It is anticipated the plant will produce 28 million kWh of solar-generated electricity per year.

SunEdison and Duke Energy collaborated on a solar energy service agreement where SunEdison, which designed and installed the project, will manage the solar farms operations and maintenance. Financing was conducted through lease finance by MetLife and Bank of America Merrill Lynch.

Middle East & Africa News Focus

Soltec Renewable Energies, Shikun & Binui Solaria team up to build 6.7MW Israel plant

Soltec Renewable Energies and Shikun & Binui Solaria are set to build a 6.7MW solar power plant in the disused copper mines of Timna Valley in southern Israel. The project, which will be one of the biggest solar developments in Israel, is the first of several large-scale joint developments planned by the two firms over the next two years.

Phoenix Solar chosen by Saudi Aramco to build 3.5MW plant

Oman-based system integrator Phoenix Solar has been chosen to build a 3.5MW solar park for the world's largest oil producing company, Saudi Aramco. The plant will be built adjacent to the King Abdullah Petroleum Studies and Research Center (KAPSARC) on the outskirts of Saudi Arabia's capital, Riyadh.

Phoenix Solar will work alongside Naizak Global Engineering Systems in designing, building and connecting the ground-mounted system. A completion date of September 2011 has been penciled in.

Last year, Phoenix Solar installed a PV testing field designed to analyse different module technologies at Saudi Aramco's headquarters in Dhahran. And the successful completion of this project helped it sway Saudi Aramco during the international tender for the Riyadh park.

Energiebau Solarstromsysteme installs one of Africa's largest rooftop arrays in Nairobi

Energiebau Solarstromsysteme has installed one of Africa's largest solar rooftop systems on the headquarters of the United Nations Environment Programme (UNEP) in Nairobi, Kenya. The 515kW array took three months to construct and was connected to grid during the UN Global Ministerial Environment Forum on February 21st; it will generate around 750,000 kWh of electricity annually.

Energiebau collaborated with Schott Solar, SMA Solar Technology and Kaneka on the project, which it claims is the first climate-neutral office building in Africa. Building work was carried out by local contractors and supervised by Energiebau.

Product Reviews

Schletter

Schletter develops module cleaning system for commercial rooftop applications

Product Outline: Germany-based Schletter GmbH has developed a novel cleaning system for PV module rooftop installations. The PVSpin is designed to be operated safely by one person and employs twin rotating brush heads fed with water through a central nozzle.

Problem: The degree of efficiency of a photovoltaic plant depends not only on the intensity of the sun, but also on the degree of module soiling. Self-cleaning of the photovoltaic modules by rain can be effective; however, in dusty environments such as on agricultural buildings, regular cleaning reduces energy degradation due to build-up of soiling material. In most cases, such cleaning operations are carried out using a telescopic rod equipped with a cleaning brush. Unfortunately, this cleaning method is not suitable for all kinds of photovoltaic plants and is also very time-consuming.

Solution: The new PVSpin cleaning device claims to offer more flexibility and economic efficiency. It works on the basis of two cleaning brushes rotating in opposite directions that are only driven by water pressure, removing soiling material in a quick and in a manner that protects the material. Hard dirt formation is removed by the rotation of the brushes and the filtered water. Furthermore, a feature that allows guidance along the module frames makes cleaning operations more convenient.

Applications: Commercial rooftop installations and power plants.

Platform: As the device weighs only about 15kg, it can be let down from the ridge and ergonomically operated by one person.

Availability: April 2011 onwards.

National Semiconductor

National's MYPVDATA SOC web interface provides performance analytics for PV systems

Product Outline: National Semiconductor has released the SolarMagic MYPVDATA Solar Operations Center (SOC). The software-as-a-service (SaaS) offering helps users analyze data collected from the PV array by delivering information through an easy-to-use web interface, allowing for the harvesting of maximum energy levels. The system also comes with ongoing service subscriptions for all current commercial customers.

Problem: Traditionally, monitoring has taken place at the inverter level, providing access to very basic information on system performance.

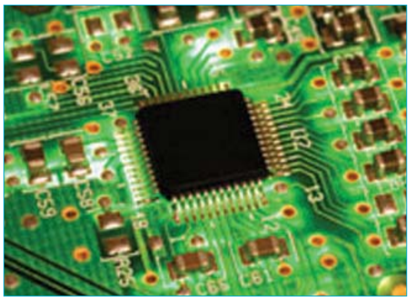
Solution: Through the MYPVDATA portal, system owners access single- and multi-site data and customize the user interface to get the most value out of the data. Daily, weekly and monthly monitoring data and reports are available, reducing operations and maintenance costs as the intricacies of the installation are understood. The company claims that with each unique installation increases ROI by minimizing excess maintenance and maximizing performance through monitoring the best installation set up. Access to array, panel, and string-level data mean inefficiencies are easily corrected by setting notification alerts that trigger the system to act (automatically or manually).

Applications: PV energy system performance analytics.

Platform: Four key elements are included in the product offering; Performance Analysis, Progress Analysis, Symmetry Analysis and Data Analysis.

Availability: Currently available; includes ongoing service subscriptions for all current commercial customers.

Azuray Technologies



Azuray Technologies integrates Linux-based embedded database in its DC-to-DC converters

Product Outline: McObject's eXtremeDB Fusion embedded database system, a Linux-based high-performance embedded database system for solar power optimization, has been integrated with Azuray Technologies' DC-to-DC converters for 'smart' solar modules.

Problem: PV module manufacturers are focusing on distributed electronics to increase solar energy generation efficiency. A potential limitation in this type of energy generation is that when one panel's productivity is hindered – by shade, mismatch and other obstructions – the decrease in power generation is multiplied across multiple panels.

Solution: Azuray's maximum power point tracking (MPPT) DC-to-DC converter technology uses embedded software to offset the effect of environmental conditions and increase the amount of solar energy generated. The eXtremeDB Fusion offers hybrid storage, allowing for different record types to be designated for storage in RAM or on persistent media (flash in this case). Some of the gateway's data is inherently transient, and storing it in memory reduces wear on the flash device. The gateway applications do not need the database server mechanism that is part-and-parcel of many DBMSs. Azuray's gateway gains performance, and reduces memory and CPU demands, by eliminating inter-process communication and other client/server overhead.

Applications: Power optimization and energy harvest enhancement products for 'smart' solar modules.

Platform: eXtremeDB forgoes client/server architecture, instead offering an in-process model in which database functions are embedded directly in application code.

Availability: Planned launch in 2011.

Product Briefings

Centrosolar

Centrosolar offers trapezoidal roofing solution for flexible thin-film mounting

Product Outline: Centrosolar has developed a new installation option for flexible thin-film solar modules, the TF Multi Professional, produced by United Solar Ovonic. This solution allows for the installation of large-surface modules on roofs covered with trapezoidal sheet metal which up to now has only been possible on plastic foil roofs.

Problem: Due to the shape of trapezoidal sheet metal used in large quantities for low-bearing roofs, such as agricultural and other light commercial out-buildings, lightweight flexible thin-film substrates cannot be employed for such irregular-shaped roofing. This limits the potential usability of such building structures for PV installations.

Solution: The TF Multi Professional substrates are mounted on a thin aluminium backsheet which can then be mounted on trapezoidal roofs in two ways: parallel or perpendicular to the direction of the recesses in the trapezoidal sheet metal, which are known as beads. Installing the module parallel to the direction of the beads requires a substructure. For this purpose, Centrosolar uses top-hat rails, which are screwed onto the elevations in the trapezoidal sheet metal at a right angle. If the modules are to be installed perpendicular to the beads, no such substructure is necessary. The modules are fastened by means of drilling screws and a special sealing tape (butyl tape).

Applications: Commercial applications with low-bearing trapezoidal roofing.

Platform: The TF Multi Professional thin-film module cells are installed on aluminium sheeting at an angle of 11°. Each unit consists of five elements. The nominal output per element is 144Wp. Centrosolar supplies all components necessary to install the system.

Availability: Currently available.

Hyundai

Hyundai's SG-Series modules come with tight output power tolerance for broad applications

Product Outline: Hyundai Heavy Industries' SG-Series monocrystalline and multicrystalline solar modules offer a wide range of applications and performance parameters with tight specifications. Hyundai's PV modules are manufactured on advanced automated production lines that include both 2 bus-bar and 3 bus-bar modules for its 54- 60- and 72-cell modules.

Problem: With end-user market requirements continuing to diversify, module manufacturers are required to offer a broader product portfolio that includes high-performance as well as low-cost high-quality modules. This also extends in complete system packages enabling simplified installation and potentially lower costs.

Solution: Hyundai's SG-Series modules are manufactured on advanced automated lines, providing high levels of quality control, producing tight output power tolerance of +3% only. The nominal output range of a 54-cell module (983 × 1,476 × 35mm, 17kg) is 194~228W, and 215~250W for a 60-cell module(983 × 1,645 × 35mm, 19kg). The 72-cell module (987 × 1965.5 × 50mm, 27kg) has the highest output, which ranges from 260W to 305W. These PV modules are silver framed but Hyundai also provides black PV modules for residential applications.

Applications: Residential, commercial and utility-scale installations. Hyundai is one of a few manufacturers that can produce both modules and inverters with one of a kind technology. All inverters come grid-tied and can be divided into two types by the addition of transformers.

Platform: Hyundai PV modules have been certified to IEC 61215(Ed.2) and IEC 61730 by TÜV Rheinland; are UL listed (UL1703) with a Class C Fire Rating. Hyundai also regularly prepares for pre-inspections and regional touring services.

Availability: Currently available.

Solyndra

Solyndra offers integrated greenhouse energy generation solution

Product Outline: Solyndra has developed a new solar application for agricultural greenhouse and shade structures that takes advantage of the ability of light to pass through the company's solar panel design. The improved nature of the panel design has been confirmed by Research CeRSAA in Italy and the Department of Plant Sciences, University of California Davis, USA, further backing the application's ability to support crop growth underneath the installation while generating electricity.

Problem: Combining solar modules into agricultural-sized greenhouses can be a significant design and engineering challenge due to low-bearing structures and greater restriction of direct sunlight.

Solution: Greenhouse manufacturers can easily integrate Solyndra panels onto the roof of a greenhouse or shade structure. Complete coverage with the panels maximizes energy output per acre and generates a uniform shading comparable to the light transferred through conventional shade structures or the process known as whitewashing, according to the company. The cylindrical design of the modules enables them to capture sunlight and generate electricity from direct, diffuse and reflected light. Growers with greenhouses may add an optional shade cloth to protect plants that require more shade during certain months of the year. Using a white cloth also allows some of the light to reflect back onto the tubes thereby increasing the energy output of the system.

Applications: Agricultural greenhouses.

Platform: CIGS cylindrical thin-film modules. Certifications/Listings: UL1703, IEC 61646, IEC 61730, CE Mark, CEC listing, Protection Class II Application Class A per IEC 61730-2, Fire Class C, MCS/BRE(UK). Warranty: 25-year limited power warranty; five-year limited product warranty.

Availability: Currently available.

How building integration can save PV: the business case

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ABSTRACT

Recent industry analysis from NanoMarkets has suggested that although current business cases for PV are running out of steam, the building-integrated PV (BIPV) sector may be able to revive PV's fortunes. The arrival of 'true' BIPV – not just flush-mounted BIPV panels, but PV-enabled glass, tiles, siding, etc. – renders possible new business cases that would otherwise simply not be an option with conventional PV. This paper puts forth a business analysis of the BIPV industry, providing case studies and data on the burgeoning sector.

In its earliest days, the business case for building-installed PV was typically concerned with off-grid applications. While this was mostly based either on purely environmental or survivalist grounds, there were also some PV buildings that were located too far away from the grid and were therefore *inherently* off-grid. The business case for installing PV in buildings at that time was essentially that there were enough people who, for what were essentially ideological reasons, wanted to live off the grid, thus making it profitable to supply them with solar panels.

But the number of people likely to ever live off-grid (for whatever reason) will most likely always be low. One reason for this is that the addressable markets for PV in the off-grid era were so small that making the decision to live off the grid would be considered quite eccentric. As a result, it can be assumed that there is a cultural factor at play in the determination of size and amounts of addressable markets. In addition, during PV's off-the-grid era, it was just about impossible to make any kind of purely economic case for deploying PV, with the exception of remote areas. PV users were essentially paying the full cost of PV in order to satisfy subjective needs. Taking into account the cultural factor, it is likely that only a relatively small proportion of the population was ever intending to take this road less travelled, and even then, only in certain geographical regions. Even today, PV insiders do not tend to refer to those living off the grid, partly a result of a strong association that has grown between PV and on-grid developments.

With the advent of on-grid PV came a sudden need for a new kind of business case for PV. The term 'on-grid PV' refers to buildings that use PV to supplement electricity accessed and bought from the grid. More recently, this term has come to include arrangements whereby buildings that produce energy using PV have the option of selling this back to the local utility.

In this new era, it has become much easier to cost justify PV, although this now has to be done with respect to subsidies and feed-in tariffs. As returns on investment (ROI) have now become real possibilities, the ideological/subjective aspect of the PV business case has become somewhat less vital to the overall PV consideration. However, PV firms are also finding themselves having to deal with a broader set of issues in their communication with potential customers, ranging from energy efficiency as a social good, to the environmental friendliness of the solar panels themselves, to the positive impact that a switch to PV would mean from a climate change perspective.

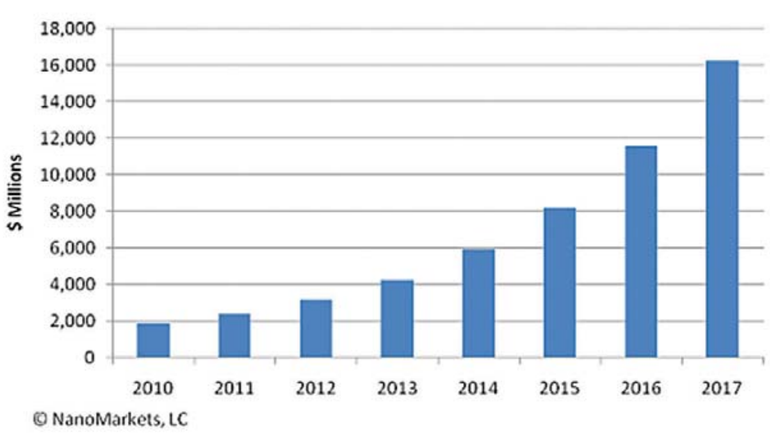

Figure 1. Estimated BIPV shipments to 2017 (NanoMarkets).

These issues have been among the staples of the business cases made by PV firms in the past five to seven years (at least). However, we think that this kind of approach has inherent limits, and that these limits, as outlined below, may soon be reached.

- The community for whom environmental issues are a prime determinant in their energy purchasing decisions remains a relatively small segment of the population, especially when this issue is considered on a global basis. Consequently, the market for PV technology as it is now addressed may not be that large to begin with. It should also be noted that at this point in time, the 'environmentally conscious' community is already reasonably well informed about what PV has to offer. This suggests that quite soon it will become harder to find first-time buyers for PV. Although potential PV users among the environmentally conscious community have not yet bought PV in the past, it is becoming less and less likely that this is because they don't 'get' what PV is all about.

- There are reasons to suspect that the environmentally conscious community may contract or have its growth significantly curtailed in the next few years, at least compared to what might once have been expected. The generally poor world economy and the weak state of the construction industry in particular – situations that are likely to persist for some time – suggest to us that people in many developed parts of the world will place immediate economic considerations over long-term environmental considerations. Moreover, the intellectual setbacks that the climate change movement has suffered in the past year will only reinforce this trend.

For these reasons, PV will soon be in search of a new business case. We believe that the arrival of BIPV provides that business case both through the medium of improved aesthetics and a radically altered economic justification for BIPV. At the most basic level, BIPV has a very


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different 'look and feel' from conventional PV: while conventional PV is made up of panels that vary primarily only by size and efficiency, BIPV consists of many different products, each with its own advantages, disadvantages and challenges, as outlined in Table 1.

Aesthetics added

By "disguising" PV as building materials, BIPV adds to the PV case by (1) potentially eliminating ugly rack-based PV systems that actually put off potential users from deploying PV, and (2) essentially adding new kinds of building products to the mix that may be considered to have their own special kinds of aesthetics. For example, PV roofing tiles may actually look different from regular tiles or may be considered to have different aesthetics precisely because they include PV.

In any case, what BIPV seems to be able to add to the subjective component of the PV case is a route – through a new PV aesthetics – to extend the addressable market for PV beyond the ideological market that PV now frequently addresses. Aesthetics also creates an opportunity for BIPV product makers to differentiate themselves in the market in a manner that is not available to manufacturers of regular PV panels. For firms in developed countries that have watched the manufacturing of PV panels shift to China, this will come as welcome news.

ROI and BIPV

In the off-grid market era, the economic part of a business case was usually either non-existent or did not need to be made. As outlined previously, the subjective ideological factor was so paramount that ROI arguments simply did not need to be considered in the buying decision for PV. In some cases, buildings were off the grid because their locations were so remote as to render them too expensive to be hooked up to an electricity source.

The new on-grid PV market was created by a series of subsidies that varies from place to place and includes both direct subsidies of capital expenditures (e.g. tax credits) and feed-in tariffs that are often highly favourable to the PV-based generator. An extensive subsidy regime was largely responsible for expanding the market from just hardcore ideological enthusiasts for PV to (at least) the environmentally concerned.

"BIPV enables a completely different cost model for PV, while the PV business case changes dramatically."

The question of whether or not there is a good ROI argument for PV has not been completely settled, but at least with the subsidies in place some aspect of the cost is offset. There are, however, some real questions about how far the ROI argument can be stretched.

Business plans for PV that today rely heavily on ROI tend to throw manufacturers of regular PV back to competing on price; so many of the factors that are taken into account for the ROI calculation are beyond the control of the panel makers themselves, with subsidies being set by governments, for example. Once a PV firm has made its choices with regard to core materials and the manufacturing processes that it intends to use, it is hard for them to differentiate themselves from other firms that have made similar choices. While they can implement some minor differences in terms of lifetimes, efficiency and reliability, these will be minimal. Reliability can also be affected by the issuing of warranties and guarantees to customers.

However, once BIPV is brought into the picture, things begin to change. BIPV enables a completely different cost model for PV, while the PV business case changes dramatically. With BIPV (and BIPV alone), the costs can be allocated between the PV functionality and the building material. This allocation process can be largely under the control of the BIPV product maker, since product design will determine how much of the product is made up of the PV panel, and how much comprises cladding or roofing material.

In addition, the advent of BIPV completely changes the ROI equation itself, since some of the costs must/can be allocated to the building materials. Depending on the approach taken in this cost allocation, radical reductions in the cost of the PV can be achieved, making the ROI case for PV much more of a sure thing.

BIPV: opening up new marketing channels

NanoMarkets believes that the case for BIPV is strengthened by the fact that it will open up existing building and electrical product supply chains to PV to a much greater extent than is currently

Type of PV	Main Markets	Advantages	Issues
Flush-mounted panels	Buildings looking for an easy way to improved aesthetics. First-generation BIPV	The primary reason for the existence of flush-mounted panels is aesthetics	Can be expensive compared with traditional PV, although costs have come down
Glass	Non-window glass in larger commercial and prestige residential buildings	Suitable for wall space in tall buildings where roof space is limited	Typically associated with large projects. Unpredictable market, but high value individual projects
Flexible BIPV laminates	Laminates that are applied to building surfaces	Designed to look better than conventional panels. They offer value propositions – and opportunities – that derive from their light weight, ease of installation and versatility	Do not substitute for – or produce any savings from – conventional building materials
Fully-integrated flexible BIPV products	Products like flexible roofing shingles and PV-integrated metal roofing	Good and controllable aesthetics and the ability to allocate costs between categories of PV power generation and architecture with considerable discretion	Many technical challenges including actually installing roofing and siding
Rigid fully-integrated BIPV	Probably some of the earliest markets for fully-integrated BIPV	Good and controllable aesthetics and the ability to allocate costs between categories of PV power generation and architecture with considerable discretion	Sometime have relatively low efficiencies; can be difficult to develop viable commercial products

Table 1. BIPV types, advantages and challenges.

the case. But while this means more competition for the dealers/integrators that have been at the centre of the PV business since its inception in the 1970s, it also seems likely that their business will be strengthened in other ways.

BIPV providers have the opportunity to sell through building and electrical product marketing channels as well as through PV marketing channels. This already happens to some degree (conventional PV products are sold in *Home Depot*, for example), but once true BIPV products are established, it should become much easier to make the case for selling PV through building-industry supply chains.

While this means traditional PV retailers and wholesalers will have more competition, it has the potential to strengthen the businesses of the local PV dealers and installers if they play their cards right. BIPV installations are inherently more complex than conventional PV installations and can prove more difficult for residential and small businesses to install themselves; this may result in local installers seeing an expansion in their installation businesses as the result of BIPV, while the product manufacturers may become more reliant on local dealers/installers to carry through their strategies. However, small local PV firms are likely to require substantial training before they can successfully install what are, in effect, roofs and siding.

The existing wholesale infrastructure for PV is likely to take on BIPV products along with existing conventional PV products. Indeed, NanoMarkets believes that business plans of wholesalers will be enhanced somewhat by these high value-added products and, as a result, BIPV product makers can expect wholesalers to be open to taking BIPV products under their wing.

BIPV and the realities of real estate

BIPV is shifting the PV industry away from one that is entirely focused on energy issues to one that is much more closely aligned with the building industry and all parts of its related supply chains. This means that BIPV business cases must also be different from conventional PV business cases in order to reflect this change.

> "BIPV will surely see the greatest adoption rates where conventional PV is already strong."

BIPV business cases must reflect the current realities of the construction and real estate businesses in various parts of the world. For the most part, these are not attractive realities. Either real estate markets have collapsed and are (at best) recovering very slowly – a theory that is in fact true in the U.S. and Europe, for example – or there are founded worries that a currently expanding construction market will soon bottom out and may actually represent a bubble that is about to burst – some would say that China is an example of such a market.

How can BIPV firms usefully build all of this into their business cases? It is hard to overlook the fact that the worldwide construction and real estate industries deemed to be "addressable markets" are not necessarily good places to be. Nonetheless, the BIPV business case can be designed in such a way that it can be made appealing even in the context of today's sad state of affairs in the real estate market. Specifically, BIPV presents an opportunity to add features and value that can increase the marketability of a building built on spec. For buildings that are built to customer design, the ability of a construction firm to be able to effectively include BIPV features may give that construction firm an edge over other construction firms.

A summing up

BIPV radically changes the business case for PV. Table 2 shows how BIPV can transform the strategic focus in the PV space. Along the subjective dimension, BIPV can help expand the market by taking PV to a new

	Subjective aspect of PV case	Objective/ROI aspect of PV case	Ability of PV panel manufacturers to differentiate in the market
Off-grid era	Primarily marketing to "hard core" environmentalists and survivalists – intrinsically small market	Not usually made, except for remote locations and then ROI advantage is usually established	Early stage market, where differentiation may not be the primary concern compared to market development
On-grid era	Subsidies broaden market to a much larger market; the "environmentally concerned". The size/growth of this market is challenged by current global economic problems	ROI cases are heavily dependent on subsidies and are sometimes questionable with regard to validity. Most of the factors that make up ROI cases are beyond (or almost beyond) the control of the PV panel maker – one exception is the price of the panel	Tendency towards commoditization. This is good for very high volume suppliers, but bad for just about everyone else.
BIPV era	Adds aesthetics into the mix and broadens the market even further by eliminating the negative aesthetics associated with regular BIPV and creating a "new aesthetics based on PV"	Fundamentally changes the PV market ROI argument and cost model as a substantial amount of the cost of the panel can be allocated as a building material	BIPV radically increases the ability to differentiate products in the market through aesthetics and multiple cost allocations. Many ways for PV firms to differentiate themselves for the first time

Table 2. Summary of PV business case evolution.

market, one that is primarily concerned with aesthetics. Along the objective dimension, by allocating some of the costs of the panel to building materials, BIPV can change the ROI argument for PV and make it a lot stronger. BIPV also opens up entirely new ways of product differentiation in the marketplace, and effectively presents an impressive new business case.

We believe that the business case for BIPV has a very wide applicability, but the fact that BIPV is about building (by definition) means that there will be important variations from one location to another. BIPV will surely see the greatest adoption rates where conventional PV is already strong, most likely in the regions of Japan, Germany and California. We believe also that future expansion in PV markets is likely to occur where governments remain benevolent towards PV and where energy costs are high, which would include some states in the northeast of the U.S.

The importance and nature of building aesthetics varies considerably from nation to nation, so BIPV may be deployed in Japan, for example, in a way that reflects local tastes and somewhat differently in Chile to reflect aesthetic tastes there. Beyond this, however, BIPV business cases can best be made where aesthetics is a particularly important factor in the construction industry as a whole. This would include affluent communities, of course, but also (at an international level) countries where prestige buildings of various kinds are under construction, for example China, India, smaller Asian nations and some wealthy Arab states.

These variations aside, NanoMarkets believes that BIPV has the potential to be a major money spinner. We think that it could generate US$11.5 billion in revenues worldwide by 2016 – a figure that should, of course, be thought of as the potential that can be achieved if the right business cases are made for this exciting new technology.

About the Author

Lawrence Gasman is the principal analyst for NanoMarkets, a market research and consultancy firm based in Glen Allen, VA. He has almost 30 years' experience of analyzing the commercialization potential of complex technologies for a number of high-profile and start-up technology clients and investment firms. His current research focuses on printable, organic, and thin-film electronics, including photovoltaics applications.

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New challenges for photovoltaic grid-connected inverters

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ABSTRACT

As PV power generation adoption becomes more widely adopted globally, the grid-connected inverter market looks set to take its rightful role as a critically important element of solar installations. The grid-connected inverter market will deliver power quality and the stability of the electricity networks in order to ensure a stable and reliable grid operation. In order to keep up with these developments, network operators will release new grid codes to monitor the increased uptake, to which manufacturers must adhere. An additional obstacle for the inverter manufacturers is the wide range of requirements and norms that vary from country to country and, in many cases, even from utility to utility. This article presents a review of the new challenges facing grid-connected PV inverters in the light of these new developments.

One of the most formidable problems that must be tackled by grid-connected inverter manufacturers is that they must comply with different technical regulations for grid-connected PV systems in almost every country. For example, each European country has different requirements for grid interfaces. Germany has the VDE 0126-1 "Automatic Disconnection Device Between the Generator and the public low voltage grid" stipulation; Italy requires compliance to the Enel standard DK 5940 "Criteria for plant connections to the grid"... the list goes on. Each of these country- and region-specific standards will have different limits for voltage and frequency variation under which the inverter must disconnect from the grid. Beside the inevitable repercussions for parameters such as different schemes for fault-ride-throughs, it will also result in higher product cost.

From a technical point of view, up to now, the more common inverter designs have aimed to feature the following parameters: temperature range of -25°C to 50°C; lifetime evaluation of around 20 years; efficiency greater than 94% over a wide range; electromagnetic compatibility; low cost; reliability; tolerance of all grid faults; power factor close to 1; and maximum power point tracking (MPPT).

Nowadays, the objective of any inverter is the conversion of DC voltage at the PV generator to a sinusoidal AC current waveform at the output of the switch converter in order to connect and synchronize the generator to the utility network. But this objective has altered of late. New requirements are being asked of PV inverters at different levels: evolution of key characteristics such as efficiency, cost and reliability; compatibility with new materials (SiC, GaN); adoption of disruptive technologies like microinverters; effective MPPT capabilities; as well as compliance with new demands such as anti-islanding methods.

Concerning new materials requirements, for example silicon MOSFETs, SiC technology has undergone significant carbide challenge improvements that now allow fabrication of MOSFETs capable of outperforming their Si insulated-gate bipolar transistor (IGBT) 'cousins', particularly at high power and high temperatures. This illustrates one way in which PV inverter efficiencies can be improved.

Inverters and standards

The MPPT efficiency, or the ratio of the energy obtained by the inverter from a PV array to the energy obtained with ideal MPP tracking over a defined period of time, is another possible cause of energy losses in an inverter. The official method of testing MPPT efficiency is currently by application of the EN 50530 standard. This standard provides a procedure for the measurement of the

Figure 1. A PV grid-connected inverter installed in a Spanish PV plant.

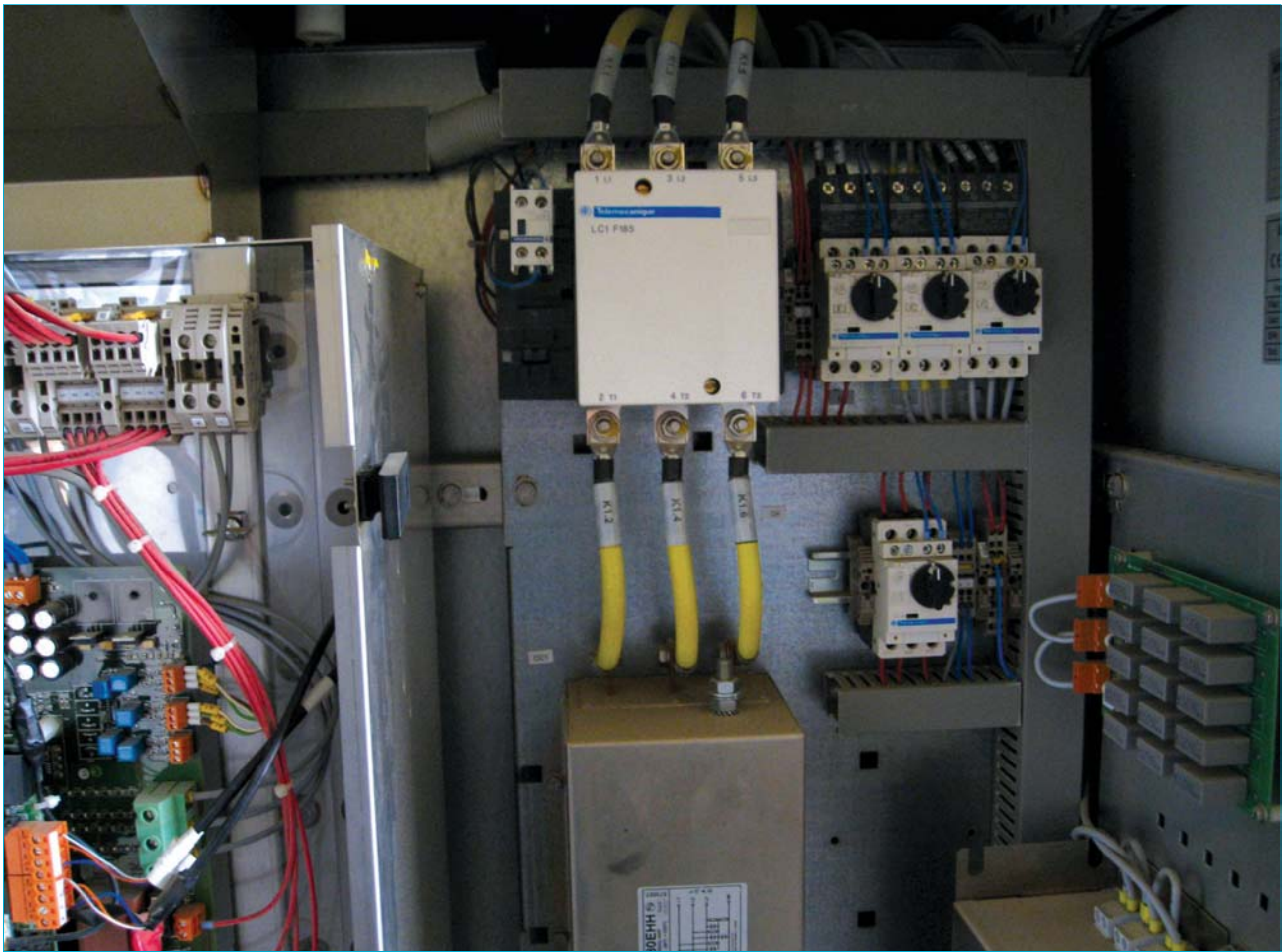

Figure 2. Electronic components of a grid-connected PV inverter.

MPPT of inverters that are used in grid-connected photovoltaic systems, and stipulates that the inverter energize a low-voltage grid of stable AC voltage and constant frequency.

"Static and dynamic conditions must also be considered in testing for this standard."

Static and dynamic conditions must also be considered in testing for this standard. The MPPT efficiency versus the overall inverter efficiency is estimated, which takes into account the static power conversion efficiency of the inverter.

However, any catalogue or handbook of PV inverters rarely provides an MPPT efficiency for an inverter; even when that figure is given, it is assumed by most to represent the rated power. On the odd occasion that this value is reached by the inverter in question, the fact that there is such a discrepancy between what is assumed to be the rated power and the reported MPPT efficiency is rarely mentioned. It is clear that there is a need for change in this sector, both from the point of view of improvement of MPPT efficiency and in the testing and display of the results.

Another factor that has been standardized is the islanding, as per the IEC 62116 standard. Islanding occurs when a portion of an electric power grid, containing both load and generation, is isolated from the remainder of the electric power grid. This is a situation with which electric power providers (utilities) must regularly contend, and can be extremely dangerous to those working on the power grid as it can lead to power flowing in the opposite direction.

EN 62116, a European standard that will be published later this year, will most likely not change very much compared to its predecessor, the IEC standard published in 2008. However, this standard will not specify setting parameters (voltage and frequency trip magnitude and trip time) nor pass/fail criteria as the region or country's specific national standards and/or grid codes must be applied in each case. Thus, standardization of inverters is not possible as it is in contradiction with the philosophy of a true international standard.

Another important issue is the increasing usage of non-linear electrical loads, such as electronic rectifiers or converters [1]. These loads can strain the grid by introducing current harmonics, creating a voltage drop over the grid impedance, with respective spectra, that leads to a non-sinusoidal grid voltage. PV inverters that feed the grid decentrally and can support the grid with reactive power are generally capable of supplying the grid with a sinusoidal active current as well as specific non-sinusoidal reactive currents, depending on the quick response of the current control. A compensating current can be determined with the measured grid voltage and the complex and frequency-dependent grid impedance, which eliminates the voltage harmonics. In order to achieve this, the grid voltage signal needs to be analysed by a group of digital filters tuned to different harmonics. The compensating current can then be determined from the filter results and the knowledge of the grid impedance angle or adequate control algorithms and adjusted accordingly.

A new PV inverter concept that is emerging onto the market is the range of smart inverter technologies for high penetration of PV, which are presenting a true challenge for inverters, as discussed within Task 14 of the IEA PVPS.

PV inverters play a key role as the interface between primary generation and the electricity grid itself. Their range of responsibilities includes the integration of protection and grid monitoring, system monitoring and control, and various other multifunctional characteristics [2].


Figure 3. The back-side of a PV module.

Power Generation

The future of inverters in high-penetration PV scenarios is uncertain. The next generation of inverters should be capable of acting as an interface between PV generation and the grid, providing reactive power during normal operation, operating during grid faults and contributing to short-circuit current and controllability of active and reactive power injection.

> "PV inverters play a key role as the interface between primary generation and the electricity grid itself."

In addition, PV inverters will need to offer dynamic grid support (fault-ride-through), adapting their behaviour to the specific requirements of the system operation and PV support fault management in the grid. The PV inverter should be a hub and centre for data acquisition, system monitoring, communication and control. It should have standardized communication interfaces and control protocols for easy interconnection. Full integration into the EMS of the grid operator will also be necessary, as well as a feature that allows for the optimized direct utilization of PV electricity travelling towards grid parity.

> "The inverter needs to be integrated into the grid management to allow for temporary short-term power curtailment during critical situations, as and when required by the grid operator"

From the point of view of integrated grid protection, a definite set of conditions should be provided that govern when a generator should remain connected and be adapted to the requirements of the system in question. Excellent communication and control is required for integration into the system's control. Smart inverters should be capable of coordinating the voltage control, the reactive power balancing, the active power limitation for frequency control and the power on demand from storage.

In addition, the smart inverter should have multifunctional characteristics such as voltage regulation, filtering/compensation of harmonics as well as backup supply functionality.

The PV inverter needs to act as an interface between local storage and the grid. In this way, it needs the capacity to integrate into grid management, to provide power on demand, peak shaving/shifting, and to be able to increase the security of supply and provision of ancillary services to the grid and the hosting capacity of the grid.

Furthermore, as a vital part of the grid management, the inverter needs to be integrated into the grid management to allow for temporary short-term power curtailment during critical situations, as and when required by the grid operator (operated by remote control).

The growth and extent of the penetration of inverters into the PV sector will require the active integration of installations into grid operation. At that point, PV inverters will become key elements towards enabling electricity grids to become more accessible to PV. The range of new requirements necessary in order to make this a reality will demand several big steps in inverter technology innovation. Some of the features that will help the sector excel in this regard include: the provision of system services; contribution to grid support; and integration into grid management with the aim of helping to significantly increase the proportion of PV-generated energy in the electricity grids.

The microinverter

A further noteworthy concept that will undoubtedly be essential to the future of PV inverters is the introduction to market of microinverters, essentially small inverters tuned to the output of a single typical panel. The concept behind microinverters was first introduced in the 1970s, with the launch of real-world products following in the 1990s. The main disadvantage of the microinverter concept is cost related: because each panel has to duplicate much of the complexity of a string inverter, the distributed and flat costs are much greater.

Microinverters are particularly well suited to use in small photovoltaic systems of 1kWp or less. In some larger photovoltaic systems that use string inverters, shading of individual modules and the subsequently lower energy harvest of the entire system can be avoided by equipping and operating those modules with individual module inverters.

The key feature of a 'true' microinverter is not its diminutive size nor its power rating, but its ability to provide one-to-one control over a single panel and its mountability either on the panel or near it. Both small string inverters and larger inverters control multiple panels and are generally mounted remotely, often indoors.

Microinverters produce grid-matching power directly at the back of the panel. Arrays of panels are connected to each other in parallel, and then to the grid feed. This has the major advantage that a single failing panel or inverter will not take the entire string offline. Combined with the lower power and heat loads, as well as improved mean time between failures (MTBF), it is suggested that overall array reliability of a microinverter-based system will be significantly greater than a string-inverter based one.

More and more microinverter brands are becoming active on the market, with product names such as Accurate Solar, Azuray, Direct Grid, Enecsys, EnPhase Energy, GreenRay Solar, Larankelo, OKE, Petra Solar and SolarBridge becoming commonplace. A new standard is due to be introduced to the industry in the near future in the form of the IEC 62109-4 standard: Safety of Power Converters for Use In Photovoltaic Power Systems – Part 4 – Particular Requirements for PV Modules with Integrated Electronic Devices.

Conclusion

Finally, it is vital that the revised standards include guidelines relating to evaluation of start-up and shut-down losses; power factors; performance outside normal operating conditions; DC current injection; MPPT performance under real conditions; overall performance measure (energy rating); active power control; reactive power control; limits for harmonics and flicker and low-voltage ride through (LVRT) capability. Topics related to electromagnetic compatibility (EMC) should also be taken into account. It is to be hoped that any future developments relating to international standardization will incorporate these topics in order to render it a worthwhile task.

Reference

[1] Burger, B., Reichert, S. & Siedle, C. 2010, "Improvement of power quality by PV inverters", Fraunhofer ISE [available online at http://www.ise.fraunhofer.de/].

[2] Bründlinger, R. 2010, "Inverter Technology enabling high penetration PV", *Proc. 25th EU PVSEC*, Valencia, Spain.

About the Author

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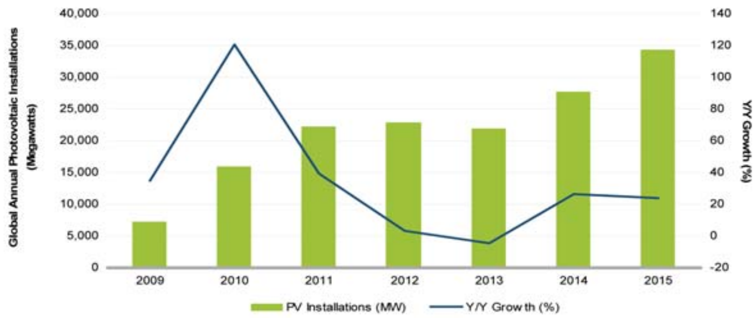
Market Watch



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News

LDK Solar signs definitive agreement for its polysilicon business

LDK Solar, along with its polysilicon manufacturing subsidiary, has signed a definitive agreement with China Development Bank Capital Corporation, Excel Rise Holdings, Prosper East and an investment fund associated with another Chinese bank, where the investors will all subscribe to a collective US$240 million in series 'A' redeemable convertible preferred shares of LDK Silicon & Chemical Technology. The wholly owned subsidiary of LDK Solar, contained in the Cayman Islands, will hold and operate LDK Solar's polysilicon division once all PRC government approvals for foreign investments have been completed.

The signed definitive agreement has given the investors the right to veto specified matters, disclosure of specific information about the polysilicon division and certain registration rights. The preferred shares on an as-if converted basis are around 18.46% of the combined issued and outstanding share capital of LDK Solar's subsidiary on a post-money basis and as part of the definitive agreement, LDK Solar has agreed to reimburse the investors with cash if the company does not reach specified net income target. Conversely, the investors consented to waive the reimbursement if LDK Solar's polysilicon subsidiary reaches its qualified IPO during 2011. The investment will be finalized once specified closing conditions, such as governmental and corporate approvals from all parties, have been completed.

Raw polysilicon.

Financial & Business News Focus

JA Solar 2010 revenue US$1.78 million: total 2011 PV shipments to pass 2.2GW

Citing 2010 as a transformational year for the company, Dr. Peng Fang, CEO of JA Solar, noted that annual revenues increased 211%, while PV shipments increased by 187%. Revenue for the year was US$1.78 million and PV shipments reached 1.46GW. Strong growth is expected in 2011. JA Solar guided total cell and module shipments to exceed 2.2GW in 2011, a 50% increase over 2010. Module shipments are expected to be approximately 500MW to 600MW. Signed supply contracts for 2011 are more than 2GW, representing approximately 90% of expected shipments this year.

JA Solar also reported fourth quarter results with total shipments in the quarter reaching a record 463MW, up from 418MW in the previous quarter and an 11% q-on-q increase. Revenue in the fourth quarter reached US$584.3 million, an increase of 6.6% compared to the third quarter.

Gross profit for the quarter was US$112.2 million, compared with US$123.6 million in the third quarter of 2010. Gross margin was 19.2% in the fourth quarter of 2010, compared with 22.5% in the third quarter of 2010, perhaps the only negative aspects from an otherwise significant 2010 for the company.

Source: JA Solar

JA Solar cell manufacturing.

Trina Solar module shipments top 1.06GW in 2010: capacity to reach 1.9GW mid-year

Trina Solar squeezed a little more module shipments out of the factory gate in 2010 than previously guided. Shipments were approximately 351MW for the fourth quarter of 2010, compared to previous guidance of approximately 300MW, resulting in total 2010 module shipments reaching approximately 1.06GW in 2010. Net revenues in the fourth quarter were US$641.8 million, an increase of 26.3% sequentially and 104.9% year-over-year. Total revenue for 2010 reached US$1.86 billion, an increase of 119.8% from 2009. Gross profit was US$584.4 million, an increase of 146.4% from 2009, while gross margin was 31.5%, compared to 28.1% in 2009.

Trina Solar guided shipment volumes for PV modules to be slightly higher than that for the fourth quarter of 2010. For the full year of 2011, the company expects total PV module shipments between 1.75GW to 1.80GW, representing an increase of 65.6% to 70.3% from 2010.

PV cell and module production reached approximately 1.2GW of annualized capacity during the fourth quarter of 2010, compared to its previous guidance of 1.1GW, based on actual manufacturing yield.

However, Trina Solar noted that its non-silicon manufacturing cost for its core raw materials increased by US$0.01 to was approximately US$0.74 per watt due to strong market demand for PV modules in the fourth quarter, indicating tight material supply. This is not expected to last as the company guided non-silicon manufacturing cost is expected to decline to approximately US$0.70 by the end of 2011.

Source: Trina Solar

Trina Solar's 'Quad Max' solar cell.

SunPower sees quarterly results fuel late-year surge, as annual revenues push past US$2.2 billion

Fueled by fourth-quarter sales of US$937 million, SunPower saw its fiscal 2010 revenues exceed US$2.2 billion and net income come in at more than US$178 million - a better-than-fivefold improvement over its FY2009 income result. The solar company said it exceeded its 2010 plan in both its residential/commercial and utility and power plant business units, recognizing 546MW in installed capacity.

SunPower cited several key milestones achieved since the third quarter, including an agreement to sell 250MW California Valley Solar Ranch power plant to NRG Solar; the industry's first publicly-rated solar project bonds, approximately €195 million, and sale of the 72MW Montalto Solar Park in Italy; the dedication of 1.4GW Fab 3 joint venture in Malaysia with AU Optronics; the signing of three power purchase agreements with Southern California Edison totaling 711MW; the expansion of the global utility and power plant pipeline to more

Photo: Tom Cheyney

SunPower closed 2010 on a strong note, and expects to exceed 1GW in production capacity by the end of 2011.

than 5GW in 2010; and a record North American commercial backlog, with 90% booked for 2011.

The updated guidance calls for Q1 2011 revenues in the US$475 million to US$525 million range, with annual fiscal revenues between US$2.8 billion and US$2.95 billion, based on 825 to 920 of total recognized megawatts.

Conergy sales increase more than 50% in 2010

Preliminary 2010 financial figures from Conergy indicate sales increased by more than 50% in 2010. Sales reached €913.5 million, compared to €600.9 million in 2009. For the first time since 2006, Conergy returned to profitability, posting a €30.1 million EBITDA, compared to a loss of €10.7 million in 2009. Conergy managed to increase its profit margin by four percentage points to 23.7%.

However, extraordinary depreciation also led to a value adjustment of deferred tax assets on losses carried forward, which meant that earnings after taxes were additionally encumbered by approximately €9.5 million.

The tax result from continuing operations thus amounted to €-13.5 million (2009: €-22.5 million). Taking into account a financial result of €-14.7 million (2009: €-21.8), the after-tax result amounted to €-42.0 million (2009: €-81.1 million). Consequently, the loss was reduced by €39.1 million compared to the previous year.

Sunways preliminary financial results higher than expected

Preliminary annual financial results from Sunways were higher than the company expected for 2010. Sales for the PV systems supplier and manufacturer reached €222.7 million, up 25% of the previous year. Sunways had expected annual sales of €215 to 225 million and an EBIT margin of approximately 6%. Sales in the fourth quarter were reported at €55.5 million with the operating result (EBIT) anticipated at about €15 million for the year.

The company noted that demand for its Ecoline solar modules that were launched in December 2010 contributed to sales. The Ecoline modules are made by LDK Solar with Sunways solar cells and in accordance with Sunways quality criteria. At a total of 16.6MW of module sales were generated in the fourth quarter 2010.

Inverter sales at Advanced Energy top US$105 million in 2010

In just six quarters, Advanced Energy Industries has seen its PV inverter sales go from zero to US$105.8 million, according to the release of full-year financial figures. Inverter revenue in the fourth quarter reached US$51.7 million, up 38% on the previous quarter. Sales to the non-semiconductor thin-film markets were also impressive at US$43.3 million, or 29.1% of total sales, compared to US$41.1 million last quarter. The company posted record fourth-quarter sales of US$148.7 million and full-year sales nearly tripled to US$459.4 million, compared to US$161.8 million in 2009. Advanced Energy guided first sales of between US$132 million - US$142 million, slightly down on the record fourth-quarter results.

Pfeiffer Vacuum increases sales to €220.5 million in 2010

Preliminary financial results for Pfeiffer Vacuum show the company has increased its sales revenues by 21.1% to €220.5 million, compared to the prior year's €182 million. A strong fourth quarter in sales led to higher than expected overall business, the company noted.

The orders received for the 2010 financial year total €223.7 million, a 38.8% increase from the previous year of €161.2 million. The Book to Bill Ratio was 1.01 compared with 0.89 in 2009. New orders received were €58.4 million compared with €43.9 million the previous year, up 33%. The company will present its full financial statements on March 29, 2011.

Source: Pfeiffer Vacuum

Pfeiffer Vacuum's 'HiPace 60 turbo' pump.

Centrotec's Ubbink unit buys stake in Solar23, looks to expand African solar business

Centrotec's wholly-owned subsidiary, Ubbink Group, has bought 60% of Solar23 though a €0.9 million capital increase by Solar23, the German-based company that specializes in solar PV and solar thermal projects in Africa. Solar23 will be integrated into Ubbink's Gas Glue Systems division.

Solar23's background primarily lies in non-grid connected solar systems and has a product range that includes: solar home systems, solar lighting systems, PV deep-well pumps for drinking water supply, power supplies for telecommunications systems, autonomous and grid-connected systems for village power supplies and solar power plants.

As much of Solar23's projects have focused in Africa over the past few years, Ubbink is looking forward to utilizing the resources and connections Solar23 has established on the continent. The management team for Solar23 will remain, to help with the transition and to help Ubbink promote its growth in Africa.

Photon Energy reveals 2010 consolidated revenue reached US$140 million

Photon Energy has completed and released its full-year financial results for 2010. The company highlighted its fourth quarter 2010 as being particularly impressive since during the time period, Photon Energy added 14.2MW of PV plants to its portfolio in the Czech Republic and 4.7MW in Slovakia, all of which were installed in time to benefit from the 2010 feed-in-tariffs offered.

Originally, Photon Energy had predicted that its consolidated revenue for 2010 would reach US$105.79 million, which was later revised for anticipated revenue of US$125.27 million. However, both projections were surpassed as the company posted consolidated revenue for 2010 reached US$138.58 million compared to 2009's posted revenue of US$29.28 million. Photon Energy also posted a total comprehensive income (TCI) for 2010 of US$24.25 million, but notes that its TCI would have reached US$37.02 million if it wouldn't have been impacted by the retroactive taxation of PV plants in the Czech Republic.

The company reported that its net profit for the year from operating activities rose by 45.5% to US$3.22 million, which although is an increase, is still weaker than the third quarter net profit level of US$5.21 million. Photon Energy advised that this drop was due, among other factors, to their focus on building proprietary projects over EPC business during 2010's fourth quarter.

Photon Energy points out that their 2010 financial results exclude the revaluation of their share in the 4.7MW of projects completed and connected in Slovakia by the end of 2010. As the projects were not officially handed over to the project companies, they could not be recorded in their particular accounts.

Looking towards the future of 2011, Photon Energy advises that it will be concentrating on two new markets: Italy and Germany, while also continuing work with its existing markets. Photon Energy is also maintaining its pursuit for capital increase of Photon Energy N.V., an exchange offer by Photon Energy N.V. to Photon Energy a.s. shareholders and a listing on the main market of the Warsaw Stock Exchange.

Emcore sales declining: solar space project delayed

After a period of strong orders for CPV systems used for commercial satellite projects, Emcore reported a decline in its backlog and guided a further reduction in sales as new orders were impacted by a delay with an unidentified satellite order. The company posted a net loss was US$3.6 million in the last quarter on combined sales of US$52.1 million. Revenue for the Photovoltaics segment was US$20.3 million, a new record, which represented a 21% increase compared to the same period a year ago and a 3% increase compared to the previous quarter.

Emcore reported a backlog for photovoltaics of US$36.1 million, a 32% decline from US$52.9 million reported in the immediate preceding quarter. The decline was due to completed projects and a delay in an expected new order. Guidance was given for the March quarter of lower revenue in the range of US$46 to US$49 million.

SolarWorld shipments increased 42% in 2010

Preliminary financial results from SolarWorld show the integrated module manufacturer posted revenue of €1.3 billion in 2010, a 29% increase over the previous year, when revenue of €1.01 billion was reported. Shipments of wafers and solar modules also increased over the previous year, reaching 819MW, up 42% over figures logged in 2009 when shipments reached 578MW.

EBIT amounted to €193 million, compared to €153 million in 2009. Margins remained static at 15%, compared with

SolarWorld's silicon wafer production facility in Hillsboro (near Portland, Ore.)

Source: SolarWorld

the previous year. Profit increased to €89 million for the year, compared to a profit of €59 million in 2009. SolarWorld also noted that it had received 90% uptake in the share swap for the acquisition of Solarparc, suggesting the takeover would be concluded shortly and would boost SolarWorld's downstream efforts.

9REN closes on €21.5 million financing for 6.5MW Italian PV plant

The 9REN Group recently closed on a funding lease from UniCredit Leasing that will go towards the financing of the Pacione 1 PV power plant. The Italian PV plant, located in the Taranto province, is complete and holds a 6.5MW capacity. Grid connection is expected to occur in the next few weeks. The Pacione plant brings 9REN's portfolio for operational solar systems to 50.6MW; 35.6MW being located in Italy and 15MW located in Spain.

Belgian PV encapsulant developer NovoPolymers gets €4.2 million in new funding

NovoPolymers has announced that in addition to expanding its Belgian production plant, the company has also received €4.2 million from its shareholders Gimy and Capricorn Cleantech Fund during the company's second financing round.

With the expansion of the company's manufacturing facility, the Belgian plant will have a production capacity of 1GWp. NovoPolymers' technology is based off thermally curable ethylene vinylacetate (EVA) sheets. They are known for their line of thermoplastic-based encapsulant sheets used in c-Si cell-based PV modules. Further, the company is developing a cured EVA system to expand its portfolio further.

Amtech Systems completes takeover of Kingstone

Amtech Systems has completed its takeover of Kingstone Technology Hong Kong by acquiring a majority stake in the company for US$9.5 million. By acquiring 55% of Kingstone, Amtech also takes control of the company's ion implant technology, which it hopes will strengthen its position in the solar industry.

The payment entails a US$5.5 million cash and stock payment and a US$4 million contingent promissory note, which will help Kingstone develop its next-generation solar ion implant technology. Should it be required, Amtech has agreed to provide further funding for technological development over the next two years. The takeover will also see Amtech inherit worldwide rights to sell and service any solar ion implant machine developed by Kingstone Semiconductor.

AES Solar buys Tessera Solar's Imperial Valley project with intent to turn CSP into PV

First, Tessera Solar sold its 850MW Calico Solar project to K Road Sun in late December and now the company has announced that its 709MW Imperial Valley solar project has been bought by AES Solar, who, like K Road, intends to convert the CSP project into a PV installation.

Although AES solar advised that it intends to work with San Diego Gas & Electric (SDG&E) on the power purchase agreement that was signed with Tessera for Imperial Valley, Patty Rollin, a managing director at AES Solar, did not disclose extensive information, of financial details, about the company's purchase or development plans for Imperial Valley.

SolarCity expands to Northeastern U.S. with acquisition of groSolar

SolarCity will be expanding its reach to the U.S. East Coast with it purchase of residential solar installer groSolar. By buying the company's residential solar installation division, SolarCity will be able to bring its SolarLease program to the Massachusetts, New Jersey, New York and Pennsylvania markets. The solar lease and solar purchase options will become available to homeowners and businesses in the new U.S. regions by early March with energy efficiency services started later this year.

SolarCity installation in San Raphael, California.

Source: Courtesy of SolarCity

In the early stages of the expansion, SolarCity will serve customers in a 100-mile radius of its operation center in Billerica and Raynham, Massachusetts, Broomhall, Pennsylvania, Albany, New York and Jessup, Maryland. SolarCity expects to extend its customer reach within the regions later this year.

U.S. DOE invests US$20.3m in manufacturing, advanced photovoltaic technologies

The U.S. Department of Energy (DOE) has pledged US$20.3 million for innovative projects in a bid to strengthen the country's solar manufacturing industry, improve manufacturing efficiencies, and reduce costs. The money will be invested as part of the DOE's SunShot program.

As part of the initiative, the DOE will provide support for companies across the solar energy supply chain, including U.S. material and tool suppliers and organizations that are developing technologies that can be adopted directly into current manufacturing processes.

The award recipients, which are pursuing projects that focus on technology improvements that will lead to improved solar cell efficiency, reduced production costs, and a stronger domestic photovoltaic (PV) industry include: 1366 Technologies' US$3 million Massachusetts-based project, 3M's Minnesota-based initiative, Varian Semiconductor's US$4.8 million, Gloucester, Massachusetts-based development and Veeco's US$4.8 million R&D program located in Lowell, Massachusetts.

Market Trends Focus

Crystalline supply chain prices falling on lower feed-in tariffs, says IMS Research

The introduction of lower feed-in tariffs in some of the key PV markets at the beginning of the year are causing prices to fall throughout the crystalline supply chain, according to the latest quarterly report from IMS Research. Polysilicon, wafer, cell, and module prices are expected to fall 7% on average in the first quarter and should continue to decline in the second quarter.

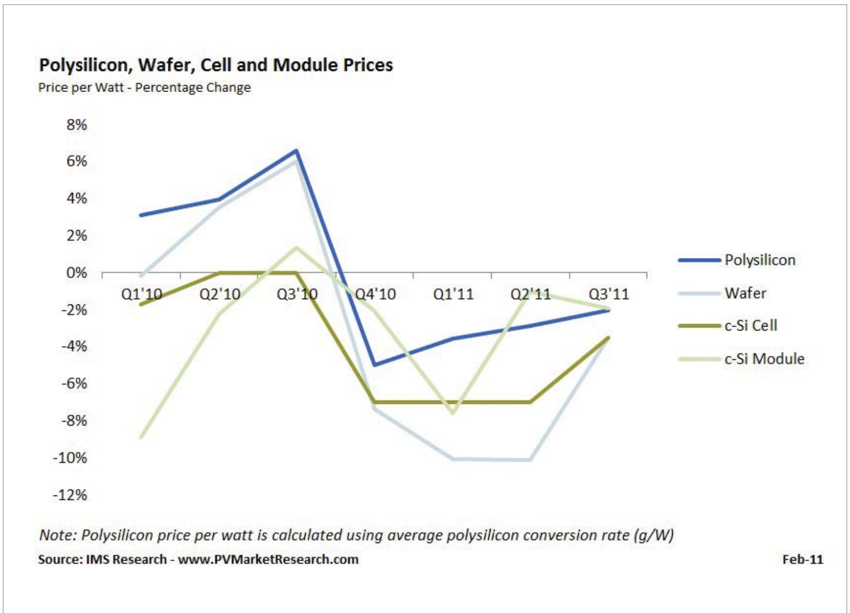
The market research firm noted that the average polysilicon contract price fell by just 2% in Q4'10. However, polysilicon spot prices are claimed to have fallen by 10%, reversing the increases seen in the previous quarter when Tier 2 and 3 suppliers had been able to sell silicon at inflated prices because of high demand and a shortage in supply.

IMS Research expects both contract and spot prices to continue falling in Q1'11, falling by 4% on average over the previous quarter. With most Tier 1 module manufacturers 'sold out' in 2010, second-tier players were able to gain market share. However, weakened demand at the end of the year meant that supplies were freed up, forcing Tier 2 module pricing to fall. According to IMS Research, Chinese Tier 2 module prices are forecast to fall by nearly 10% in the first quarter of 2011.

Evergreen Solar's manufacturing costs rise as ASPs fall

Duties on its imported aluminium module frames pushed Evergreen Solar's manufacturing cost per watt higher as average selling prices (ASP) fell, according to unaudited preliminary results for the quarter ended December 31, 2010. Total manufacturing cost per watt was approximately US$1.92, an increase of US$0.04 per watt from US$1.88 per watt reported for the third quarter of 2010, but ASPs declined 6% in the quarter to US$1.90 per watt.

As a result, gross margin declined to approximately negative US$0.4 million, or -0.5%, versus a gross margin of US$6.5 million, or 7.5% for the third quarter of 2010. Evergreen Solar noted that cash and cash equivalents were approximately $68.4 million ending the quarter.



Source: IMS Research

Polysilicon, wafer, cell and module prices, February 2011.

Global Tariff News

Germany

Germany's cabinet has confirmed that it will cut solar power subsidies by up to 15% in July 2011, ending the ongoing dispute between the economy and environment ministries. Parliament is scheduled to vote on the cuts in March, which were originally planned to only take effect in 2012.

If, however, the market slows and projected market growth for the entirety of 2011 is less than 3.5GWp, the first feed-in tariff adjustment won't occur until the beginning of 2012, as previously planned. Furthermore, the new mechanism allows for a FiT increase should installations not reach 2.5GW.

Spain

The Spanish Government has made the controversial decision to again cut the financial support offered to solar power generators. The Government's proposal involves a cap being placed on the number of hours of subsidized generation that solar plants can sell to the grid, reducing this limit from 1,753 hours down to 1,250 processing hours.

Additionally, systems mounted on single-axis trackers will now only be funded for the first 1,644 hours; systems with double-axis trackers will see payments for the first 1,707 hours only. This will apply to all PV plants connected to the grid by September 2008. As a form of reimbursement, PV plants will receive the feed-in tariff payments for three more years – an extension from the original 25 years to 28.

Italy

A sudden rise in the number of solar power installations in Italy is being investigated by the country's Government over fears of feed-in tariff fraud, according to Industry Minister Paolo Romani. Around 55,000 requests for Government incentives covering projects with a total capacity of 4GW were received by GSE, the state energy services agency, as developers rushed to sign up before FiT rates expired at the end of the year. According to the new Conto Energia III, Italy will begin reducing its funding for solar electricity in three phases starting from June 2011.

UK

Although the UK's solar industry has seen a productive beginning since the introduction of the feed-in tariff in April 2010 the country's Government could potentially put a stop to future development. The UK now has approximately 60MW of installed capacity, which equates to around 23,000 installations, the majority of which are residential. However, the country's Department of Energy and Climate Change has made several rash announcements in recent months which have caused a lot of investor anxiety in the industry.

Showing its support for the residential sector, and highlighting its opposition to medium-to-large-scale projects, the Government's most recent decision to review the feed-in tariff levels for all projects of 50kW or above has halted the progress the market has thus far made. A final decision on how this review will affect non-residential installations is expected by the summer recess.

Czech Republic

The Czech Senate has approved a new law, which will add a 26% tax on solar energy production over the next three years, as well as 32% tax on carbon credits awarded to solar companies in the next two years. The new taxes will apply to all PV plants that were guaranteed to receive a fixed feed-in tariff for a period of 20 years.

The solar production tax on revenue will not apply to solar plants placed on top of buildings with a capacity lower than 30kW. This solar tax will be retroactively applied to all ground-mounted PV built in 2009-2010 in the Czech Republic.

France

France's industry minister Eric Besson may decide to hold tenders for some types of solar energy projects as a way to slow the industry's development, which has increased dramatically due to falling equipment costs. 'Tenders would be best-suited' for ground-based projects, explained Besson at a conference in Paris. Rules may vary depending on the type and may be ready by the middle of February; no details were provided for rooftop installations.

The Government has already suspended solar energy projects with a capacity of more than 3kW for three months as it contemplates potential subsidy cuts and measures to limit growth after this surge in development. Capacity is expected to rise to about 2,150MW at the end of 2011 from just 200MW in 2009, according to France's energy regulator.

The country's solar energy market could also see a 500MW cap from 2011 in addition to the projects that have already received permits by the end of 2010. The French Government estimates that 3.4GW of projects have received construction permits in 2010 and roughly 2GW of these projects could ultimately get built in the 18-month timeframe which stretches to the first quarter of 2012.

Turkey

After months of speculation surrounding the country's solar feed-in tariff, Turkey has now made photovoltaic power generation subsidy payments law. Under the regulation, payments for renewable energy generation will be determined as dollar cent, as opposed to Euro cent, in Turkish Parliament.

Accordingly, solar generators will be paid US$13.3 cents per kilowatt hour. These prices will be applied for 10 years to those which apply for RES between May 18, 2005 and December 31, 2015. For companies beginning operation later than December 31, 2015, the FiT rates will be determined by the Council of Ministers.

If the products utilized for the plants carry the 'Made in Turkey' stamp, additional credit will be given for five years after the facility's establishing date. This support will be applied from US$0.4 to 2.4/kWh. There is, however, a 600MW cap in place up until December 31, 2013. For applications later than that date, the Council of Ministers will be authorized to determine total installed power.

California

The California Public Utilities Commission (CPUC) has voted unanimously to approve the state's program designed to drive small to mid-sized renewable energy development. The Renewable Auction Mechanism (RAM) next-generation feed-in tariff program, which requires investor-owned California utilities to purchase electricity from solar and other renewable energy systems from 1.5MW up to 20MW in size, is now set to go ahead as planned.

The Commission vote establishes a 1GW pilot program for power from eligible mid-sized renewable energy systems. The program requires California's three largest investor-owned utilities to hold biannual competitive auctions into which renewable developers can bid. Utilities must award contracts starting with the lowest cost viable project and moving up in price until the megawatt requirement is reached for that round. The program is expected to be operational by the spring of 2011.

Australia (ACT)

Australia's Capital Territory (ACT) feed-in tariff has been expanded to include medium to large-scale solar projects in order to cater for larger commercial and industrial farms as well as community groups. According to the Australian Solar Energy Society, the gross feed-in tariff, which pays a premium for all solar energy generated, is now available for solar panel installations 30kW to 200kW.

Concern was raised over fears that the expansion would eat heavily into an existing overall cap of 15MW installed capacity, which includes residential installations. However, according to the ACT Government's announcement, a separate 15MW cap has been created for medium-scale solar farms as well as a further 15MW cap for a community category.

The ACT feed-in tariff program has spurred the installation of over 3,500 home solar power systems to date; already working towards the 15MW installed capacity cap designated for microgenerator installs.

Japan

The Japanese Government is considering cutting the rate that utilities pay for surplus solar power by 12.5% in April. The Ministry of Economy, Trade and Industry plans to lower the feed-in tariff from the current rate of JPY48 (€0.37) per kilowatt hour to JPY42 (€0.37) per kilowatt hour.

The ministry will make its final decision on whether to cut the tariff or not by March 2011. A drop in the cost of solar panels in Japan is thought to be the reason behind the proposed cut.

Taiwan

The Taiwanese Government has reduced the feed-in tariff for solar power for 2011 by approximately 30% from the levels in 2010 due to the falling cost of solar photovoltaics installation equipment. State-run Taiwan Power will now pay NT$7.33 (€0.184501) per kilowatt-hour for power generated from ground mounted solar installations, compared with NT$11.12 (€0.279897) for 2010, the Ministry of Economic Affairs said in a statement at the end of January this year. The 2011 price for roof-top solar power is as high as NT$10.32 (€0.259637).

Advanced encapsulation for photovoltaics: where are the opportunities?

Paul Markowitz, NanoMarkets LC, St. Louis, Missouri, USA

ABSTRACT
One of the most important ways in which inorganic thin-film photovoltaics (TFPV) and organic photovoltaics (OPV) can distinguish themselves from more conventional crystalline silicon photovoltaics (c-Si PV) in the marketplace is through the commercialization of flexible photovoltaic products using those technologies. But flexible photovoltaics brings with it some challenges of its own in terms of excluding air and moisture from the cells; challenges that translate into opportunities for suppliers of advanced encapsulation materials and systems as well as for TFPV and OPV firms.

Although flexible PV has been talked about for many years, in reality it is limited to just a few products in very limited volumes. However, today there are a number of factors that are combining to push it more solidly into the market. For one thing, the PV market situation in the past couple of years has been dragged down by the worldwide economic downturn, and PV will increasingly need to turn to niche markets to achieve decent revenues, especially if governmental support for PV declines in the future, as we expect. Combine that with growing competition from commodity c-Si panels and the TFPV and OPV industries are looking for newer, higher value products that they can both sell and protect from competition.

As it happens, flexible PV offers an apparent route to achieving these goals. Flexible building-integrated PV (BIPV) products, such as flexible roofing shingles, open up new markets for PV; large markets that are concerned as much or more about aesthetics as they are about being 'green.' There is also a developing niche market for items such as rollable solar chargers for portable electronics, and PV applied to textile products like umbrellas, handbags and clothing.

At least two kinds of opportunities for encapsulation suppliers are created by the current situation. First, there is a need to improve on the existing glass substrate + glass encapsulation paradigm. This is an opportunity, not just because this is where the bulk of the market is right now, but also because rigid TFPV is often associated with the highest performance and there will always be a need for high-performance TFPV products. Second, there is the (still wide open) opportunity to create a novel flexible encapsulation method that will prove an enabling technology for intrinsically flexible products. We believe that this technology would – in the technical sense of the term – be a disruptive technology, in that it could prove to be a key enabling technology that opens up BIPV markets and perhaps even technically related markets such as intrinsically flexible displays.

Rigid photovoltaics products can generally be easily encapsulated in glass, which forms a suitably impenetrable barrier for air and water (with some exceptions, as will be discussed). Removing the glass from the outside of these modules leaves the devices within at the mercy of whatever barrier material is used instead. Plastic films – typically both the cheapest and the simplest encapsulation materials – are often not up to the task, especially for the more sensitive of the TFPV and OPV technologies. Firms that can produce robust, easy to use, and in some cases relatively inexpensive encapsulation solutions stand to benefit financially as they bring flexible applications within reach of TFPV and OPV, or even open entirely new markets to these PV technologies.

"Rigid photovoltaics products can generally be easily encapsulated in glass, which forms a suitably impenetrable barrier for air and water."

On the flexible products side, the lack of an existing high-volume market of flexible PV to consume new encapsulation materials is of some concern to flexible encapsulation developers, but there is not as much risk as one might think. Big companies like Dow Chemical are getting behind flexible PV, and the nascent flexible encapsulation market is actually quite 'diversified' – that is, it does not rely solely on photovoltaics. Other highly sensitive emerging technologies are also waiting in the wings for better flexible encapsulation developments. Most notable of these is the market for OLEDs for both lighting and displays, as well as e-paper for signage and displays.

OLED materials are as sensitive to moisture as are CIGS and OPV materials; as with OPV, they are sensitive to oxygen. Like many flexible PV applications, OLED lighting is also at the transition from development to commercialization. Flexible encapsulation developers moving into commercialization will not have long to wait for a rapidly growing market.

As a result of the needs of flexible PV devices and the shortcomings of existing encapsulation technology, some segments of the PV industry are chomping at the bit for better encapsulation solutions; 'better' in this case being from the standpoint of either performance or cost. In order to make money in the encapsulation business, it is important to understand where performance enhancements are needed. NanoMarkets' research indicates that the best markets for advanced encapsulation firms to concentrate on are thus CIGS PV and OPV.

CIGS: different from other inorganic TFPV

Not all TFPV is created equal in terms of the types of encapsulation needed. In fact, in the inorganic TFPV segment, the differences in requirements are so great that, when the encapsulation industry talks about advanced encapsulation for 'inorganic PV,' in most cases it is really referring to CIGS. The most moisture-sensitive of the inorganic thin-films commonly used for photovoltaics, CIGS has an inherent degradation mechanism in the presence of moist heat. The aluminium-doped zinc oxide (AZO) front electrode also contributes somewhat to its sensitivity.

The sensitivity of CIGS is in contrast to thin-film silicon PV, which is much less sensitive and can often use fairly simple encapsulation solutions, even polymer films. Furthermore, encapsulation for flexible CdTe PV is essentially a non-issue, since

the CdTe sector is so completely dominated by a single company – First Solar – which is doing just fine supplying only rigid, glass-encapsulated products. Were First Solar or a competitor to introduce flexible CdTe PV devices, they would not be as sensitive as CIGS is to moisture.

CIGS needs advanced encapsulation for flexible products, to extend lifetimes and improve reliability. This is especially important because the CIGS industry has its sights set – more so than any of the other PV technologies – on flexible BIPV products. These solar shingles and other flexible products aim to offer the double whammy of high performance and flexibility, all in a package that is both aesthetically superior to conventional panels and accessible to the mainstream building markets where flexible building materials are the norm for things like roofing. Such products now exist only using thin-film silicon PV technology, but they are very limited in conversion efficiency and thus performance. CIGS PV stands to double the performance of current products, allowing higher power output on limited-size building surfaces and thus demanding a substantial premium. It is also important that the modules last as long as the conventional building materials and conventional solar panels; however, this is the very goal of advanced encapsulation for CIGS.

> "CIGS industry has its sights set – more so than any of the other PV technologies – on flexible BIPV products."

As is the case for CdTe PV and most other PV technologies, CIGS's encapsulation problems are negligible for the most part in rigid products as glass surrounds and protects the cells. CIGS can certainly have a robust market – provided the supply can be developed – in rigid products, but NanoMarkets predicts that flexible applications will make up a much larger proportion of the market for CIGS PV than it does for the other inorganic PV technologies. Producers and developers of flexible CIGS products will pay a premium for encapsulation that works, and will take advantage of cost reductions as they become available.

OPV needs encapsulation

So if CIGS needs advanced encapsulation as 'icing on the cake', OPV needs encapsulation as the cake batter itself. OPV is so sensitive to air and moisture that even the lifespan of glass-encapsulated modules is limited by intrusion of these elements. That is, for conventional OPV panels, besides being much lower in power output and not much different in price versus other PV, they also have much shorter lifetimes. As a result, advanced encapsulation is needed for glass-encapsulated OPV products.

> "OPV cannot compete unless it carves out niches for itself where other forms of PV cannot or will not compete."

But advanced encapsulation has a lot more to offer than just marginal increases in lifetime. OPV is a struggling technology; there can be little demand for a product that is far lower in conversion efficiency than other widely available technologies, and that is not much – if at all – cheaper besides. OPV cannot compete unless it carves out niches for itself where other forms of PV cannot or will not compete. There is no significant market for OPV without these niches, nor without reasonable product lifetimes for those niches.

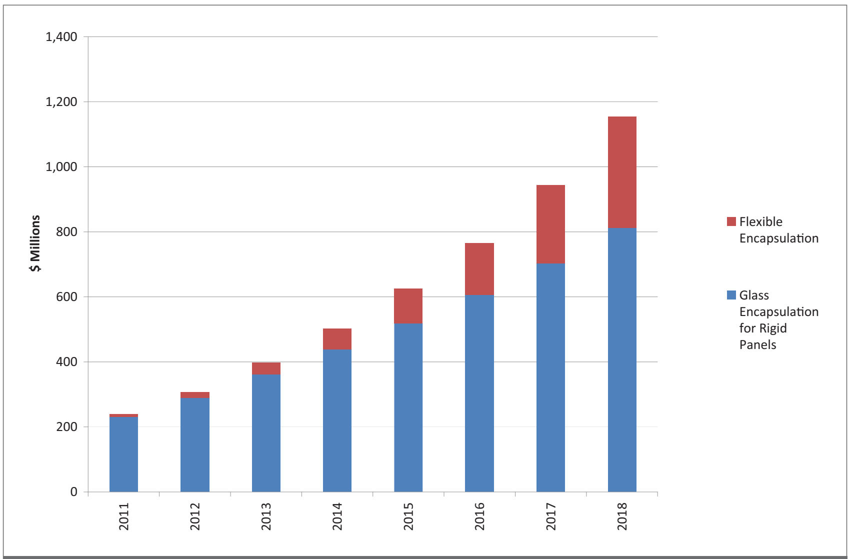
This represents the big difference between the needs of OPV and CIGS. While CIGS has both the conventional PV panel market and the rigid BIPV market to fall back on without advanced encapsulation, OPV is standing on the edge of the abyss. Perhaps OPV can distinguish itself enough in some short-lived portable or embedded products – indoor chargers, perhaps – but to really achieve significant volumes and money, OPV needs to be deployed outdoors, and this will certainly not happen in the form of conventional panels.

Advanced encapsulation is thus the key to OPV-based BIPV products, even before it meets the need to distinguish itself in the marketplace from other PV technologies. Whether OPV can position itself into some BIPV niches, be they sectors that require high flexibility, transparency or sustained performance in low light (all features where OPV outperforms other PV), depends first on OPV meeting the lifetimes required for BIPV installations.

The same can be said for glass-encapsulated OPV-based products. For example, one big potential market for OPV lies in the BIPV glass segment. OPV will likely be among the first PV technologies to achieve BIPV glass panels with a uniform, tinted appearance instead of the striped patterns typical of inorganic TFPV-based BIPV glass or the large silicon cells that are periodically spaced within the glass in c-Si BIPV glass. Uniformly tinted BIPV glass can certainly open new markets to PV, for example in windows where clear visibility is required or an opaque pattern is simply undesirable.

Nevertheless, this transparent BIPV glass market cannot exist if the products are not up to the standard lifetimes of BIPV glass, which currently stands at around 30 years. OPV is not yet suitable for BIPV glass largely because encapsulation systems are not yet robust enough. But the premium for BIPV glass is so much higher than the cost of conventional PV panels that even quite costly encapsulation solutions can be lucrative for both the encapsulation supplier, who makes money selling a high-value, high-margin product, and the OPV-based BIPV glass producer, who finds a virtually limitless market opened.

Because this niche for transparent BIPV glass cannot be filled by other PV technologies, it seems likely that OPV would be able to command a premium for such products, even given OPV's low conversion efficiency. NanoMarkets believes that it is not the low conversion efficiency of OPV that is keeping it from the BIPV glass market, but the lack of sufficient encapsulation solutions and the resulting short product lifetimes. This is



Source: NanoMarkets

Figure 1. Encapsulation market for thin-film and organic PV ($ millions).

why there is such a huge opportunity for developers of new, advanced encapsulation materials and systems.

All this points to NanoMarkets' conclusion: CIGS PV and OPV developers will be willing to pay premiums to get their hands on the best encapsulation materials. The marketing of premium encapsulation products needs to be appropriate. In our view, encapsulation firms have had the importance of cost emphasized to them so much over the past few years, that it might be something of a shock to the collective system to refocus their marketing and business development efforts on an encapsulation product that delivers better performance at higher cost.

As we have noted, encapsulation is now quite literally essential to the survival of the OPV industry, so encapsulation firms can almost hold this industry hostage. Furthermore, the premium nature of CIGS PV – BIPV products in particular – certainly also leaves room for the use of premium encapsulation materials, provided they produce real and marketable improvements in device lifetime and reliability.

Of course, premium encapsulation solutions are not the only kind for which opportunities exist. There are plenty of applications for both CIGS and OPV that can be served by existing encapsulation technology, and cost reduction is always an important motive. For example, flexible PV chargers would likely have a service life of only a couple of years and would thus not need the most advanced encapsulation technology, even if built with OPV. For portable charging, the pertinent question is how the charger is used. One would not cut corners on encapsulation for an OPV-powered solar umbrella, for instance, as the high exposure to the elements would quickly degrade the device. But for some applications such as portable chargers for personal electronic devices, the power-consuming devices are typically protected from the elements regardless of the power source, and an OPV-powered portable charger could reasonably be expected to be provided the same protection. Portable chargers paired with a personal electronic device also benefit from the short replacement cycle typical of cell phones and other devices; a charger might not be expected to last much beyond two years.

There are also several claims in the CIGS space that the flexible encapsulation challenge has been solved to the extent needed for flexible BIPV products. Currently, the most effective solutions for transparent, flexible encapsulation of these highly sensitive devices are dyad systems. These systems combine layers of two different kinds of materials – generally a polymer and a ceramic – in alternating fashion, typically for multiple dyads or layer pairs.

The idea is for the ceramic to plug pinholes in and slow diffusion through the polymer while the polymer seals the defects in the ceramic. The more layers that are built up, the greater the reduction in moisture penetration. With enough layers the performance can certainly be adequate, but these systems become costly and time-consuming to apply. Furthermore, the deposition and curing conditions may cause damage to heat-sensitive underlying layers. There is certainly an opportunity for less costly and more user-friendly encapsulation solutions for CIGS and for OPV in applications where lifetimes are already long enough.

Opportunities of a lesser kind

Advanced encapsulation developers and suppliers will have to weigh the opportunities on offer by CIGS and OPV, the two PV technologies most in need of new materials. On one hand, CIGS offers higher volumes than OPV, even though the encapsulation requirements are not quite as high. On the other hand, advanced encapsulation – with very high performance – is critical to allowing OPV to break out of the relatively low-volume short-lived and indoor markets and venture out into the 'real world.' So, while CIGS PV will probably provide more money to advanced encapsulation suppliers, OPV should not be overlooked simply because it is low in volume.

NanoMarkets believes that advanced encapsulation suppliers and developers will be largely wasting their time peddling their wares in markets where mainstream polymers will suffice or where glass encasement already provides an impermeable barrier. Crystalline silicon has relatively low encapsulation requirements. These are rigid cells that are not particularly sensitive to air or water, and tend to be encased in glass regardless. Encapsulation is not a problem beyond using polymers to seal the edges; perhaps even in place of one pane of glass. Advanced encapsulation does not concern c-Si PV.

The story is similar for CdTe. While more sensitive than crystalline silicon, it is also currently always packaged in glass, providing good barrier protection. First Solar has dominated this category and has sold only conventional panels; both of those facts appear unlikely to change soon.

> "While CIGS PV will probably provide more money to advanced encapsulation suppliers, OPV should not be overlooked simply because it is low in volume."

There are some opportunities for cost reduction for encapsulation of thin-film silicon PV, as flexible versions of these devices do need some protection from the elements, particularly when they are used for BIPV. As these devices are not nearly as sensitive to air or water as are CIGS and OPV, polymer films can generally suffice; cost reduction efforts are generally to use lower-cost polymer films or simpler application processes. And rigid products are again encapsulated in glass, providing protection far beyond the minimum required.

Acknowledgements

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About the Author

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European PV installation projections to 2015

Henning Wicht, Senior Director & Principal Analyst, IHS iSuppli

ABSTRACT
Germany and Italy are forecasted to drive solar demand to new highs in 2011, with rumours of installations up to 22GW on the cards for this year. The German and Italian markets, scheduled to peak in 2011 and 2012, respectively, face a potential problem in terms of where to sell their modules if these two countries cannot accommodate 10GW of installations per year. The emerging markets can solve part of this challenge and will deliver new opportunities to the solar industry. Some Asian, European and Middle Eastern regions will require up to of 6GW of solar-generated electricity, while the Americas, Africa and Australia are each projected to install approximately 1GW in 2014. This paper takes a look at the development of these emerging markets and provides a projection of likely installation figures up to 2015.

Solar installations in 2011

December 2010 and January 2011 brought political news that affected the industry both negatively and positively.

The good news

In Q4 2010, installations in Italy grew at a much faster pace than was expected by industry consensus. An investigation by iSuppli of Italian EPCs, utilities and associations reveals that Q4 2010 installations in Italy reached 1GW. On January 25th, GSE, the official register for the Italian PV industry, announced that 1.85GW have been officially connected, with an additional 4GW registered. iSuppli expects Italy to install 4GW in 2011 thanks to the fast-growing installation capacity and excellent investment within the country.

The uncertainty

On February 2nd, the German parliament accepted Minister Röttgen's proposal of a mid-year feed-in tariff (FiT) cut in Germany. The amount of the FiT will be set according to the amount of systems installed in March, April and May. Under this new regime, iSuppli forecasts that between 7.3 and 9.4GW will be installed in Germany this year.

The 'not so good' news

The solar markets in Spain, France and the Czech Republic will not expand. Plans to implement serious measures to reduce the solar investor business are underway. The Spanish government is expected to reduce funding of existing solar power parks by approximately 30%. Furthermore, the FiT for new ground installations will drop to €0.14/kWh in 2011.

France suspended any further funding for larger solar systems until it finalizes its new tariff scheme at the end of Q1 2011. The Czech Republic plans to have stopped state support by March 2011 for ground-mounted plants

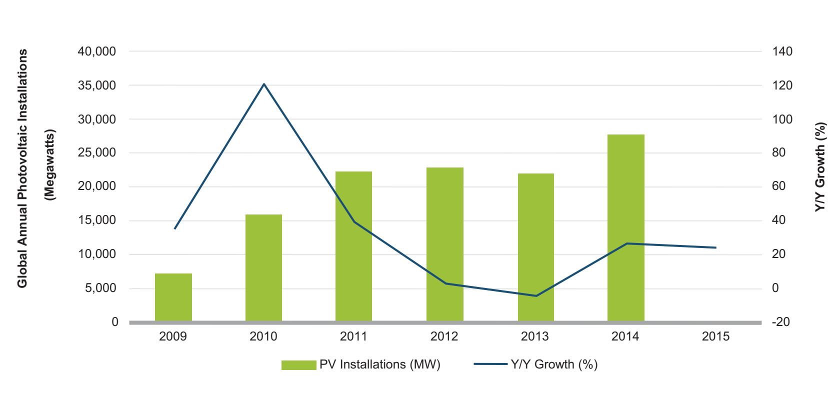

Figure 1. Annual global PV installations showing year-on-year growth projections to 2015.

Taking into account these multiple changes, iSuppli expects that about 22GW will be installed in 2011, growing by about 40% over figures seen in 2010. Looking forward to the period from 2012 to 2014, markets are not expected to see

Country	2009	2010	2011	2015	CAGR 2015 vs. 2010 (%
Belgium	292	390	488	814	20
Bulgaria	7	20	70	340	103
China	160	400	700	1,999	50
Czech Republic	397	1,331	350	350	-28*
France	250	520	550	873	14
Germany*	3,806	7,846	9,400	5,000	-11*
Greece	36	120	235	485	42
Italy	720	1,950	3,900	2,750	9
Japan	480	950	1,100	2,686	30
South Korea	168	145	170	353	25
Ontario (Canada)	69	213	730	1,009	47
Spain	70	250	345	1,000	41
United Kingdom	6	95	350	740	67
USA	489	937	2,073	5,018	52
Rest of World	290	798	1,779	11,019	93
Total	7,240	15,966	22,239	34,435	23

Table 1. PV installations by country to 2015(e) [1].
** Considering the mid-year FiT adoption, total installations for Germany in 2011 are expected to reach between 7,300 and 9,400MW.*

any further significant growth; on the contrary, Germany's market looks like it will contract from 9GW to 5GW.

Germany's FiT review for 2011 and 2012

On January 20th, 2011, Minister Röttgen announced the submission to Parliament of the following changes:

- The FIT shall be adapted at the end of June 2011 if installations are forecasted to reach more than 3.5GW for the full year.
- Total installations in April, March and May 2011 will be extrapolated to an annual value, i.e. the sum of these three months' installation figures will be multiplied by four.

If the derived annual value is:

- < 3.5GW, there will be no FiT cut in July 2011
- > 3.5GW, the FiT cut in July 2011 will be 3%
- > 4.5GW, the FiT cut in July 2011 will be 6%
- > 5.5GW, the FiT cut in July 2011 will be 9%
- > 6.5GW, the FiT cut in July 2011 will be 12%
- > 7.5GW, the FiT cut in July 2011 will be 15%.

For 2012, the FiT will be reduced across the board by 9%.

In the case that installations for the entirety of 2011 do not match the forecasted numbers (applied to the mid-year 2011 FiT cut), this 9% figure will be increased or decreased accordingly. The sum of the two FiT cuts (July 2011 and January 2012) will yield a total according to the 2010 legislation. The only exception in this case is that the maximum cut to be applied will be 24% (instead of 21% as planned in 2010).

To illustrate these figures via an example, take the scenario where 1.3GW are installed from March–May. The full-year 2011 (extrapolated) forecast of 5.2GW leads to a 6% FiT cut in July 2011. However, in December, the register shows that only 4.4GW have been installed over the course of the entire year. Therefore, the FiT applicable in 2012 will be reduced by only 6%.

Expectations for Germany's market in 2011

As of January 28th, 2011, we at iSuppli assume that the FiT changes as announced by Minister Röttgen will receive the support of the parliament during February/March and become mandatory by March 2011. It is likely that German installations in 2011 will follow a similar pattern as that seen in 2010. Installations will pick up during February/early March and will peak in April, May and June. As a consequence, Q3 will be modest, but Q4 is expected to be very strong before the application of new regulations in 2012.

Period	Installations without legislative changes (iSuppli forecast as of Q4 2010)	Installations with FIT cut mid-2011
Q1 2011	500MW	1,000MW
Q2 2011	1,200MW	3,600MW
Q3 2011	3,200MW	800MW
Q4 2011	4,500MW	1,900–4,100MW
Total	9,400MW	7,300–9,400MW

Table 2. Possible scenario for German installations based on official announcements made on January 20th, 2011.

- Moderate Q1: 1,000MW
- Very strong Q2: 3,600MW
- Modest Q3: 800MW
- Strong Q4: 1,900–4,100MW

  Total: 7,300–9,400MW

Note: installer capacity in Germany is about 1,000 to 1,500MW per month.

Italy's projections

The Italian PV Agency, GSE, has counted 5.8GW of new installations for 2010. As of January 25th, 2011, the previous two years' figures are as follows:

2009: 711MW newly installed
1000MW cumulative at year-end

2010: 1.85GW newly installed, registered and connected
5.8GW newly registered
0.5–1GW installed (estimated)
3GW registered on paper

The following expounds why we at iSuppli do not believe that 6GW has been installed in 2010. Module demand would have exceeded shipments, leading to a module shortage, which did not happen in Q4. On the contrary, inverter and module inventories are building up in Q4. Moreover, 4GW of installations would require investments of €10 billion, a figure that would not pass unseen.

We confirm that 2 to 3GW of new installations is a realistic number for Italy in 2010. Looking forward to, 2011 it is clear that the Italian energy suppliers and solar stakeholders are alarmed that installations might overheat, and altering the FiT would be the natural consequence. However, it is difficult to predict how important the solar market is to the Berlusconi government and how long the Berlusconi government will stay in power. At time of writing this report (February 7th, 2011), we have no concrete indication that an additional FiT change can be expected in 2011.

USA: the power lies in the States

With a shift to a conservative congress, federal incentives are less likely to be renewed in the near term. At the last moment before it was adjourned, the Treasury Cash Grant program was renewed through the end of 2011, helping investments that are not as driven by 'tax appetite.' Incentives to stimulate demand now lie at the state level.

California continues to support solar with the defeat of Prop. 23, which would have repealed the state's renewable energy targets (a.k.a. AB 32). Funding continues to be an issue at the state level, restricting growth opportunities in the residential and small commercial sectors. This market dynamic is very turbulent for suppliers as

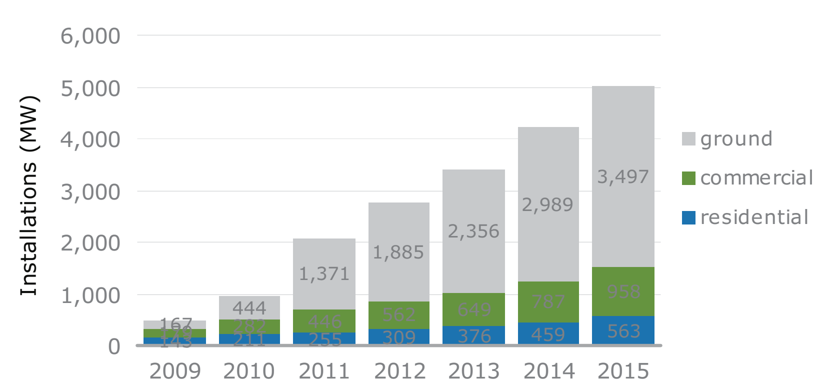

Figure 2. Annual PV installations (MW) by application in the U.S. showing year-on-year growth projections to 2015.

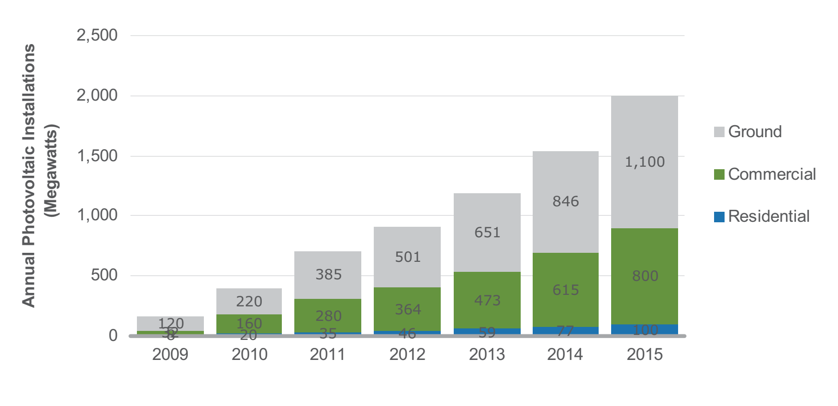

Figure 3. Annual PV installations (MW) by application in China showing year-on-year growth projections to 2015.

inconsistent demand keeps the distribution channel inefficient, thus leading to prices remaining artificially high. This is the case for states like Connecticut, which has US$3 million in funding allocated to its incentive programs this year.

For 2010, iSuppli expects the U.S. market to reach 940MW, a figure that will more than double to 2GW in 2011. By far the largest market in the U.S. will be the ground/utility market with many large projects commencing operation in the 2011 timeframe. This trend will continue through the 2015 timeframe.

China: the giant is slowly awakening

In November, China's Ministry of Finance published the list of suppliers to the Golden Sun Program. Yingli has taken the lion's share of module supply in 2010, announcing that it will have supplied 70% of the country's modules. In addition to its two funding programs, China's Ministries announced that it will further support utilization of solar in China, with plans to reach at least 1,000MW per year from 2012 onwards.

The Golden Sun program: 440MW remaining for 2010 and 2011

In a second incentive program, the Chinese government instructed eight provinces to launch bids for solar projects at a total of 100MW per region. iSuppli expects this program to be executed over the course of three years from 2010 to 2013.

France

On December 10th, 2010, Prime Minister Fillon announced the momentary cessation of support for new solar installations. This solar moratorium is heavily affecting the French solar market. Investors and installers are under threat and fearing for their investments. Tragically, numerous solar plants under construction totalling 100–200MW have not yet seen the light at the end of the tunnel (nor the return on investment). Even investors are having to prepare for the new regulatory scheme, which will not be ready by March 2011.

It is very likely that the French market will be limited to a range of 500–700MW per annum over the next three years. Nevertheless, the French market might still offer attractive investment conditions.

iSuppli confirms its conservative long-term view. With 760MW of new installations expected in 2014 and 870MW in 2015, iSuppli's outlook for the future segmentation of the French market is as follows:

- The French government will continue to support small rooftop installations, probably at attractive rates.
- Large rooftop installations may have to apply and will be selected based on a quarterly contingent, similar to that of Spain.
- Ground installations may be regulated through a bidding process.

UK

An announcement made on February 8th, 2011 saw the UK energy department launch a "comprehensive review" of the solar power FiT system after concerns that funds intended to promote self-generated power risk being diverted to industrial-scale solar arrays.

"Large-scale solar installations weren't anticipated under the feed-in tariffs scheme we inherited and I'm concerned this could mean that money meant for people who want to produce their own green electricity has the potential to be directed towards large-scale commercial solar projects," said energy secretary Chris Huhne. He pledged to complete the review by the end of this year and leave tariffs unchanged until April 2012. Changes will apply only to new entrants; existing solar installations will be unaffected.

> "If the market triples in 2011, the UK government would be the first *not* to react."

The solar market in the UK saw fast growth in Q4 2010, estimated at 48MW. For all of 2010, iSuppli forecasts 95MW. The first power parks are being installed, e.g. ib vogt's 5MW plant in Cambridge and the 5MW Kernow Solar Park in Cornwall.

The UK government expressed a clear focus on the residential sector. The official plans translate into the following installation targets:

- 2011: 60MW
- 2012: 150MW
- 2013: 350MW
- 2014: 600MW

On October 20th, 2010, the government announced that no FiT changes were scheduled for 2011. However, if the market triples in 2011, the UK government would be the first *not* to react. Remembering that the UK's public budget are extremely meagre in comparison to other countries while consumers are having to shoulder increasing taxes, VAT and low public salaries, an additional burden for solar will be perceived as unpopular. As a result, the FiT faces a reduction. Numerous installers, wholesalers and module makers are going on pilgrimage to UK this autumn. German, Taiwanese and Chinese suppliers in particular are opening offices and signing module orders from companies including juwi, ET Solar, Centrosolar and Delsolar.

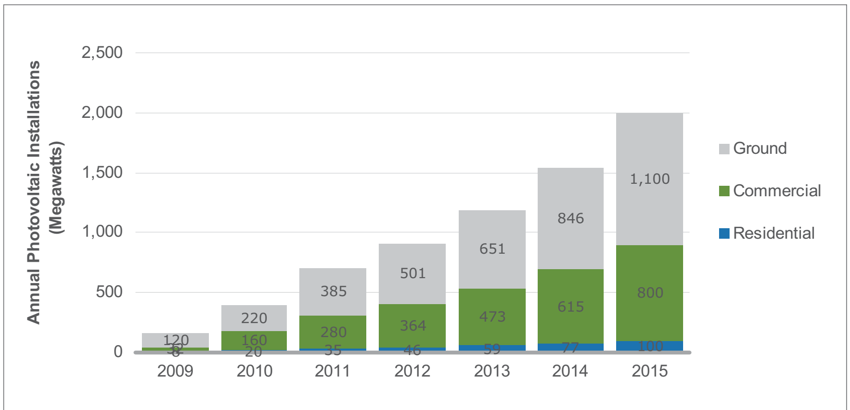

Figure 4. Annual PV installations (MW) by application in the UK showing year-on-year growth projections to 2015.

Emerging markets

Today's booming solar markets in Europe (Germany and Italy) are expected to peak during the coming years. But if Germany and Italy cannot take 10GW per annum, where will the modules be sold? And can emerging markets solve this potential problem and install 10GW by 2014?

Of the 200 nations around the world, approximately 15 regions offer solar funding programs and can be considered solar markets. As a result, these regions form the bulk of today's installations. All other regions, categorized as 'rest of the world,' represent 5% of 2010's installations so far, but are expected to increase and represent 25% by 2014 (see Figs. 5 and 6 and Table 3).

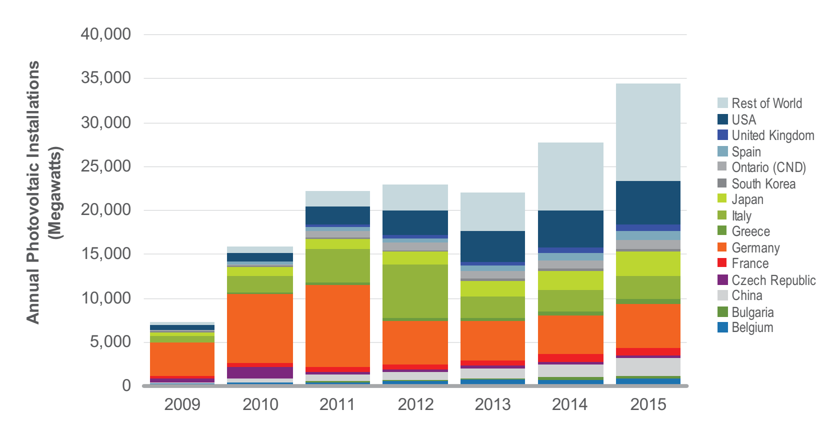

Figure 5. Annual PV installations (MW) by country/region including emerging markets to 2015(e).

"Of the 200 nations around the world, approximately 15 regions offer solar funding programs and can be considered solar markets."

This 25% market share corresponds to 8GW, so it would seem that emerging markets can indeed solve the problem of shrinking module demand if Europe becomes saturated.

The next question is, of the 185 remaining nations, which will show the most promise and prove itself worthy of investment from a module manufacturer's perspective? Assessment of the market drivers suggests that Asia, (rest of) Europe and the Middle East will be the first to open up.

Solar installations in emerging markets are driven by several factors:

- Increasing need for electricity in fast-growing economic regions (South-East Asia)
- High solar irradiation, making solar competitive versus fossil fuels
- Fast installation and operation compared to nuclear and co-fired power plants
- Rapidly dropping prices of solar systems.

In addition, stable politics and economic power play important roles in developing solar business. Taking into account electricity needs, solar irradiation, economic power and political continuity, iSuppli expects that by 2014 Asia and the rest of Europe and the Middle East will offer the most significant emerging markets.

Asia and EMEA (Europe & Middle East) are forecasted to form the bulk of emerging markets up to 2014. Large populations and fast increasing needs for electricity are driving local markets in Asia. India and a number of countries including Malaysia and Philippines will launch solar funding programs in 2011/2012, while plans for a very large (70MW) solar power plant have recently been announced in Thailand.

Europe is driven by political REE targets. In addition, even the smaller regions are expected install solar programs. South of Central Europe, Israel, Turkey and Middle Eastern countries such as the UAE and Egypt are expanding their solar activities. High irradiation, low environmental impact, and independency from fossil fuels are driving the uptake of solar power in these regions.

However, despite the high irradiation in the region, iSuppli does not expect Africa to exploit its potential until 2014. South Africa, Morocco and the Desertec Initiative currently represent the solar flagships in Africa.

On the other hand, Australia could well be the next new thing in terms of solar uptake. But despite the continent's offering many sun hours and low-cost carbon-based electricity, the fact that it only has about 22 million inhabitants leads iSuppli to project the country to increase its solar installations in the next years, but to for the market to remain at a much smaller size than others.

In America, outside of the U.S., the greatest solar activity is in Canada with Mexico just beginning its solar conquest. Mexico, already short on sources of electrical power, is close to seeing solar become a regular means of power supply. High irradiation of 1,500–2000kWh/kW and electricity rates of €0.15–21/kWh will mean that the country can pay off any solar investment after 10 years – even without subsidies. However, only a small fraction of the population can finance such solar systems. Loan credits for solar systems are not common and, due to budgetary limits, no political funding can be expected.

Such low public budgets are to be found in all South American nations. Therefore, these markets will not immediately increase their solar power uptake, despite having such high levels of irradiation. The solar front-runners are Argentina, Chile and Brazil, where demonstration plants are currently being built. Similarly, Peru is moving ahead with four 20MW PV projects planned for 2012.

In summary, as a result of the social, political and economical powers, iSuppli expects emerging markets to take off in Asia and EMEA with the Americas

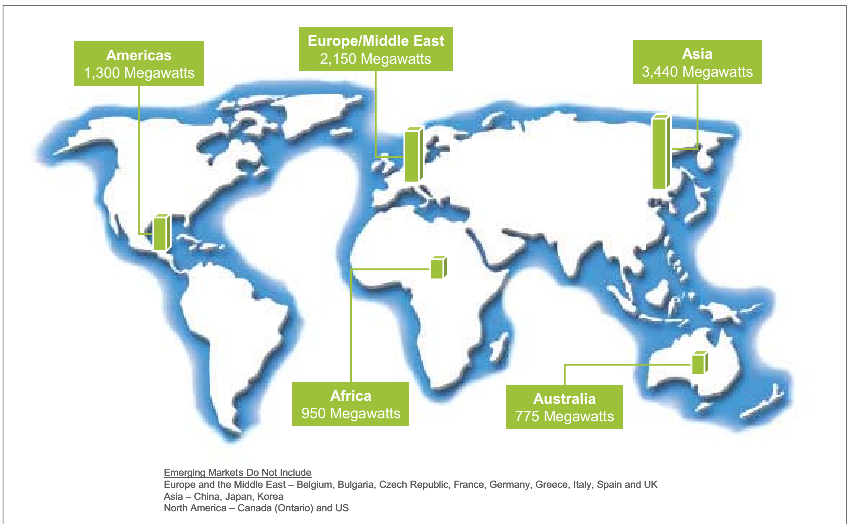

Figure 6. Emerging markets: regional PV installations in 2014(e).

	Population	Electricity needs (GDP per capita)	Economic power kWh/kW	Solar irradiation in solar	Political interest	Forecasted market shares in ROW in 2014
Australia	+	+	+++	+++	++	9%
Americas*	++	++	++	++	+	15%
Africa	++	++	+	+++	+	11%
Asia**	+++	+++	++	++	++	40%
Europe*** & Middle East	++	+	+++	++	+++	25%

**Americas: not including USA, Ontario (CND)*

***Asia: not including China, Japan, Korea*

****Europe: not including Germany, Italy, France, Spain, Belgium, Greece, CZR, Bulgaria and UK*

Table 3. Comparison of emerging market drivers by region.

Market Watch

and Africa following their lead. Business opportunities are sure to appear, but the business mechanism will be different from that seen in the European markets.

The next generation of solar markets in Europe will be different, with the appearance of three new segments in addition to the established solar markets:

- High-electricity markets
- Large-scale, low-margin markets
- Local content-driven markets

High-electricity rate markets

Some markets, e.g. Mexico and Brazil, are close to grid parity in the residential segment due to high electricity rates. According to iSuppli's Q3 2010 forecast, the European markets will slow by 2012, triggering the interest of system installers and module suppliers in developing these high-electricity rate markets. Wholesale and module suppliers can work hand-in-hand by setting up PV packages, including financing for the residential and small industrial rooftop segment (solar kit). Brazil and Mexico should be addressed first for their to high electricity rates. Both markets are expected to install approximately 100MW of new installations by 2014. In 2010, system prices were still high (€6/W installed) and above European averages, mainly because the installations are very individual in nature and the volumes shipped were small (between 1 and 5MW per year).

Large-scale, low-margin markets

The bidding for power plants – similar to the structure currently applied in the U.S. and China – represents a second market segment likely to appear in the emerging markets. As demonstrated recently in China, 130 companies and consortia submitted proposals to build 13 PV power plants. The electricity rates proposed by the companies range from US$0.108 to US$0.222/ kWh, which is lower than any FIT. While it seems difficult to obtain margins at US$0.11/kWh even at irradiation levels of 1,900kWh/kW, it shows that the strategic competition on solar plants has begun. At these prices, PV will compete against fossil and nuclear power. It will be interesting to see how the Spanish market will react in 2011 when tariffs for ground installations drop to €0.15–16/kWh.

Local content-driven markets

Ontario (Canada) opened the floor to a third market segment of solar: regions supporting solar via funding but requiring local content. India is applying a similar strategy by demanding that the installed modules – and even the solar cells from 2012 – must be made in India in order to qualify for funding. Both regions intend to foster the regional industry, either via local production of global suppliers or by supporting national producers (India). The final objective is to create jobs and develop a strong local industry.

> "Governments and tax payers will pay a premium to finance higher FiT rates to balance out the higher cost (and prices) of local production."

On the other hand, it is still debateable whether these rules will conform to GATT regulations. In any case, governments and tax payers will pay a premium to finance higher FiT rates to balance out the higher cost (and prices) of local production. Other regions such as South Africa intend to stimulate local production. Requesting local content is not in line with the current production strategies of Chinese and Taiwanese producers, who are focusing on economies of scale. It will be interesting to see whether large suppliers will modify their business concept by introducing stipulations such as the requirement of modules bing locally produced.

Suppliers that are able to adopt strategies to serve these markets will be able to escape the maturing markets in Central Europe. The next solar business model will ask for joint ventures and partnerships with local utilities and extended services, including financing and operations. Training and quality control of installers will become essential to developing the confidence of end users and investors. In addition, the emergence of easily installed new products, from solar kits to microinverters, will bolster the opportunities available for the less experienced installers.

Reference

[1] iSuppli PV Market Tracker Q4 2010 and iSuppli Research Notes Q1 2011 [available online at http://www.isuppli.com/Photovoltaics/Pages/PV-in-2011-Prepares-for-22-Gigawatts.aspx].

About the Author

Henning Wicht (Ph.D.) is Senior Director and Principal Analyst at iSuppli. He established the iSuppli Photovoltaics Market Research group in 2008, which centres on an integrated PV industry research model entitled the Photovoltaics Market Tracker. Before joining iSuppli, Henning founded and led the technology consulting firm WTC, acquired by iSuppli in April 2008. Earlier in his career, he worked for CEA in France and Germany.

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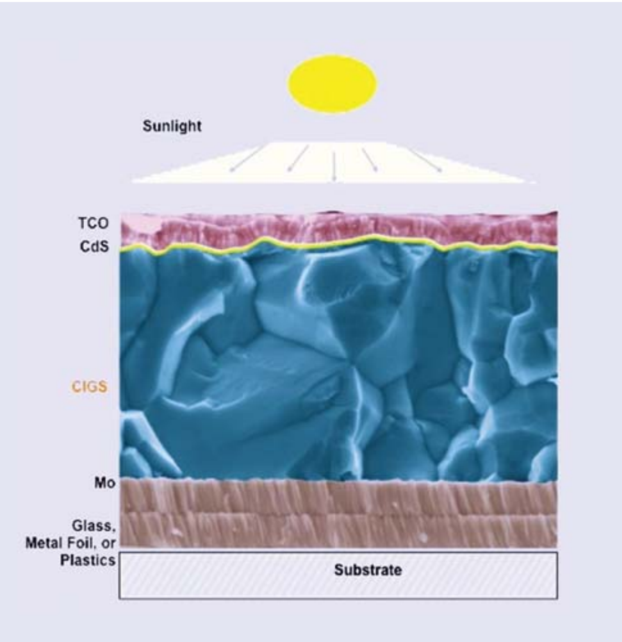
Suniva implements ion implantation, First Solar turns knobs, CIGS gets purified

The crash and ongoing burn of cell maker SpectraWatt makes the success of Suniva, another Team Solar USA player, all the more noteworthy. The company, which has three cell manufacturing lines running at max capacity near Atlanta and should soon announce its plans to expand production, has established itself not only as capable of competing with the Chinese and other global entities, but as a technology leader in the crystalline-silicon arena.

In a technical paper appearing exclusively in the 10th edition of *Photovoltaics International*, Suniva revealed that it has introduced ion implantation into volume production of its high-efficiency solar cells – an industry first.

"The technique offers several advantages over conventional $POCl_3$ and in-line diffusion technologies, including single-side dopant incorporation; in-situ oxidation for superior surface passivation; elimination of the PSG removal step; elimination of the junction edge-isolation step; precise doping control and novel dopant profile engineering by varying implantation dose, implantation energy, and implant damage annealing recipe; and patterned dopant regions for selective emitter and possibly interdigitated back contact-type cell structures," according to the paper.



Admittedly, attempts to incorporate ion implantation in cell processing are not new, but the technique never gained traction because of the perceived double-whammy of slow throughput and high cost. But as the paper points out, "interest in ion-implanted emitters has reawakened, with the potential of the implantation technique recognized as a way to produce advanced high-efficiency cell structures with fewer processing steps."

Suniva has partnered with implant equipment aces Varian Semiconductor Equipment Associates, "which led the development of high beam current, fast wafer handling, high-throughput implanters specifically designed for the PV industry."

No discussion of Team Solar USA would be complete without a mention of First Solar, the premiere purveyors of cadmium telluride thin-film modules as well as project development and engineering/procurement/construction of large-scale PV farms. The company is notoriously tight-lipped when it comes to information about its R&D and production endeavors, but once in a while a few tasty morsels make their way onto the blog buffet.

Raffi Garabedian, who directs First's disruptive technology efforts at its skunkworks facility in Santa Clara, spoke at the Thin Film Summit in December in San Francisco. Most of his presentation on cost reduction potentials offered nothing out of the ordinary from the viewpoint of the industry's cost reduction leader – such as the company's targets of 52 cents per manufactured watt and at least 80MW run rate per production line by 2014.

Yet at the end of his presentation, he talked about a few examples of "blocking and tackling" where First looks to "turn knobs" and make engineering improvements in the areas of run rate, conversion efficiency and yields. He cited enhanced laser scribe throughputs, optimization of temperature ramp rates on glass (both heating up and cooling off), and improved module-lamination cycle times as focus areas. He also mentioned "lots of activity" looking at back contacts and what he called "new materials systems" – all done with cost reduction in mind.

Speaking of new materials systems, he wouldn't confirm (or deny) First's not-so-secret investigational efforts into CIGS. "We think about everything under the sun," he said of the company's disruptive technologies efforts. But he did opine that the key limitation to the quaternary TFPV compound is its manufacturability: "We haven't seen proof yet that CIGS is manufacturable in high volume."

Several CIGS outfits have made great strides over the past year to counter Garabedian's qualm. One example of improved manufacturing processes came out during a presentation by Air Liquide's Ravi Laxman, whose company works closely on the materials supply, delivery, and abatement fronts with dozens of thin-film firms.

Laxman talked about how the use of hydrogen selenide, a key ingredient in the CIGS film stack, has evolved for the better. After encountering process difficulties, several key customers of Air Liquide stopped using H_2Se purified to four or five 'nines' levels because of increased moisture concentration in the gas phase.

It seems as the cylinders emptied, the amount of H_2O increased exponentially in the remaining gases, severely affecting the quality of the films and subsequently the performance of the modules themselves. As the impurities mount, the pipes handling the gases also show increased corrosion caused by higher H_2Se and H_2O content – a potentially bedeviling problem in the long term.

Tearing another page from the semiconductor playbook, the gas and chemicals vendor realized that the solution lay in improved handling of the H_2Se feedstock and increasing the purity levels of the feedstock material, since higher purity gases cause less corrosion, according to Laxman.

Tom Cheyney is North American editor for the *Photovoltaics International* journal and writes blogs and news for PV-tech.org.