Ninth Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS

Fraunhofer IPA: wet wafer separation techniques

The dawn of APC: Fraunhofer IISB delivers the low-down

Challenging First Solar: Abound on ramping CdTe production lines

NREL's atmospheric thin-film deposition technique overview

REC: reducing BOS costs with new technology and economies of scale

Third Quarter, August 2010

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Photovoltaics International

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Cover image shows a pulsed laser deposition system used for growing thin-film devices at the National Renewable Energy Laboratory (NREL). Image courtesy of NREL.

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Publisher's foreword

Shaping up for another bright year in the solar industry!

As it's now August, we can take a look back at the first half of 2010 and see that installations by world-leader Germany have reached 3GW. This incredible statistic shows that despite – or perhaps because of – uncertainty regarding FiT policies, the solar industry continues to grow at a prodigious rate.

IMS Research has projected that second-quarter 2010 module shipments reached 3.7GW (p. 212) – if this is the case, that puts us in line for a strong finish to 2010 despite imminent FiT reductions in Germany. Most industry analysts now predict that the global 2010 market worldwide will reach 14GW.

To cope with this projected doubling of demand in 2010, PV manufacturers and system integrators are ramping operations and relying on new technologies and processes to enable the market. In this issue of *Photovoltaics International* – our biggest ever, weighing in at a respectable 224 pages – you will gain unique insight into some of the most important industry developments.

With such a large increase in production needed to fill demand this year, a new focus has emerged on greening the supply chain. **Wacker Chemie** (p. 44) takes us through the necessary steps to achieve environmentally-friendly and sustainable polysilicon production.

Production throughput is explored in a number of papers looking at semiconductor processes that are being adapted for and adopted in PV manufacturing. **IBM** (p. 88) explores the application of a CMOS (complimentary metal oxide semiconductor) line to cell processing; **Fraunhofer IISB** (p. 79) looks at advanced process control techniques; and in two world firsts, CdTe manufacturer **Abound Solar** (p. 128) gives us a unique look at ramping up their production lines while **MiaSolé** (p. 177) gives us a first look at characterization-enabling volume production of their CIGS modules.

Costs are being reduced in the production phases of the industry, and the focus is shifting more and more onto the installation and BOS components used. In the first of a two-part article, **REC Solar** (p. 207) sheds some light on the emerging trend for system integrators to create pre-configured systems, thus reducing the costs of installation.

EU PVSEC is fast approaching, so be sure to catch the *Photovoltaics International* team in Hall 3, L2/D1. Don't forget to pick up a copy of the free *PVI Lite* edition, and check out our on-site news coverage in both written and video format. If you haven't already done so, remember to subscribe to our bi-weekly e-newsletters at **www.pv-tech.org** as we will be issuing a daily email containing all the latest breaking news from the show and must-see technologies.

You can also catch our team at Solar Power International and Solarpeq over the coming months.

Sincerely,

David Owen
Photovoltaics International

Photovoltaics International

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

Editorial Advisory Board

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

Gerhard Rauter, Chief Operating Officer, Q-Cells SE

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

Takashi Tomita, Senior Executive Fellow, Sharp Solar

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

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

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

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

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

Dr. Zhengrong Shi, Chief Executive Officer, Suntech

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

Dr. John Iannelli, Chief Technology Officer, Emcore Corp

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

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

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

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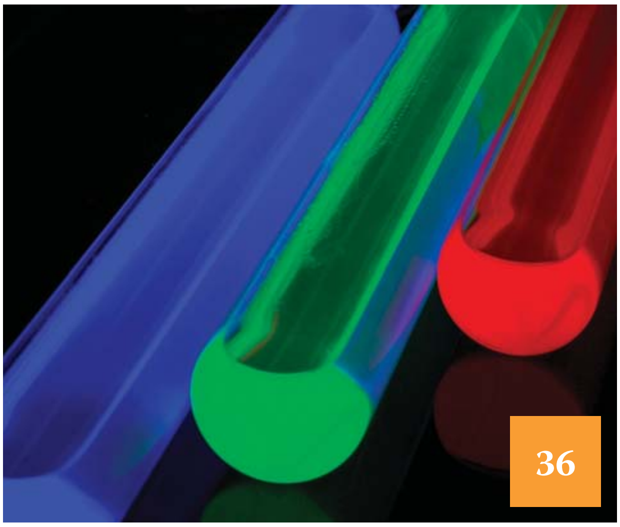

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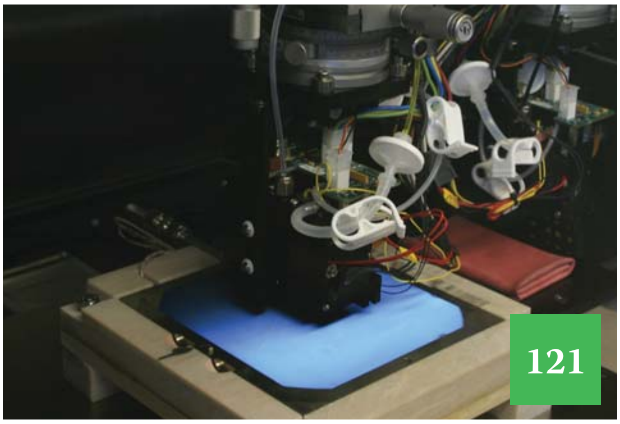

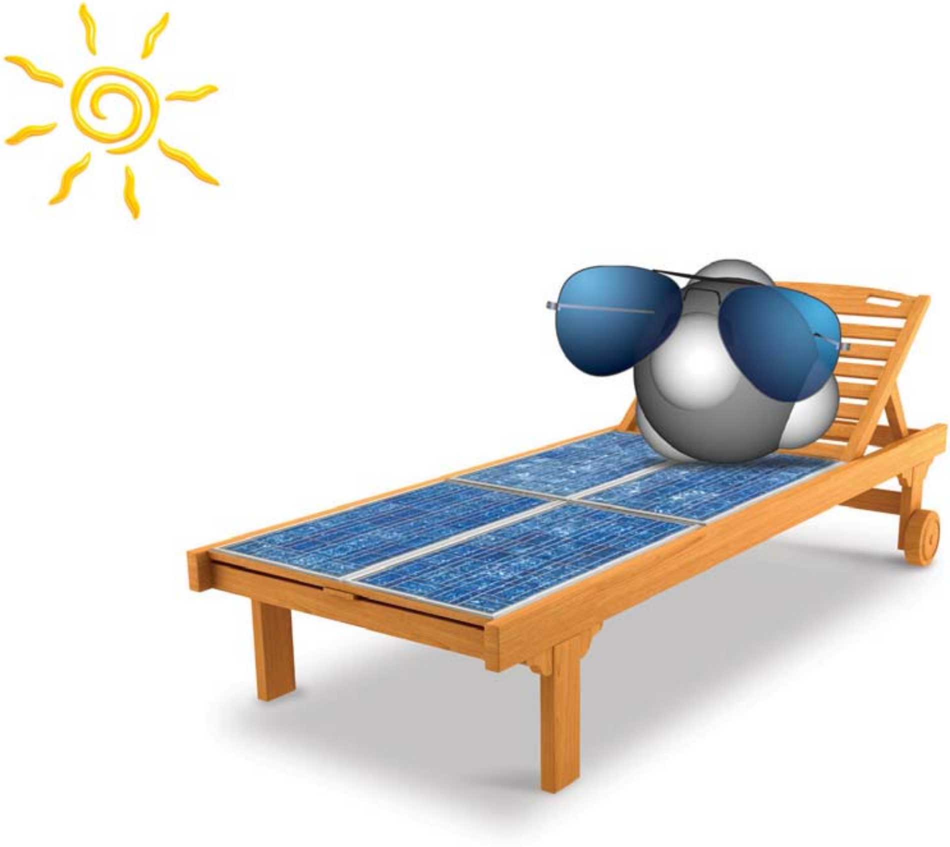

SILANE (SiH_4) FINDS ITS PLACE IN THE SUN

Before the sun's powers can be put to work, solar cells bask in silane. Essential to solar cell manufacturing, silane gas (SiH_4) helps economies worldwide fully realize solar's promise.

Uniquely positioned as the largest manufacturer and supplier of silane, REC Silicon provides thin film and crystalline cell producers with a secure and reliable source to safeguard their PV solutions. Our patented silane technology pairs quality and consistency with an annual capacity fast approaching 27,000 MT. Expanded capacity to help drive grid parity.

REC Silicon's ultra-pure Signature Silane™ is supplied worldwide via the industry's largest bulk silane ISO module fleet. See why our delivery system, global distribution network and safe handling expertise all shine brightly with customers seeking improved performance and cost advantages.

➔ Learn about silane business solutions for your applications at **recgroup.com/silane**. Ask to view our Silane Safety presentation.

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Fab & Facilities

SunPower taps GE to provide ultrapure water system for new Malaysian joint-venture solar-cell fab

SunPower has chosen GE to provide the ultrapure water systems for the new SunPower-AUO joint-venture Fab 3 solar-cell fabrication plant under construction in Malaysia. The UPW equipment will save more than 230 million gallons (>870 million litres) of water relative to other technologies, the companies said.

The facility will be one of the largest silicon solar manufacturing factories in the world and is expected to begin operations near the end of 2010 and ramp production during the following two years. The facility is located 20km north of Melaka, Malaysia, in a region that has experienced prior water shortages and drought.

GE will design, supply, and install the advanced UPW system featuring the internationally patented high-efficiency reverse-osmosis (HERO) process. The system, operating on a challenging and variable feedwater source, will provide 2400 gal/min (9085 L/min) of ultrapure water for manufacturing.

Aerial view of SunPower's Fab 3 in Malaysia (artist's impression).

Capacity News Focus

Sanyo boosts HIT solar module production in Japan to meet demand

Strong demand for solar cell modules in Japan is forcing Sanyo to squeeze more capacity from its PV production plants in Nishikinohama and Shiga. A further 5MW per annum is expected from its plant in Nishikinohama due to productivity improvements from existing lines, taking capacity to 40MW. The main increase comes from its plant in Shiga, which will reach a capacity of 250MW by March 2011. The Shiga plant is currently undergoing a 100MW expansion, doubling capacity but a further 50MW is now planned by adding more lines at the facility in the same timeframe.

Overall, Sanyo is planning on almost doubling its HIT solar cell production capacity to 600MW, by March 2011. Current capacity stands at 340MW, according to the company. Sanyo said that the Japanese market is expanding rapidly due to installation subsidies from the national and prefectural governments, as well as the national government's new surplus electricity purchasing program for solar power.

Stion plans 100MW plant and monolithically integrated thin-film module circuits

Following-on from the investment and production partnership with leading semiconductor foundry TSMC, CIGSSe thin-film start-up Stion has said it will go ahead with a 100MW capacity expansion at its plant in San Jose, California. The company said it had raised US$70 million in Series D financing to bring its total fundraising to date to over US$114 million. Stion expects to bring more than 500 direct and indirect jobs to the region in 2010 and 2011.

Sanyo's HIT cell.

Fab and Facilities Order Focus

Apollo signs US$2.55 billion deal with Hanergy for turnkey thin-film line

Apollo Solar Energy has revealed a major turnkey equipment agreement worth US$2.55 billion (approximately HKD19.84 billion) with Hanergy, signed on May 20. Apollo will provide Hanergy with equipment and an integrated turnkey line for the manufacture of silicon-based thin-film solar modules.

Furthermore, Hanergy has agreed to become a major investor in Apollo, and has been added to the group's shareholders. On the date of the signing of the sales agreement, the companies also agreed that Hanergy subscribe, or procure the Hanergy nominee to subscribe, for 4,911,528,960 subscription shares at the subscription price of HKD0.239 per subscription share.

ib vogt commissioned for solar manufacturing plant in India

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

Praxair wins bulk gases deal for Evergreen Solar's China plant

Having supplied bulk industrial gases for its solar wafer manufacturing facility in the U.S., Praxair has won a multiyear supply agreement with Evergreen Solar Energy China for its solar wafer manufacturing facility in Wuhan, China. The contract will be serviced by Praxair China.

Stion's panels are produced using monolithically integrated circuits and are not made from individual cells, which it claims enables streamlined high-yield production with flexibility in product design. The module form factor is 2ft. x 5ft and benefits from improved performance in partial shading, according to the company.

Solargiga acquires 51% interest in Qinghai Chenguang for silicon ingot facility development

China-based monocrystalline silicon solar ingot and wafer manufacturer, Solargiga, has entered into a cooperation agreement with the Xining Economic & Technology Development Zone Administration Committee to acquire a 51% interest in Qinghai Chenguang New Energy for the construction of monocrystalline silicon solar ingot production facilities with an average annual production capacity of 2,000 tonnes.

The cost of the acquisition will be RMB45.9 million and will be paid by way of capital increase through cash injection. The total investment amount of the project will be RMB300 million, 30% of which will be funded by Solargiga and the existing shareholders of Qinghai Chenguang by proportionate shareholding; the rest will be funded by bank loans.

The construction of the new production plant will be divided into two phases, with the initial phase commencing in 2010 with 96 monocrystalline solar ingot pullers installed by the end of the year, the company said. Production will begin in April 2011, with full production capacity reached in July 2011. The construction of the second phase will commence by the end of 2011, with an additional 96 monocrystalline solar ingot pullers to be installed at the end of 2012. Full capacity is expected to be reached in mid-2013.

Qinghai Chenguang also intends to build a 200kW photovoltaic demonstration power station in the production plant area, which will be sponsored by the Xining Economic & Technology Development Zone Administration Committee under the national policy of "Golden Sun Programme".

Odersun opens new SunTwo facility in Fürstenwalde, Germany

Odersun has inaugurated its second solar factory SunTwo in Fürstenwalde (Spree), Germany. The company began ramping up the production at the new facility when it achieved the IEC 61646 certification back in January 2010.

During the opening ceremony of SunTwo, the economics minister of the state of Brandenburg, Ralf Christoffers, also acknowledged a new thin-film solar module, which will be utilized in building design. The factory has a current capacity of approximately 20MW, which is expected to increase to 30MW with the installation of two additional production lines in the factory. Odersun has invested around €50 million for concept, planning, construction and equipment supply.

Photo: Susanne Wolkenhauer

Economics Minister of the State of Brandenburg, Ralf Christoffers receives new Odersun module.

Schunk Group completes largest plant expansion in its history

The Schunk Group added around 140,000 square feet of floor space and renovated 45,000 square feet at its headquarters plant in Hessen, Germany. The completed expansion has allowed for the company to increase its manufacturing, purifying and coating custom-made carbon fibre reinforced carbon and graphite components for the solar, semiconductor and polysilicon industries.

The expansion has enabled the company to handle the entire process chain from producing the materials, planning, developing and fabricating the components all the way to quality assurance and testing. The thermal post-processing of the CFC materials is conducted at the 37,500 square foot Thermal Technology Centre that has recently been opened. The facility has been designed for producing carbon-fibre reinforced composites. In terms of the purification and coating processes, new reactors for CVD and CVI have been installed in another 37,500 square foot facility.

Initial production of Yingli Green 400MW capacity expansion begins

Yingli Green has begun the initial production of its latest 400MW capacity expansion, including 300MW of Panda monocrystalline silicon-based production capacity at the Baoding headquarters, and 100MW of multicrystalline silicon-based production capacity in Haikou, Hainan Province.

Eyelit revenue boosted in the quarter by Solyndra and SolarWorld plant expansions

Privately held manufacturing software firm Eyelit said it had tripled its first-quarter license revenue and recorded a 75% total company revenue growth since the same quarter last year, which was led by CIGS company Solyndra for its 500MW Fab2 project. Also of note was SolarWorld's new solar wafer production plant in Freiberg, Germany. Eyelit also said that its overall company staffing grew by more than 25%, with a 60% increase in consulting services during the first quarter to support the growing global demand for Eyelit products.

Courtesy: Solyndra.

Solyndra's Fab2 facility.

Courtesy: Avancis.

Attending the ceremony (pictured left to right): Dr Jörg Baumbach, CEO Hartmut Fischer, Mayor Andrea Staude, Wolf-Dieter Meier and Hartmut von Wantoch.

Avancis breaks ground on 100MW 3rd gen CIS thin-film plant

With a current capacity of only 20MW, CIS thin-film manufacturer, Avancis, has broken ground on a new 100MW plant in Torgau, Germany. The company will ramp the facility in the first quarter of 2012, using its third-generation cell process technology, which achieved 15.1% efficiency (30 x 30cm^2, fully encapsulated CIS solar module) in January. The company announced plans in early June.

Avancis has a 20MW facility and employs 150 people at the plant. A further 50 researchers are based in Munich. The new building will be constructed along the same lines as the existing plant, according to the company. The new-build project on the 25,000m^2 site is expected to be completed within the next 18 months.

SilexSolar is to expand production capacity at Sydney Olympic Park facility

SilexSolar will expand the production capacity at its Sydney Olympic Park (SOP) manufacturing facility, in response to reportedly increasing demand for the company's Australian-made solar photovoltaic panels for the domestic rooftop market.

The expansion will take place in two stages, the first of which is planned for the fourth quarter of 2010, with the scheduled installation of automated assembly equipment which will take the capacity from ~13MW to ~20MW per year by early 2011. The second stage of equipment upgrades will occur in the middle of 2011, with the aim of increasing annual panel production capacity to approximately 35MW; however, the second stage will depend on continuing demand. The total capital expenditure for the two-stage upgrade will be approximately AUS$2 million.

SilexSolar is also developing higher efficiency solar cell technology at the SOP plant in collaboration with the University of NSW and Suntech Power under a research program, which was recently awarded AUS$5 million funding from the Australian Solar Institute. This project aims to increase solar cell efficiency from around 17% to approximately 20% by 2012, which would potentially increase the panel plant's production capacity. SilexSolar is the only Australian manufacturer of crystalline silicon solar cells and panels, and claims a strong commitment to Australian solar technology innovation.

Other News Focus

New CFV Solar Test Laboratory facility be based in New Mexico

The CFV Solar Test Laboratory, jointly owned by CSA Group, the Fraunhofer Institute for Solar Energy Systems ISE, the Fraunhofer USA Center for Sustainable Energy Systems CSE and VDE Testing and Certification Institute, has revealed that its new solar module testing laboratory will be based in Albuquerque, New Mexico.

The new lab will be located within the Mesa del Sol development of Albuquerque meaning that it will be in close proximity to Sandia National Labs and the University of New Mexico. The facility will start operations in late 2010 and will test products for certification to North American and International PV test Standards. Fraunhofer CSE and Fraunhofer ISE will also operate an additional research and development facility at Mesa del Sol, focussing on long-term reliability, decreased cost and increased performance of PV modules.

Quantum, Evergreen Power establish 30MW module manufacturing plant in Ontario

Quantum Technologies' German affiliate, Asola, has signed an MOU with Evergreen Power to establish a joint venture manufacturing plant in Ontario, for the production and distribution of solar modules in Canada. The planned initial production capacity is 30MW, with the potential to generate revenues in excess of CAD$60 million annually. The joint venture company will market the modules under the "Asola" brand. Quantum also recently acquired Ontario-based Schneider Power, which has a portfolio in excess of 1,000MW of clean electricity generation development projects across two continents.

Suntech opens representative office in France

In order to better serve its local partners in France, Suntech has opened a representative office in Montbonnot (Isere). The new facility features a solar product training centre for distributors and installers and for professionals to provide hands-on installation training, particularly for Suntech's BIPV "Just Roof" offering. The office will be also be home to a technical customer support team.

Wacker Chemie signs PPA for Fesil silicon-metal production site acquisition

Wacker Chemie has signed a PPA with Fesil group for the acquisition of its silicon-metal production site based in Holla, Norway. The transaction will still require the approval of Wacker's supervisory board and Fesil's board of directors as well as clearance by the antitrust authorities.

Under the terms of the proposed contract, Wacker will take over all of Fesil's production facilities, including the related real estate, and plans to continue employing the site's existing workforce. Holla Metall's production capacity is around 50,000 metric tons of silicon metal annually, which corresponds to about one third of Wacker's current yearly needs. Closing of the transaction is expected before the end of Q3 2010.

Location Briefings

Solar Valley, Germany

Solar Valley Germany – a sustainable region in the heart of Germany

Location: The Solar Valley, located in the centre of Germany, is comprised of a network of 29 international operating firms, nine leading research institutes, and four universities. The Solar Valley Centre for Silicon Photovoltaics has the highest density of companies involved in the photovoltaics industry.

Introduction: In order to initiate private investments in solar electricity systems, the town of Bitterfeld-Wolfen and the district of Anhalt-Bitterfeld launched an initiative – the "1000-Dächer-Programm" (1,000 roofs programme). This initiative is aimed at all citizens in the region who want to make an active contribution to protecting the environment by installing a photovoltaics system on their roof and at the same time achieve secure returns over a period of 20 years. As for the industry, solar cell manufacturing giant Q-Cells and module manufacturer Sovello from Thalheim are signed up.

Sovello is providing a quota of solar modules with special conditions for the first 1,000 roof projects and is offering local installation companies special training courses. For financing a rooftop solar electricity system without capital, the Kreissparkasse Anhalt-Bitterfeld will provide support as a partner.

Key features/incentives:

- With the "1000-Dächer-Programm," Solar Valley Germany is emphasizing its position in photovoltaics and at the same time presenting itself as a modern and environmentally-friendly place to live and work
- Around 3,600 jobs in the solar industry attest to the area's economic strength
- Generous investment incentives cover a high percentage of capex
- Fast-track project realization, due to the close proximity of the world's leading PV equipment suppliers and superior engineering as well as local authority services and support
- Leading glass producers and glass suppliers located in Saxony-Anhalt offer best siting conditions
- Close R&D cooperation with Germany's leading PV research institutes and four universities
- "Shorter time to markets, via state-of-the-art infrastructure for lower rate of long-term transport inventories
- Skilled and flexible workforces, low labour costs
- Nearby international schools to join the solar family life.

Key tenants

Q-Cells, Sovello, Calyxo, Solibro, Sontor and Malibu.

Greece

Location: Greece offers a wide range of investment opportunities, due to the country's geographic location and competitive advantages. Greece is a natural gateway for more than 140 million consumers in Southeast Europe and the East Mediterranean, a region with a GDP of almost €1 trillion.

Introduction: Greece's energy market is at the forefront of transformative changes that are attracting investors from around the globe. The country is encouraging the development of renewable energy investments with a series of incentives. Solar energy is the most favoured of all RE investments and a number of small- and mid-size companies have already taken advantage of the many opportunities offered. Today's capacity in installed PV has reached 65MW and, under conservative scenarios, the capacity is expected to exceed 1200MW by 2020.

Infrastructure: Next Solar is establishing a manufacturing facility in Greece. Solar Cells Hellas and Copelouzos Group have already begun the production of solar cell modules. In the port city of Patras, a wafer and cell plant has been built, and two additional plants, with capacities of 30+ MW/yr, are under construction. Near the city of Tripoli, a thin-film manufacturing unit with a capacity of 60+ MW/yr has also begun operation. Technical support for these plants is provided by engineers and technicians from the nearby University of Patras.

Key features/incentives: The Greek renewable energy market has seen an annual growth rate in the range of 5% during the last three years. The future is even more promising, since electricity production from renewables should reach 20%, from 7% today. Advantages of investing in Greek Solar Energy:

- New RES Law 3851/4-6-210 – in order to boost investment activities, the licensing process is to be completed within 12 months rather than two to four years
- Priority dispatch by the system operator
- 20-year power purchase agreement (PPA)
- New regulation - incorporating the European (2002/91/EU) regulations on energy efficiency of buildings, into the existing Greek Law 3661/2008. Compliance with these regulations will lead to numerous improvements/investments in building materials and energy-related infrastructure.

Key Players: Greek Public Power Corporation – PPC, Rokas-Iberdrola, EDF, Copelouzos Group.

What they say: "We came to Greece in 2000, in view of the upcoming Games, and since then have had revenues in excess of $500 million. We believe that Greece is a great place to invest and our rate of growth compared to other east Mediterranean countries is significantly higher here." **Steve Martin**, Executive, General Electric Energy.


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Product Briefings

Applied Materials

'SmartFactory' MES from Applied Materials includes APC capabilities

Product Briefing Outline: Applied Materials has launched its Applied 'SmartFactory' MES software that is claimed to be an out-of-the-box factory automation solution. SmartFactory can be deployed in less than 60 days to improve product quality, boost productivity and cut operational costs, and is said to be the first MES available with integrated advanced process control (APC) capability.

Problem: Comprehensive, real-time information about all aspects of fab operation. Is necessary to make decisions and track performance metrics to achieve consistent, day-to-day product quality and output. Without the right data/data tracking across the entire factory, it can be difficult to manage costs and reduce waste in the manufacturing line.

Solution: The SmartFactory system features pre-built, technology-specific scenarios to monitor every machine and all work-in-progress material movements, manage production sequencing, create an audit trail, and deliver instructions to shop floor workers via a consistent, task-focused graphical user interface. The SmartFactory system's optional APC module uses Applied 'E3' technology to interface directly with production equipment, enabling real-time, run-to-run (R2R) process tuning and fault detection and classification (FDC) to increase process capability and reduce unplanned down time. SmartFactory features pre-defined industry functions and templates that ensure rapid deployment.

Applications: All solar manufacturing facilities.

Platform: Based on Applied's 'FAB300' MES software suite, used in 300mm semiconductor fabs, the framework approach allows the software to be expanded with plug-in components from Applied's portfolio of factory automation software.

Availability: Currently available.

Dranetz Energy

Dranetz Energy's Platform EP1 targets energy audits and power demand studies

Product Briefing Outline: The Dranetz Energy Platform EP1 is a handheld electrical energy and power demand analyzer specifically designed for conducting facility energy audits and power demand studies. The EP1 is a tool for gathering, recording and reporting "where, when, and how much" electricity is used.

Problem: Energy usage can be a significant cost for PV manufacturers. The lack of industry standards, especially in the area of production equipment, means that energy specifications are often different from actual real-world findings. Energy usage audits enable manufacturers to target lowering energy usage and address 'out of spec' equipment to help lower the cost per watt.

Solution: With the growing emphasis on green facilities, the EP1's Energy Platform Report Writer (EPRW) software offers facilities engineers and electrical contractors a cost-effective means of gathering and reporting the data required to document energy savings. The EP1's ability to record both forward and reverse energy is essential in grid-tied alternative energy system analysis, and is useful in certifying a facility's energy consumption and carbon footprint.

Applications: Manufacturing facilities for energy/cost reduction programs, alternative energy monitoring and power/harmonic studies.

Platform: The Dranetz Energy Platform is equipped with eight input channels — four current and four voltage — and is easily set up to monitor and record three-phase, split-phase or single-phase circuits. Measured data can be displayed onscreen or imported into EPRW (included) or DranView (optional) software that provides powerful reporting features including trending and energy-usage reporting.

Availability: Currently available.

cmNAVIGO

cmNAVIGO 2.0 Solar Edition MES from Critical Manufacturing offers integrated quality management tools

Product Briefing Outline: Critical Manufacturing's cmNAVIGO 2.0 Solar Edition allows photovoltaic manufacturers to combine a highly flexible and pre-customized rich set of manufacturing execution and analytical solutions with tightly integrated quality tools.

Problem: While solar manufacturers keep looking for new ways of achieving lower costs and higher throughputs, they face manufacturing processing challenges that require continuous monitoring and adjustment of process and equipment variables.

Solution: cmNAVIGO 2.0 Solar Edition introduces a complete set of integrated quality management tools, including statistical process control (SPC), process compliance and exception management. In addition, the MES Software uses an interactive Microsoft 'Silverlight 3.0'-based web interface, and features: advanced hierarchical material tracking, with sub-material tracking; tracking and traceability of durables, such as crucibles; manual and automatic data collection, with sampling, aggregations and calculations; user-customizable dashboards with online production line status; pre-configured reports for most common KPIs such as cycle-time, yield, uptime, PPH, MTBF, MTTR, etc.

Applications: Crystallization, wafering, cell manufacturing and module assembly.

Platform: Navigo's architecture was built on Critical Manufacturing's foundation and is claimed to allow seamless integration with other manufacturing applications and layers, enabling total leverage of interoperable services and packaging of complex business processes.

Availability: Currently available.

MEECO

MEECO offers solar-grade gas moisture monitor for fixed gas applications

Product Briefing Outline: MEECO has introduced the first mini P_2O_5-based moisture monitor, the 'M-i', which is specifically designed for solar-grade gas moisture monitoring.

Problem: High-purity gases can have a direct impact both positively and negatively on solar cell conversion efficiencies. The need to monitor for moisture in the gas delivery system helps prevent gas degradation and contamination, as well as process problems that could impact yield.

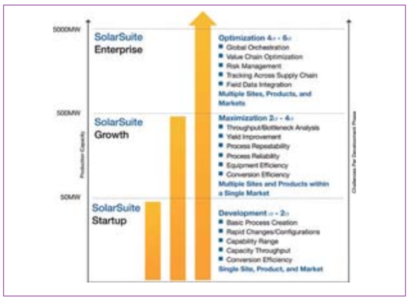
Solution: An electrolytic moisture sensor functions by absorbing and electrolyzing all of the water from a controlled flow of sample gas. The resulting electrolysis current is an absolute measure of the amount of moisture entering the detector by Faraday's Law, which states that every water molecule that is electrolyzed produces two electrons in the detector circuit. The M-i moisture monitor is designed for fixed gas applications and does not need to be calibrated against a moisture standard. The M-i measures an ideal range of 500 ppb to 1000 ppm. Utilizing MEECO's electrolytic technology, the new device is palm-sized and provides continuous, no-drift, on-line moisture analysis at a very low cost (under US$2,000).

Applications: Fixed gas applications with a range from 500 ppb to 1000 ppm.

Platform: The M-i moisture monitor is claimed to be the first mini P_2O_5-based moisture monitor available on the market, offering proven stability, precision and repeatability.

Availability: Currently available.

Camstar



Camstar's SolarSuite version 4.5 handles manufacturing scale-up and fully automated lines

Product Briefing Outline: Camstar Systems has released SolarSuite 4.5 for general availability, which includes technology advancements and new packaging options. Customer reports claim that, for example, a CIGS module manufacturer increased asset utilization by 12%; a CPV and multi-junction cell manufacturer increased conversion efficiency by 38%; and a vertically integrated c-Si module manufacturer reduced production scrap by 20% by using the new system.

Problem: The fast-paced growth of the PV manufacturing industry requires MES systems to be adaptable to a wide range of changing dynamics, be they multiple fab expansions or new technologies and processes.

Solution: Specific enhancements in version 4.5 – driven in collaboration with leading manufacturers using the application – include expanded capabilities for global enterprises to manage multiple manufacturing sites and outsourced operations. In combination with Camstar's Cell Controller, it simplifies integration with a wide variety of machine, equipment and tool interface protocols used in automated factories while supporting complex manufacturing processes. New packaging options mean that the SolarSuite can meet the needs of companies in startup, growth and enterprise modes, and enable scaling from one mode to the next.

Applications: Process support for <20 transactions/sec in 50MW plants to >150 transactions/sec in 500MW PV and thin-film manufacturing plants.

Platform: Configured on the Camstar Enterprise Platform, it encompasses Manufacturing Execution, Quality Management, Process Planning, Operational Intelligence and Equipment Integration.

Availability: Currently available.

Edwards

GXS dry pump from Edwards improves process throughput for crystal puller and laminator applications

Product Briefing Outline: Edwards has developed a new GXS dry pump designed to support pumping requirements for silicon ingot manufacturing and laminator applications in the solar industry. The GXS dry pump can operate on as little as 3.9kW of input power (depending on the pump version) and is said to use 57% less energy than competing piston pumps.

Problem: The GXS provides the optimized thermal control and dust handling capability needed to meet the pumping challenges encountered in these processes. The high atmospheric pumping speed capability of the GXS also enables faster chamber pump-down, reducing cycle times and improving throughput.

Solution: The GXS uses a tapered variable pitch screw profile that allows for tight clearances without the need for rotor coatings. It also enables compression variations along the rotor axis for improved thermal stability and better thermal control, The high efficiency motors are inverter driven and can run in idle mode. Inert, non-oxidizing oil is used to lubricate the gears and bearings of the pump with no maintenance required between major services.

Applications: The GXS dry pump has been optimized to meet the specific pumping process requirements for solar laminator and crystal pulling applications.

Platform: At least 50% smaller than competing pumps at approx. 0.4m (W) x 1.1m (L) x 0.8m (H), the GXS dry pump is a low-noise (<64db(A)) option. The pump is compatible with Edwards' Fabworks data monitoring system so that pump parameters can be monitored and trended in real-time.

Availability: Currently available.

Gas abatement for crystalline silicon solar cell production

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ABSTRACT
This paper presents and discusses the merits of layout, systems and options for exhaust treatments in PV cell production. Such treatments usually comprise central acid scrubbing, NO_x scrubbing, Volatile Organic Compound (VOC) removal and several local treatments for dust, silane, and VOCs, while caustic scrubbing is an option for monocrystalline PV cell production. As direct and indirect major emissions from typical production steps have already been identified [1], this article focuses on a full emission pattern and identifies two sectors, VOC and NO_x treatment, as most important for environmental impact analysis.

Process steps and their need for exhaust treatment

Summary of production

Producing a crystalline silicon solar cell typically comprises the following steps:

- saw damage removal/texturing
- emitter formation (doping with phosphorus)
- phosphorus silicate glass (PSG) etching
- silicon nitride deposition
- screen printing of the metallization
- edge isolation.

Studies have been carried out to identify direct and indirect major emissions from typical cell production steps [1]. As a result, this article confines its focus to the full emission pattern. Two particular treatment types, VOC and NO_x, are found to be most critical to environmental impact analysis.

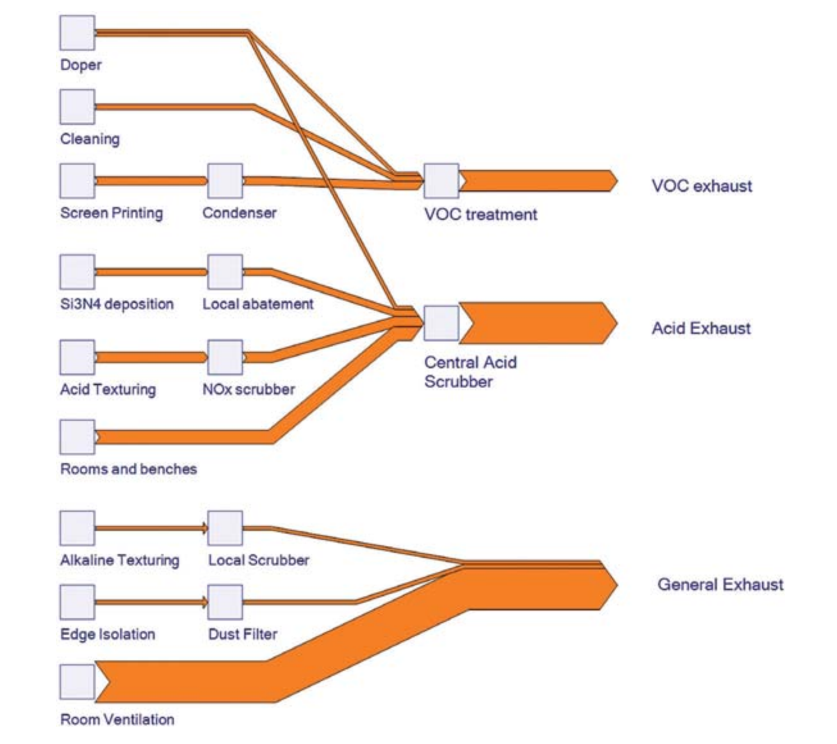


Figure 1. Schematic layout of a PV line exhaust system.

Summary of emissions

As silicon wet etching is included in the production sequence, liquid HF is used in all crystalline silicon solar cell lines. The respective emissions of HF gas have to be scrubbed. In most modern installations, mixtures of HNO_3 and HF are used for the so-called 'acid texturing' step and generate NO_x and HF emissions, which also have to be reduced before emission. Consequently, wet HF and NO_x scrubbers are present in many installations. Emissions from storage rooms and tanks may also be connected to the central acid exhaust system, depending on the design of the tanks in question.

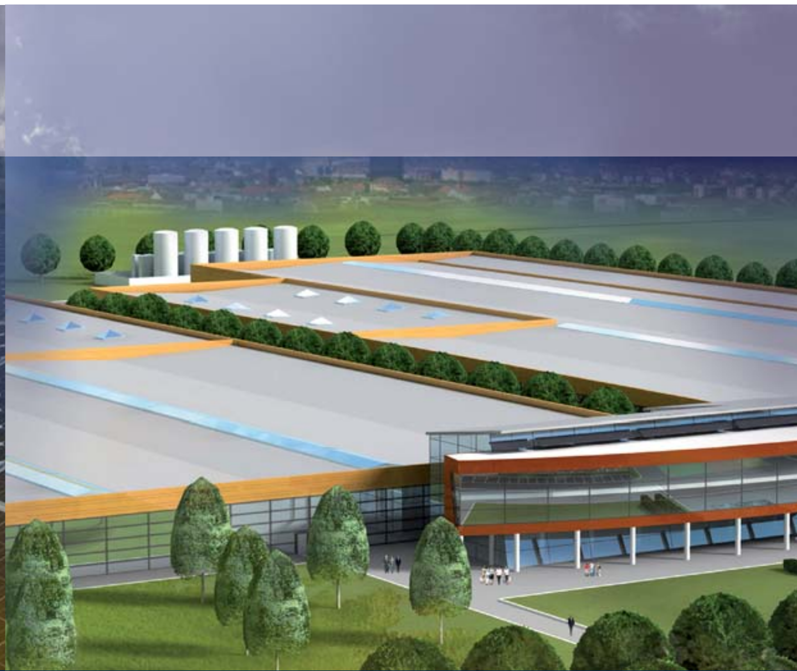
The more traditional doping process uses furnace-type equipment and $POCl_3$ as a phosphorus source. This equipment releases $POCl_3$ as an unused process gas, which reacts to produce HCl and H_3PO_4 upon contact with moisture, and Cl_2 during the process itself. Therefore, the equipment needs to be connected to the acid exhaust system.

Vacuum processes are typically used to deposit Si_3N_4 layers. To this end, mixtures of SiH_4 (silane) with NH_3 (ammonia) are used. These mixtures require exhaust treatment for safety and emissions reasons, a task which is usually taken on by so-called local abatements, as discussed in the following section.

"Vacuum processes are typically used to deposit Si_3N_4 layers."

Screen printing usually evaporates all of the solvent in the printing paste and produces rather dilute VOC exhaust streams, which nevertheless have to be treated. Other applications of solvent may contribute to VOC emissions; the right choice of a VOC treatment depends on the nature of these additional VOC sources. Such additional sources comprise temporary extractions from cleaning benches using the same solvent as screen printing, but also vaporization of solvent (e.g. isopropanol) from hot etching baths (mono-Si production) and solvent (e.g. ethanol) used for the spray doper process.

Edge isolation can be done with vacuum plasma etch or using the more recently adopted methods of laser cutting or wet processes. The plasma edge isolation requires fluorine gases that have a high Global Warming Potential, but is generally phased out. The laser



edge isolation produces combustible dust which has to be handled according to safety standards [2].

Types of exhaust systems

These requirements usually lead to installation of the following duct systems for extraction and treatment:

- General exhaust
- VOC exhaust
- Acid exhaust with a NO_x collection subsystem and local abatements for silane.

The local abatements can be hooked up to the acid exhaust system, although the rests of both ammonia and silane are not acidic, but alkaline or neutral, respectively. Usually, the acid system is the only corrosion resistant system available in a fab, unless a separate ammonia exhaust system is required. "Available" can also mean that from space management point of view the "caustic" extraction system is too far away for connection.

Ammonia exhaust (caustic exhaust) is only required in the case of cleaning processes evaporating alkaline gases in a concentration requiring scrubbing. In that case, the local abatements of the Si_3N_4 deposition should be hooked up to this system, a general layout of which is shown in Fig. 1.

The duct system for noncorrosive exhaust generally uses a galvanized spiral wound material. If the possibility of condensation is an issue, longitudinally welded or pleated ducts are preferable. For corrosive applications, PVC and PP are common materials. PVC is slightly more resistant against oxidative attack, as HNO_2/HNO_3 condensate in the ductwork. However, leakage rates of a PVC system are generally higher than in a PP system due to the fact that PVC is glued and not welded. When taking off the underpressure temporarily, e.g. for maintenance, corrosive liquid may trickle down from the ducts at all connection points that have not been properly glued in a PVC duct.

Local treatments

The pump exhaust of the Si_3N_4 deposition is best cleaned by local abatements because of higher inherent safety, avoiding the transport of self-igniting gas over a long distance in the fab. SiH_4 is oxidized to SiO_2 under hot conditions, either by flame or electrical heating, followed by a wet scrubbing stage which takes temperature down, washes out SiO_2 dust and removes NH_3. Oxidation under cold conditions is possible, but produces an only partially oxidized SiO_{2-x} dust, which can undergo exothermic oxidation reactions. This can lead to dangerous runaways, inducing fires. Under these conditions, ammonia is partially oxidized and partially scrubbed with water, so that rest concentrations can be left with the acid system without interfering with the performance of the acid scrubber.

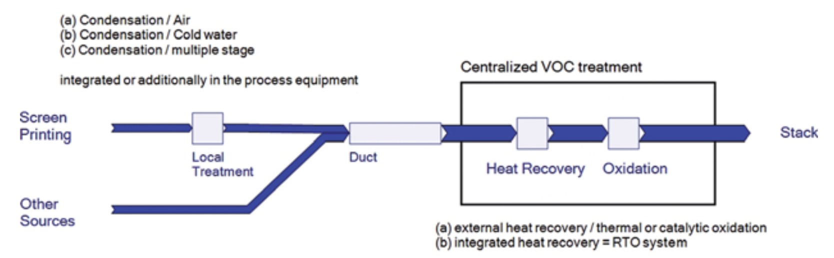


Figure 2. Typical VOC treatment combinations.

Option	Local Treatment	Centralized Installation	References	short name
0	none	none	Calculation Reference	no T
1	Catalytic Oxidation	none	Pilot Test	loc KOX
2	Condensation	none	Standard for small Fabs	loc C
3	Condensation	Catalytic Oxidation (KOX)	M+W Group project	loc C + KOX
4	Condensation	Regenerative-Thermal Oxidation (RTO)	M+W Group project	loc C + RTO
5a	Thermal Oxidation, 400 °C, one outlet	none	supplier A	loc TOX a
5b	Thermal Oxidation, 800 °C, all outlets	none	supplier B	loc TOX b
6	Condensation	Biotrickling-Filter	Design Draft M+W Group	lok C + Bio

Table 1. Options for local VOC treatment.

"The pump exhaust of the Si_3N_4 deposition is best cleaned by local abatements because of higher inherent safety."

Local treatments for VOC exhaust such as condensation traps at the printer/dryer or firing furnace stages of the screen-printing process have been widely used.

While these traps are unable to guarantee a match with the emission limits, they are nevertheless installed, because 'natural' condensation tends to occur after the printer/dryer machine step. Since the resulting VOC exhaust is dilute and cannot be concentrated due to the cited polymerization reaction, any central treatment is expensive in terms of cost, but also from an environmental impact perspective.

The typical layout of the VOC treatment is shown in Fig. 2. Options and potential combinations are summarized in Table 1 as the basis for the life-cycle assessment (LCA), as described later.

The VOC ductwork in between the process tools and the centralized installations always suffers from condensation of polymerized solvent material, darkening and hardening over time. Even thorough condensation does not remedy the situation. Keeping the

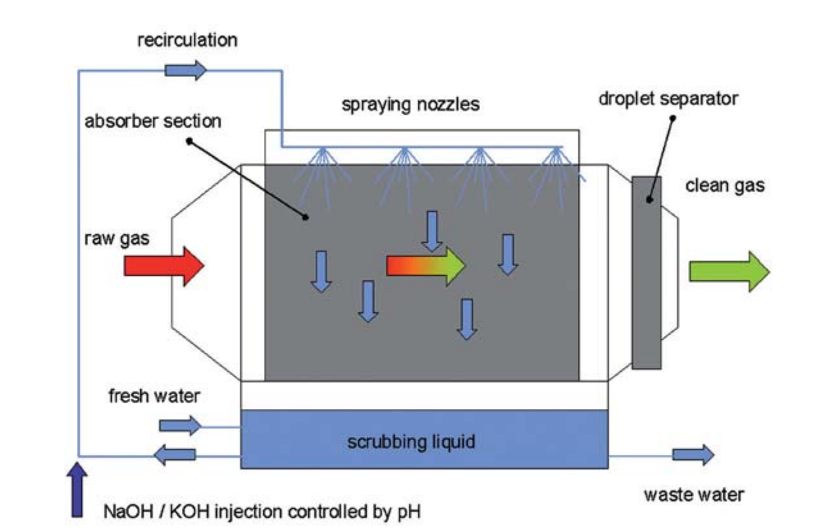


Figure 3. Centralized acid scrubber cross-section.

1. Absorption in water with HNO_3 recovery		
$2\ NO_2 + H_2O$	→	$HNO_3 + HNO_2$
2. Absorption in water with neutralization		
$2\ NO_2 + 2\ NaOH$	→	$NaNO_2 + NaNO_3 + H_2O$
3. Absorption in water with oxidation		
$2\ NO_2 + 2\ NaOH + y\ H_2O_2$	→	$(1\text{-}y)\ NaNO_2 + (1+y)\ NaNO_3 + (1+y)\ H_2O$
4. Absorption in water with reduction		
$2\ NO_2 + x$	→	$N_2 + H_2O$ + other products
5. Gas phase SCR DENOX process		
$3\ NO_2 + 4\ NH_3$	→	$7/2\ N_2 + 6\ H_2O$

Table 2. Options for NO_x treatment.

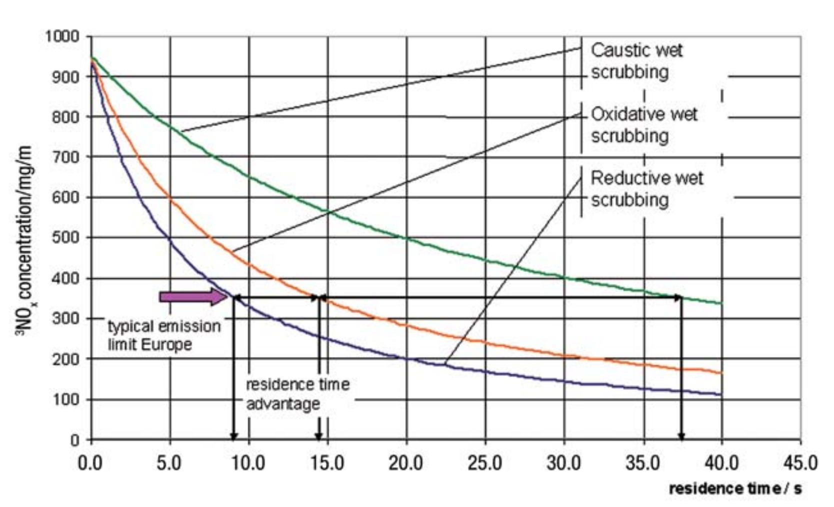


Figure 4. Dimensions (residence times) required for wet scrubbers of different type (example for given scrubbing chemical concentration, NO/NO_2 ratio and input concentration).

polymers in the gas phase by elevating the temperature or insulation is also not an option. Therefore, the approach taken in today's practices is regular cleaning through suitable openings. Development of metallization paste with non- or low-polymerization organic compounds could be a feasible way of reducing this cost of abatement and duct cleaning.

However, local treatment of VOC exhaust, based on flame oxidation, as introduced by some suppliers, solves the technical problem of dirty exhaust lines, but leads to significant increase in CO_2 footprint for the VOC treatment considered. These scenarios are included as No. 5 in Table 1's LCA comparison. Local VOC treatments based on catalytical oxidation promised a better energy efficiency and hence a more favourable CO_2 footprint (No. 1 in Table 1), but failed because of the presence of catalyst poisons.

Therefore, as long as is feasible, central VOC treatments still have to be preferred over local solutions, since low CO_2 footprint is a vital product property expected by the customer.

Local abatements for edge isolation etch should be of burner type capable to decompose the PFC gases used in the older process. Local treatment for Si dust created by laser cutting tools should be an explosion proof filtration [2].

Centralized treatment

Centralized treatment for VOC comprises either thermal recuperative, thermal regenerative or thermal catalytic systems. Central catalytic systems are not affected by catalyst poisons to the same extent as the local catalytic systems, probably because of heavy metals and other reactive compounds that are left in the ductwork. They have, however, proven to be suitable for reasonable steady-state operation.

Environmentally speaking, the best option would be a biofilter or biotrickling filter [3], but due to the possible instability of operation, they have not yet been considered for PV applications. Because of the high energy needed to heat up air without major caloric content, this type of treatment, if not properly engineered, can have a significant, negative influence on the environmental impact of the PV cell produced [4]. (Heat recovery is usually included, but not up to an infinitely high level for cost reasons.)

Central acid scrubbers are counter-current or cross-flow wet scrubbers with neutralization, as used in many other installations (see Fig. 3 for a cross-section schematic). Absorption rates exceeding 95% of HF are easily accessible. The waste water of this scrubber is usually subjected to F precipitation to calcium fluoride (CaF_2) in the waste water treatment central. NO_x scrubbing is in most cases a subsystem of the acid system, thus avoiding a separate set of fans for the relatively small NO_x exhaust air flow rate, as shown in Fig. 1.

Because of the late introduction of acid texturing to the production process, NO_x scrubbing has also had a delayed introduction to the fab facility system, exclusively based on wet scrubbing in the first years of application. Later, competitive NO_x reduction techniques – such as selective catalytic reduction (SCR) and reductive wet scrubbing – were considered and installed.

An overview of available methods is given in Table 2. These methods are

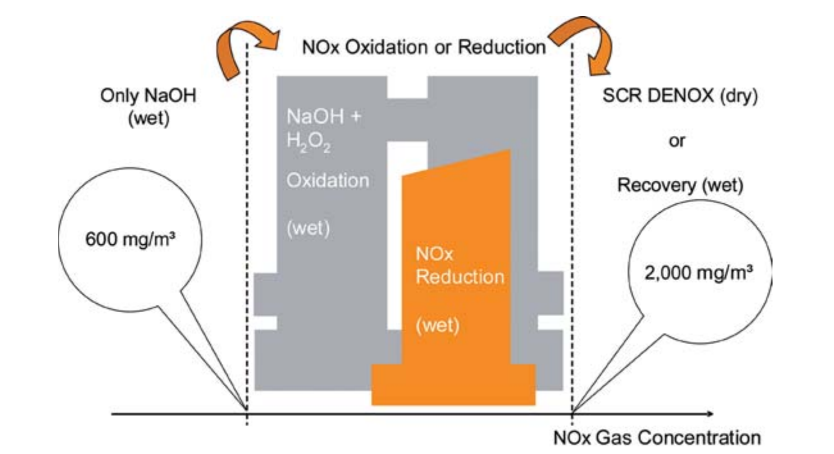


Figure 5. Areas of application of NO_x removal techniques (100MW line).

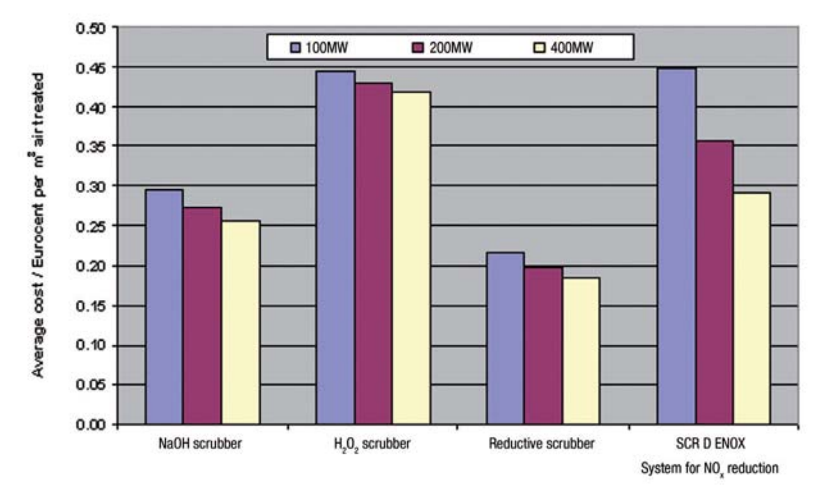


Figure 6. Cost of Ownership (COO) and areas of application of NO_x removal techniques.

formulated using NO_2, although NO_x is mainly a mixture of NO with NO_2, but NO itself is only marginally water soluble.

Reaction 1 is executed under pressure to allow for complete absorption of NO_x in water. The mixture of HNO_3 and HNO_2 is kept under oxidizing conditions (without neutralization) so that HNO_2 is finally also converted to HNO_3, which is then recovered. The high investment reserves this solution for high NO_x mass flow.

Reactions 2 to 4 are usually referred to as 'scrubbing' solutions. Methods 5 and 1 are useful with higher concentrations of NO_x. Reaction 5 is executed at elevated temperature (typically 200°C) and with a controlled injection of ammonia or urea. Control-loop tuning is essential to avoid NH_3 overshoot in the exhaust gas, while steep frequent peaks are difficult to handle.

Different chemicals are in use for Reaction 4, including sulfides, sulfite, or ammonia salts. Their application depends on waste water discharge conditions and/or fab waste water treatment structures, as there is always a chemically important residue of chemical 'X' (reduction agent) in the waste water.

For a given set of NO/NO_2-ratio, chemical concentrations of the scrubbing agents and tower characteristics, the difference in gas residence time in the scrubber for a typical NO_x removal rate is shown in Fig. 4. Since oxidation and reduction (Reactions 3 and 4, respectively) are faster consecutive reactions (with a higher reaction constant *k*) than the hydrolysis step (Reaction 2), the corresponding absorption rate, which is proportional to $\sqrt{k}$ [5] increases accordingly, and allows smaller scrubber constructions – albeit at elevated operational cost – and slightly higher environmental impact, as shown in the LCA section.

Because of the slow reaction, purely caustic absorption is only feasible for moderate NO_x inlet concentrations, lower than that usually found in PV fab exhaust. Oxidative or reductive scrubbing is usually installed for PV applications. For even higher NO_x concentrations, SCR or reclaim solutions are feasible and in use. The limits given in Fig. 5 are related to an emission limit of $350mg/m_3$. With higher emission limits, pure caustic scrubbing is feasible at higher concentrations and the limit for SCR application also shifts to higher values.

"SCR technology should be considered should concentrations reach above $2000mg/m^3$ at the NO_x treatment input."

On the other hand, the specific cost rate also depends on line size, as shown in Fig. 6. Generally speaking, the reductive scrubber has the lowest overall cost, but under the condition that the waste water is accepted for discharge. Fig. 6 shows some major tendencies that tend to be present in any project. The exact breakpoints, however, have to be defined by a project-specific calculation, including the precise cost rates for energy, raw and waste water, and chemicals of a given site or project.

Life Cycle Assessment

Life Cycle Assessment (LCA) summarizes all life-cycle environmental impacts for an inspected activity. This assessment includes all raw materials and primary energies as well as the emissions and their treatment, onsite or offsite. The services necessary to run a production, including transportation, are also included. This so-called 'cradle-to-grave' analysis is necessary for a fair comparison of process technologies or products.

The European Integrated Pollution Prevention Guideline [6] requires that such considerations be made for relevant installations.

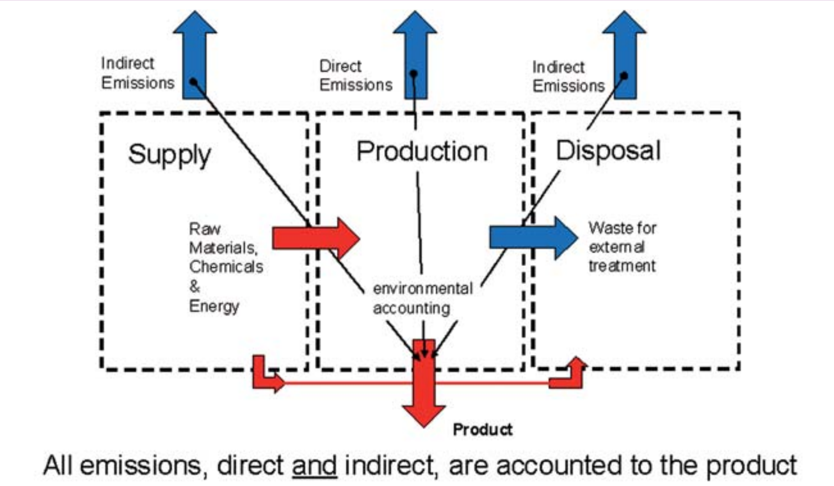


Figure 7. LCA boundary limits.

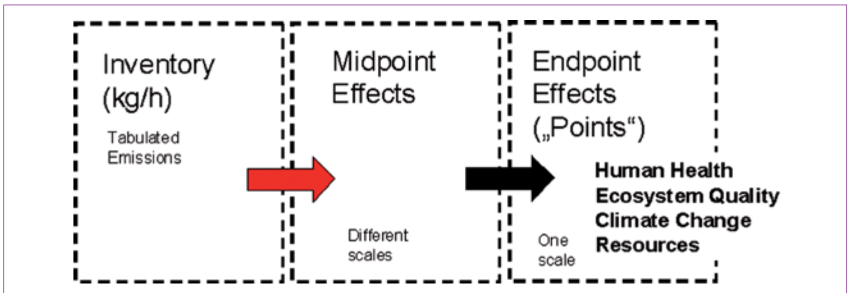


Figure 8. Environmental valuation with IMPACT 2002+.

The overall impact of PV cell fabrication has been published [7] based on the IMPACT 2002+ scale [8], the main results of which are shown in Figs. 9 and 10. Fig. 9 contains all impacts in a cradle-to-grave calculation. Fig. 10 contains the PV production steps with the exception of the contribution of silicon as a raw material in order to better illustrate the breakdown to different effects. It is clear that the presence of silicon (via the trichlorosilane route) is the predominant contribution. It can be expected that some progress will be made over the next few years by implementing new and improved production methods of silicon, which are less energy demanding. (Silicon production indirect emissions and other indirect emissions data are taken from ECOINVENT [9].)

Fig. 10 clearly illustrates that indirect emissions (energy use, use of chemicals, PV cell plant) are more important than direct emissions (emissions from the solar cell fab). Only by including indirect emissions in the calculations can a representative judgement of the environmental impact of photovoltaic manufacturing be obtained.

Chemical consumption and energy consumption in exhaust abatement is negligible, except for the energy demand for VOC treatment. A comprehensive comparison of VOC treatment technologies in PV has been published [10], a summary of which is given in Table 1. Fig. 11 shows the environmental footprint of these technologies, relative to the total environmental footprint of solar cell production. The environmental footprint of an optimized VOC treatment is about 6% of the total factory's environmental footprint. Another design, which is still at the design stage, leads to ~50% of the fab's overall environmental footprint in three out of four impact categories, and 90% in the category 'resources'. The global warming effect for this new design would increase by a factor of 1.5, which further underlines the fact that VOC treatment systems must be designed taking into account the advantageous environmental properties of the PV cells produced.

Interestingly, for VOC emissions, the best environmental approach is the 'No Treatment' route, but this option will not meet environmental legislation in most countries.

For NO_x treatment, however, the 'No Treatment' option is the worst case, mainly because the untreated emissions would affect human respiratory systems. This 'untreated' scenario is shown in Fig. 12, which would account for as much as 12% of total production impact. Ecosystem quality is affected in a minor way due to acidification effects on water and soil.

Despite the existence of other methods,

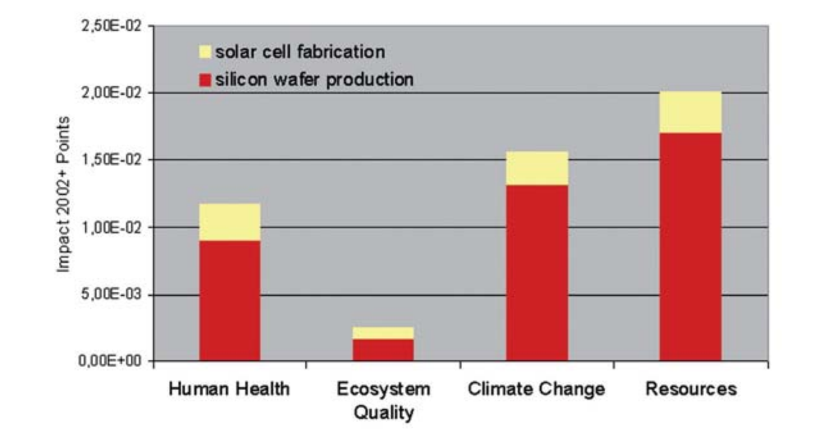


Figure 9. Environmental impact of PV cell fabrication per m² of Si solar cell.

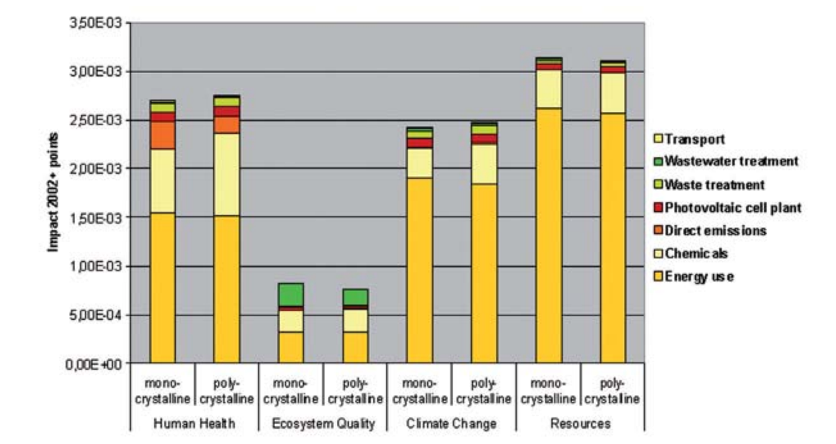


Figure 10. Environmental impact of PV cell fabrication excluding raw silicon usage per m² of solar cell.

wet scrubbing techniques are the only options LCA-analyzed in this work as they are the most commonly used methods. The waste water is meant to contain only nitrate and no nitrite, which requires the installation of a suitable nitrite oxidation stage in the waste water line.

Treatment can dramatically reduce the effects on human health. According to legislation in many European countries, the emission limit is 350mg NO_x/m^3. In Spain and Singapore, for example, the 700mg/m³ limit allows a much higher impact to human health, as indicated in Fig. 12. On the other hand, treatment produces new impacts in the 'resources' and 'climate change categories because raw materials (chemicals) and electrical power is required to treat the NO_x gas according to the IMPACT 2002+ valuation.

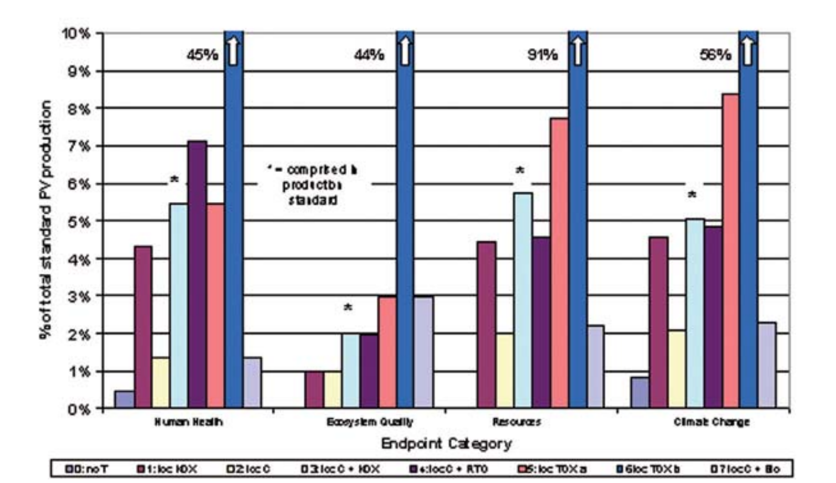


Figure 11. Assessment of VOC treatment as % of total standard production impact (See Table 1 for legend).

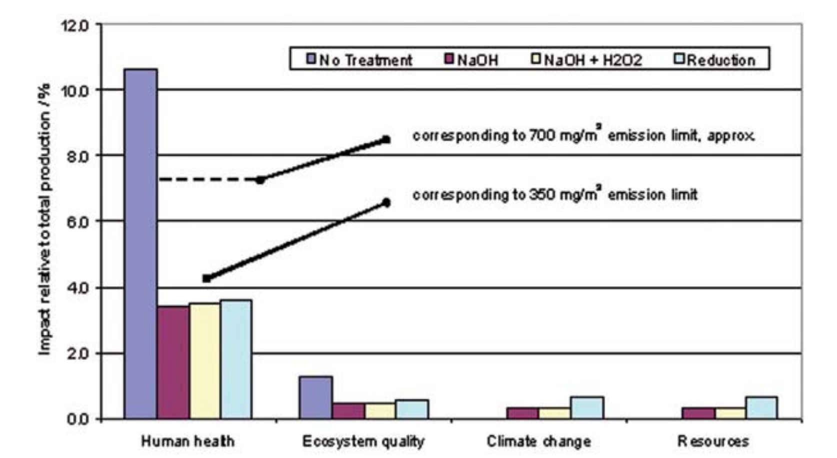


Figure 12. Assessment of NO_x treatment as fraction of total standard production impact (See text for legend).

However, the benefit for human health can be regarded as more important than the additional impact in these two categories. The three wet scrubber types are most similar in their environmental profile, while the 'reductive' type requires slightly more resources.

Summary

For VOC treatment, it is important to have a balanced mix of suitable local treatments and an energy-efficient centralized treatment. Local burners should be avoided in this case because of the negative impact to the solar cell's CO_2 footprint.

For NO_x treatment, Selective Catalytic Reduction (SCR) technology should be considered should concentrations reach above 2000mg/m^3 at the NO_x treatment input. Otherwise, wet scrubbing technologies apply. Emissions higher than 350mg/m^3 in the clean gas have a considerable effect on life-cycle NO_x emissions of the solar cell, and on human health.

Centralized ammonia scrubbing is only necessary in special cases, while standard scrubbers are best suited to acid scrubbing.

Local abatements for silane are in most cases integrated into the acid system, although the respective rest gases are not acidic. If centralized ammonia scrubbing is available, the silane abatements may be hooked up. Dust removal from laser applications must incorporate explosion proofing in case of Si dust.

If designed with all of these factors in mind, the environmental footprint of the exhaust system of a PV cell manufacturing plant is not excessive compared to other contributions.

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Disclaimer

The data used in this study have been compiled with care in order to show the status of production and abatement technology of today. Nevertheless, none of the authors takes liability for any damage arising from using the given information for design, build or operation. Systems different from these described here or not described above need not necessarily be inferior.

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Solar PV manufacturing in Canada

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ABSTRACT
Canada is aggressively pursuing solar photovoltaic manufacturing. Ontario, the province leading the charge, is already the manufacturing hub for other products in Canada and currently boasts one of the most generous feed-in tariffs in the world. This incentive is closely tied to domestic content restrictions in order to foster Canadian photovoltaic manufacturing. In addition, a host of other tax incentives and research and development stimulus packages are making Canada an increasingly popular destination for both established manufacturers and start-up companies.

Introduction

Although sunny weather – and the resulting high solar fluxes and photovoltaic systems that go with it – are probably not on the top of anyone's list when you think of Canada, the "True North" is opening up some intriguing possibilities for solar photovoltaic manufacturers. Although the 2009 and 2010 Federal budgets clearly indicate that the Canadian Federal government is not directly investing to support financial incentives for PV, it is providing funding for sustainable energy infrastructure to the provinces [1, 2]. The manufacturing hub of Canada is Ontario, which is Canada's largest province (the equivalent of a U.S. state). It has more than 12 million well-educated people (more than 50% of whom have post-secondary education) and a very strong support of renewable energy. Following the success of many of the world's governments in this area [3], Ontario has moved to improve the economics of renewable energy projects by offering a feed-in tariff (FiT). Ontario currently boasts one of the most generous FiTs in the world, and an assortment of other incentives that have both established companies and startups flocking to the north.

The Ontario feed-in tariff

Renewable energy holds popular support throughout Canada; however, Ontario has made the most notable efforts towards expanding its renewable energy sector. In 2009, the Ontario Power Authority (OPA) launched the FiT program supported by the Green Energy and Green Economy Act 2009 [4] to procure renewable energy [5]. The Ontario FiT covers several renewable energy technologies, boasting the largest rates for solar PV, as shown in Table 1. (All economic values in Table 1 and throughout this paper are in $CAD; at time of writing, ~$US.)

FiT programs are based on contracts with a local utility to purchase energy generated by renewable energy technologies with variable capacity [6]. In the Ontario FiT case, this rate is guaranteed for 20 years, which has made installation of PV in the province quite profitable.

In addition to the obvious direct jobs created by installing PV systems in the province, the Ontario FiT directly encourages PV manufacturing in Ontario as a result of provincial content standards [7]:

- For solar PV projects with a contract capacity greater than 10kW, the minimum required domestic content level is 50% for FiT contracts that have a milestone date for commercial operation prior to January 1, 2011 and 60% thereafter.
- For micro-FiT contracts (<10kW), the minimum required domestic content level is 40% for FiT contracts that have a milestone date for commercial operation prior to January 1, 2011 and 60% thereafter.

With the use of local labour on the installation and balance of systems (BOS) components such as racking being made locally, it has been relatively easy for Ontario's PV development firms to meet the current domestic content standards. However, when the percentage increases in 2011, it will be necessary to have at least some of the main components manufactured in Ontario. The news has caused an explosion of announcements about PV materials, with several cell and module manufacturers setting up shop in Ontario (see Table 2). Currently, Canada's PV industry is in its infancy, but many companies are considering some form of assembly or manufacturing in Ontario to comply with the FiT domestic content restrictions.

> "It has been relatively easy for Ontario's PV development firms to meet the current domestic content standards."

Just as the impermanent nature of FiTs in Europe directed the industry down the more conservative route, so too has Canada's situation developed. Most of the companies listed in Table 2 are planning to start with assembly, which consists of some of the back-end processing including wiring and laminating, rather than start-to-finish manufacturing of modules. In addition to the manufacture of materials, cells and modules for the PV industry, there has been an even greater explosion of BOS manufacturers in the region in the past year, as seen in Table 3.

Again, much of the manufacturing listed in Table 3 is for inverter assembly of parts made elsewhere, although there is a growing interest on the part of existing Ontario firms with skill sets in the area of racking design and manufacture in entering the PV BOS space. It should be noted that the company lists in Table 2 and 3 should not be considered exhaustive as the number of companies entering the Ontario market is rising at a breathtaking pace. This is particularly important given the context – the installed PV capacity of all of Canada was in the tens of MWs even in 2008 when installations were dominated by small-scale systems on cottages and off-grid applications.

Size	Rate
MicroFIT* – Rooftop or ground-mounted	
Less than 10kW	80.2c/kWh
Rooftop-mounted systems	
10 – 250kW	71.3c/kWh
250-500kW	63.5c/kWh
Greater than 500kW	53.9c/kWh
Ground-mounted systems	
Less than 10MW	44.3c/kWh
Aboriginal adder	1.5c/kWh

Table 1. Ontario feed-in tariff rates.
**As of July 1, 2010, there have been over 16,000 applications made for the micro-FiT program and the size of the systems indicate most are ground-mounted. The OPA has thus proposed that ground-mounted solar PV projects of 10kW or less will be eligible to receive a price of 58.8 cents per kilowatt-hour rather than the roof-mounted micro-FiT rate.*

Company	Product (expected date of operation)	Webpage/press release
Arise Technologies Corp.	Solar-grade silicon – pilot production	www.arisetech.com
Bosch	Thin-film PV (in partnership with SET)	www.thestar.com/business/article/773554--bosch-latest-to-tap-ontario-s-solar-market
Calisolar, Inc. (formerly 6N Silicon)	Solar-grade silicon	www.calisolar.com
Canadian Solar	PV modules (2010)	phx.corporate-ir.net/phoenix.zhtml?c=196781&p=irol-newsArticle&ID=1361594&highlight=
Cyrium Technologies	Solar cells for concentrated photovoltaics	www.cyriumtechnologies.com/index.htm
Everbrite Solar	Thin-film PV modules (2010)	www.everbritesolar.com/Home/tabid/61/Default.aspx
Flexible Solar Cell Technologies	Flexible solar cells, in development	www.flexiblesolartech.com/
German Solar Corporation	Solar arrays (early 2010)	www.ledc.com/index.php/ledc/show_NEWS/1040
Greenpower Farms	PV modules (November 2010)	www.greenpowerfarms.com/index-3.html
Heliene Canada	PV modules (August 2010)	www.heliene.ca/products/index.aspx?l=0,9,10,22
Menova Energy	"Power-Spar" - solar concentrator to provide heat, hot water, and electrical power	www.power-spar.com/Power-Spar/index.php
Morgan Solar	Concentrated PV (2011)	www.morgansolar.com/about.php
Opsun Panels	PV modules (third quarter 2010)	www.opsunpanels.com/press.html
Photowatt Ontario, Inc.	PV modules (third quarter 2010)	www.photowattontario.com/about.html
PRISED Solar, Inc.	Silicon refinement development	www.prisedsolar.com/Standard/Default.aspx
Quadra Solar	Concentrated PV	www.quadrasolar.com/
Routes AstroEngineering	Space-grade PV modules for satellites	www.routes.com/pdf/Solar%20Panels%20Jul-05.pdf
Samsung	PV manufacturing (2013)	www.thestar.com/news/ontario/article/753816--mcguinty-heralds-samsung-green-energy-deal?bn=1
Silfab SpA	PV modules (July, 2011)	www.silfab.eu/it/releases.php/1277
Siliken Renewable Energies	PV modules (fourth quarter 2010)	www.siliken.com/comunicacion/noticias/ficha?contentId=1031&languageId=1
Solar Semiconductor	PV modules (2010)	www.solarsemiconductor.com/abt-news-aokville-plant.htmlZ
Solar Source Corp. of Canada/HHV	Crystalline PV modules (2011)	www.solarbancorpgroup.wordpress.com/
SolGate	Solar PV modules, 75-230W	www.solgatesolar.ca

Table 2. Ontario's photovoltaic materials, cell and module manufacturers.

By encouraging the development of renewable energy in Ontario, the government hopes that the FiT Program will [8]:

- help Ontario phase out coal-fired electricity generation by 2014 – the largest climate change initiative in Canada
- boost economic activity and the development of renewable energy technologies
- create new green industries and jobs.

Completion of these goals is imperative. Coal is on its deathbed in Canada, as a recent announcement from the Federal government demanded that when each of the remaining 51 coal-burning units in Canada reaches the end of its economic life, it will have to meet with new standards or close down with no exceptions or carbon trading [9]. Meanwhile, Ontario will have all of its coal plants either shuttered or only burning biomass by as early as 2014.

In addition to meeting the provincial government's campaign promise of shutting down all coal-fired electricity in the province and ushering in a renewable energy era, the government also sees support of PV as an economic development tool. Support for this view was recently provided by a financial analysis for investment in a theoretical 1GW turnkey amorphous silicon PV manufacturing plant. The financial analysis looked at six scenarios and quantified the benefits for both the provincial and federal governments for [10]:

i) full construction subsidy
ii) construction subsidy and sale
iii) partially subsidizing construction
iv) a publicly owned plant
v) loan guarantee for construction
vi) an income tax holiday.

The revenues for the governments are derived from: taxation (personal, corporate, and sales); sales of panels in Ontario; and saved health, environmental and economic costs associated with offsetting coal-fired electricity. The study found that in less than 12 years, both governments enjoyed positive cash flows from these investments even for the most aggressive plans. Furthermore, the scenarios both saw governments earning well over 8% on investments from hundreds of millions to $2.4 billion [10]. The results showed that it is, financially speaking, in the best interest of both the Ontarian and Canadian federal governments to implement aggressive fiscal policy to support large-scale PV manufacturing.

> "The Ontario government is actively pursuing agreements with PV companies to stimulate manufacturing in Ontario in addition to the policies outlined in the FiT."

It is also apparent that the Ontario government is actively pursuing agreements with PV companies to stimulate manufacturing in Ontario in addition to the policies outlined in the FiT. Earlier this year, the Ontario government signed a $7 billion agreement between and Samsung C&T Corporation and the Korea Power Electric

Corporation (KPEC) for both solar PV and wind manufacturing facilities – an agreement that was spurred on by the stability ensured by the FiT program [11]. The government is supplying the Korean consortium with a $437 million economic "adder" to the FiT to ensure that manufacturing jobs are created, with the stipulation that they will set aside scarce transmission capacity in the western part of the province to ensure the group does not have too long to wait in the grid-connection queue. The Premier of Ontario, Dalton McGuinty, has made it clear that if any other consortia – local or foreign – want to talk about manufacturing, energy development and job creation on a large scale, then he is listening [12].

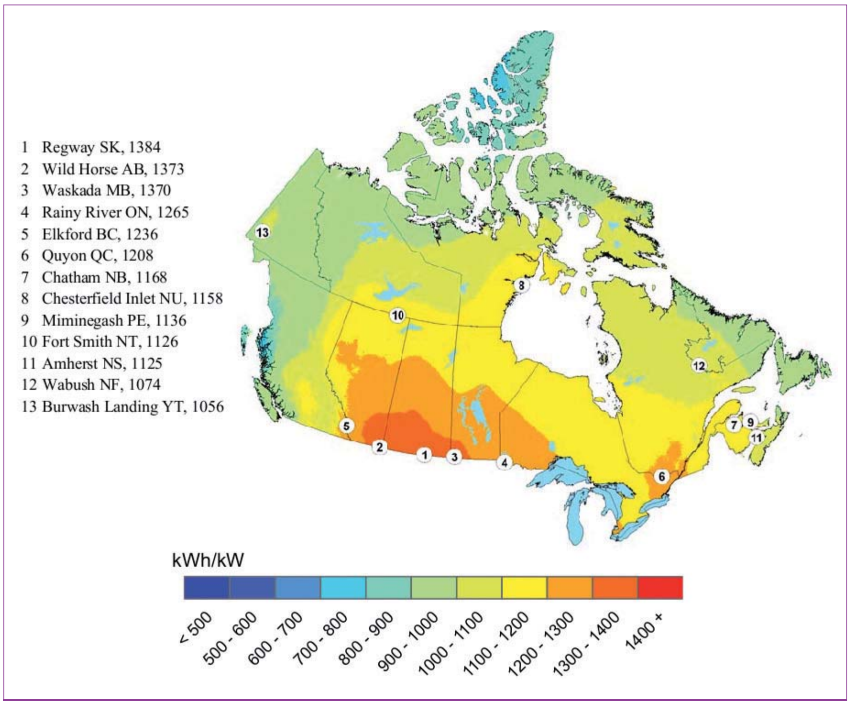

Figure 1. Yearly solar photovoltaic potential map for latitude tilt in Canada and 'PV hotspots' in each province and territory in Canada [14].

Innovation incentives

In addition to deployment of PV, Canada also strongly encourages research and development work related to renewable energy. Each province has its own programs: Ontario has 1) up to $1.5m investment opportunity through the Eastern Ontario Development Fund; and 2) Advanced Manufacturing Incentive Strategy (AMIS), which provides interest-free loans for up to five years to encourage companies to invest in leading-edge technologies and processes. At the Federal level there are two programs that are helpful to PV manufactures: IRAP and SR&ED. IRAP, the Industrial Research Assistance Program, provides technical and business advisory services and financial assistance to small and medium-sized enterprises [13]. This program would be best suited for start-up companies. The Federal and Ontario Scientific Research and Experimental Development (SR&ED) incentives generate significant tax savings; among the most generous in the G7, these incentives can cut the cost of R&D from $100 to less than $41 (see Table 4).

Company	Product (expected start date)	Webpage/press release
Abuma Manufacturing	Solar mounting & trackers	www.abuma.com/
Advanced Solar Investments	Polymer racking for flat rooftops	www.advancedsolarinvestments.com/
Anchor Danly	Mounting frames	www.anchordanly.com/
Atlas Tube	Solar mounting frames	www.atlastube.com/
Cachelan	Web-based monitoring of solar systems	www.cachelan.com
Conergy Ltd.	Ground- and roof-mounting Systems	www.conergy.ca
Conserval Engineering	Mounting system for PV/solar thermal modules	www.solarwall.com/en/products/solarwall-pvt/solarduct-pvt.php
Domcast Metals	Racking & support structures	www.domcastmetals.com
Dyco Solar Inc.	Solar roof, pole & ground mounts	www.dyco.ca/index.html
Eco Energy	Solar electronics, charge controllers, low voltage disconnectors for PV systems	www.eco-energy.ca/
Extrudex Aluminum	Solar roof and ground mounts	www.extrudex.com/
Flextronics -Enphase Energy	Microinverters (May 2010)	www.enphaseenergy.com/downloads/Enphase_Press_Release_Ontario.pdf
Fusetek	Fuses for solar PV applications	www.fusetek.com/
Green Sun Rising	PV and solar thermal mounting hardware	www.greensunrising.com/indexNew.htm
Greenfield Hydroponics	PV-powered greenhouse	www.greenfield-hydroponics.com/
HB Solar	PV flat roof mounting system	www.ingo@hbsolar.ca
Hybridyne Power Electronics	Inverters	www.hybridynepowerelectronics.com/Page_02.05.htm
Opsun Panels	Mounting systems	www.opsunpanels.com
PLP Solar	Roof ground mounts, large ground mounts, power enclosures	www.preformed.on.ca
Polar Racking	Commercial rooftop racking	www.polarracking.ca
Samsung	Inverters (2013)	www.theenergycollective.com/TheEnergyCollective/57131
Sasco Strut	Mounting frames	www.sascocan.com
SatCon Power Systems	Development & manufacturing of power electronics & control systems for alternative energy	www.satcon.com/company/index.html
Schletter Canada	Solar mounting systems (May 2010)	www.schletter.de/us/component/content/article/180.html
Schneider Electric (Xantrex)	Inverters (August 2010)	www.schneider-electric.ca/
Sciencetech, Inc.	Solar simulator systems	www.sciencetech-inc.com
Siemens Canada Ltd.	Inverters (November 2010)	www.siemens.ca/web/portal/en/press/
SMA Solar Technology AG	Inverters (2010 Q3)	www.sma.de/en/
Solar Converters, Inc.	Power controls for renewable energy systems	www.solarconverters.com
Solar Signals, Inc.	Off-grid solar-powered transportation signs (roads, marine, rail)	www.solarsignals.com
Solera Sustainable Energies Company	PV system controls	www.soleraenergies.com
Spectra Aluminium	Aluminium racking	www.solarsignals.comspectraaluminum.com/Markets-Served
Spectra-Nova Technologies	Solar cell & module test equipment, spectral response units, & array simulators	www.spectra-nova.com
SunLink Corporation	Solar roof and ground mounts (2010)	www.sunlink.com/files/sunlink-04-13-10-Ontario.pdf
Sun-Link Solar Tracker	Solar trackers	www.sunlinksolartracker.com
Sunrise Power	Inverters & mounts	www.sunrisepower.ca/Products.html
Sustainable Energy Technologies	Inverters (2010) – packaged systems with Bosch (2010)	www.sustainableenergy.com

Table 3. Ontario's solar PV equipment manufacturers.

The eligible Ontario research institutes include universities and colleges of applied arts and technologies. The 20% refundable Ontario Business-Research Institute Tax Credit (OBRI TC) for manufacturers was determined using a Federal 22.12% tax and an Ontario 12% rate, which gives a total of 34.12%. Finally, it should be noted that all companies considering locating in Canada or Ontario should seek professional tax advice.

Potential demand

Canada's population is concentrated along the U.S. border in relatively high solar flux areas and thus actually represents a considerable potential demand as seen in Fig. 1 [14], which shows the yearly solar PV

Description		R&D Expenditures	R&D Expenditures at eligible Ontario research institutes	Non-R&D Expenditures
Gross expenditures		$100.00	$100.00	$100.00
Ontario – 20% OBRI Tax Credit			-$20.00	
Federal investment tax credit – 20%		-$20.00	-$16.00	
Tax deductions	$80 x 34.12%	-$27.30		
	$64 x 34.12%		-$21.84	
	$100 x 34.12%			-$34.12
Ontario exemption of Federal investment tax credit	$20 x 12.0%	-$2.40		
	$16 x 12.0%		-$1.92	
After-tax cost of $100 expenditure		$50.30	$40.24	$65.88

Table 4. Tax credit example.

potential map for latitude tilt in Canada and 'PV hotspots' throughout Canada.

A recent study introduced a five-step procedure to estimate the total rooftop PV potential, a process that involves the geographical division of the region; sampling using Feature Analyst extraction software; extrapolation using roof area-population relationships; reduction for shading, other uses and orientation; and conversion to power and energy outputs [15]. Wiginton et al. found that the potential annual energy production of over 30% of Ontario's demand can be met with province-wide rooftop PV deployment [16]. However, there is also a considerable amount of land in Canada that has a large potential for energy production if used for solar farms. Specifically, a recent study [17] looked at the land with the lowest possible value for agriculture, the worst soil, and featured an appropriate slope and situation close to the electrical grid such that establishment of a solar farm in the area would be economic. With these criteria, over 90GW of potential was found for ground-based solar farms on marginal land in a relatively small area of south-eastern Ontario alone. Thus, it is clear that the potential for technically viable PV in Ontario and Canada as a whole is enormous and provides a ready market for PV manufacturers.

Conclusions

Due to far-sighted policies to support renewable energy such as the Green Energy Act in Ontario, Canada is becoming an increasingly popular destination for both established solar photovoltaic manufacturers and start-up companies.

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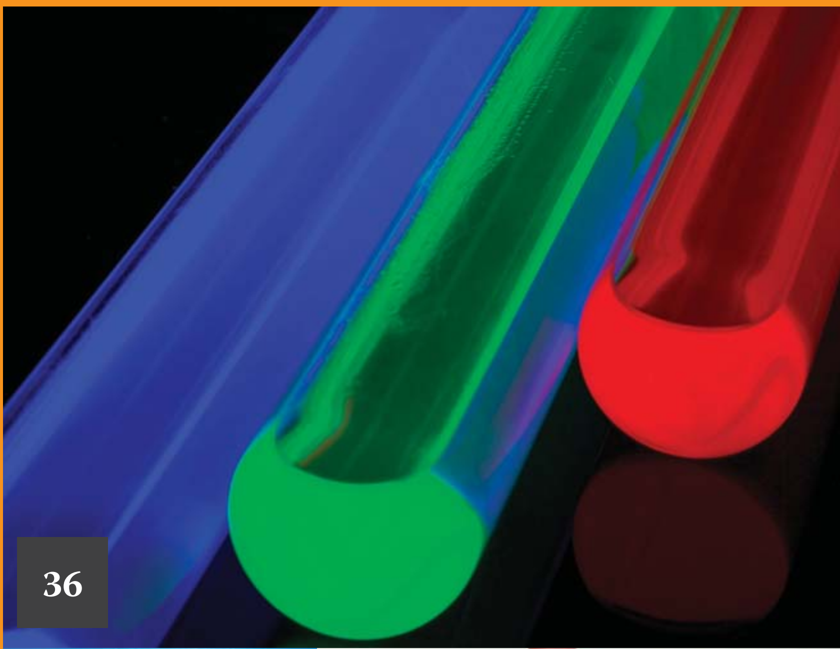
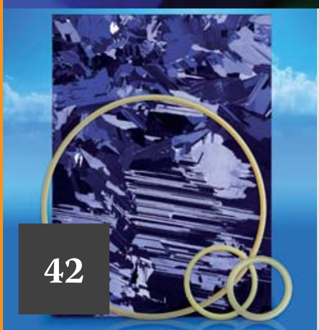
Materials





OCI targets title of world's second-largest polysilicon manufacturer by 2011

Continued capacity ramp at OCI could see the Korean-based polysilicon manufacturer become the world's second largest producer on the back of another 5,000 metric ton (MT) expansion. The construction began in June 2010, with completion expected by October 2011 at a total cost of KRW220 billion. The new expansion at its existing facility Gunsan, Jeollabukdo, Korea would result in a capacity of 32,000MT per annum with one of the lowest manufacturing costs.

OCI claims to be producing and supplying 10-nine grade polysilicon, with the production capacity capability to produce 11-nine grade purity polysilicon. The polysilicon producer has a capacity of 6,500MT at its P1 Plant, 10,500MT capacity at P2 Plant and 10,000MT at is P3 Plant, which will be completed in December 2010. OCI will have a total production capacity of 27,000MT but with debottlenecking activities expects capacity to top 32,000MT.

Polysilicon inspection.

Polysilicon News

GCL-Poly expects to reach 2GW of solar wafer capacity by October

GCL-Poly has updated its solar wafer capacity expansion plans, highlighting that it expects to reach 2GW by the end of October 2010. Previously, GCL-Poly had said this figure would be reached by the end of the year. The company also noted that wafer capacity has reached 1.2GW. The quality and conversion efficiency of its wafer products will be improved through technological upgrades and technical innovation, the company said. GCL-Poly reiterated that production cost of wafers would also be significantly lowered through a reduction of material usage.

Hoku, Suntech amend polysilicon supply contract

Hoku Materials and Suntech Power have now amended their polysilicon supply contract, removing all milestones, adjusting the contract term, and rescheduling the initial shipment date. Suntech is now no longer obligated to pay the scheduled US$30 million prepayment that was previously committed, yet Hoku will retain the US$2 million in prepayments that Suntech has already paid, which will be credited against future shipments of polysilicon.

These payments are separate from the US$20 million that Suntech invested in Hoku's common stock through a private placement in early 2008. The term of the agreement was shortened to one year to match Suntech's prepayment of US$2 million, and pricing and volume were fixed for the term of the agreement. The agreement will automatically be renewed after the initial term with the same terms unless terminated by either party. Hoku is not obligated to deliver polysilicon until June 2011.

GCL-Poly subsidiary begins commercial operations at 200,000MT hydrochlorination facilities

Jiangsu Zhongneng Polysilicon Technology Development, a subsidiary of GCL-Poly, has begun commercial operations at its 200,000MT hydrochlorination facilities. The facilities ensure the stable production of polysilicon and significant upgrade of product quality to a higher level, allowing full recycling of by-products, and achieving lower polysilicon production cost to reach levels similar to that of global incumbents.

This hydrochlorination project was a significant element in the technical improvement program initiated by Jiangsu Zhongneng in 2010, with the aim of increasing polysilicon production volume and enhancing the competitiveness of GCL-Poly's polysilicon products. The technical improvement

GCL-Poly wafers.

Source: GCL-Poly

Source: GCL-Poly

GCL-Poly's 200,000MT hydrochlorination facility.

program marked the cooperation between the GCL-Poly's R&D centre and other leading polysilicon technical service providers in the U.S. via the application of advanced technologies such as hydrochlorination.

Since the technical improvement program began, the company's hydrochlorination facilities have reached a total capacity of 500,000MT per annum, which can fully satisfy the recycling requirements for polysilicon production. The company said it expects to bring down polysilicon production cost to reach levels similar to that of leading incumbents after the 200,000MT facilities have been fully ramped up.

Business News

Secretary of Energy awards US$122 million for an energy innovation hub

Caltech will be leading the way for the Joint Centre for Artificial Photosynthesis (JCAP) with some help from U.S. deputy secretary of energy, Daniel Poneman's US$122 million award for the energy innovation hub. The project will focus on replicating nature's photosynthesis energy process as a new approach to energy production for commercialized use. The award will be distributed over a five-year term to a multidisciplinary team of scientists chosen for the project.

The hub will be directed by Nathan Lewis and George Argyros, both chemistry professors at the California Institute of Technology. Caltech will also partner with the Berkeley Lab and a slew of other California universities including: Stanford, UC Berkeley, UC Santa Barbara, UC Irvine and UC San Diego. The centre will be located in the Jorgensen Laboratory building on the Caltech campus.

Selection for the program was based on a scientific peer review and directed by the DEO of Science, who will maintain federal oversight responsibilities for the hub. This fiscal year the hub will receive US$22 million, with an additional US$25 million every year thereafter for the next four years, subject to congressional appropriations.

MEMC completes acquisition of solar silicon ingot specialist Solaicx

MEMC Electronic Materials has now completed the acquisition of privately held Solaicx. The unusually cash-based purchase, originally announced in May, was completed with an initial merger consideration of US$66 million, plus an additional US$10 million that is equal to amounts that have recently been invested in Solaicx by its existing security holders. The acquisition is expected to be accretive to earnings per share in 2011.

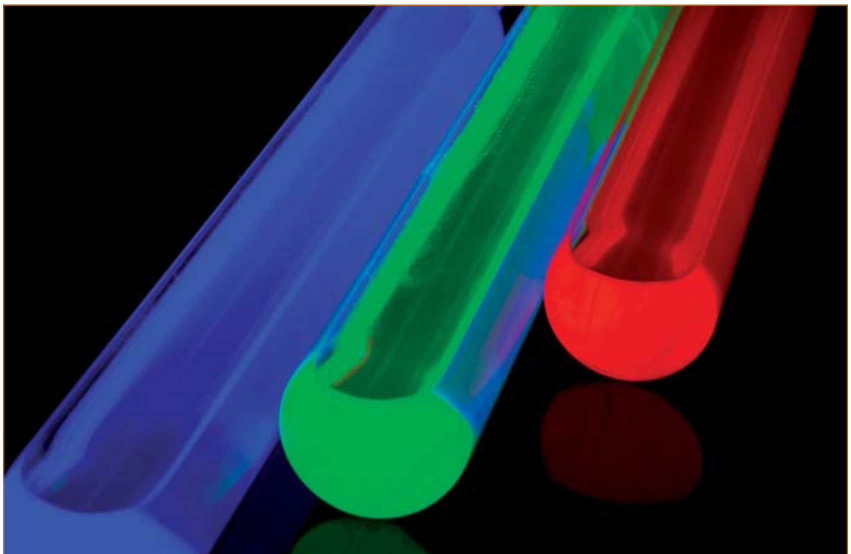
MEMC now has proprietary continuous crystal growth manufacturing technology that yields low-cost, high-efficiency monocrystalline silicon wafers for the PV solar industry. The company also has low-cost polysilicon and crystal operations in North America, with support offices around the world. As part of the acquisition, the company has also granted special inducement grants under its shareholder-approved 2001 Equity Incentive Plan to retain certain Solaicx employees. MEMC granted restricted stock units valued at up to US$2.358 million, subject to performance and time-based vesting beginning on the first anniversary of the closing, subject to these employees being engaged by MEMC on the relevant dates.

Nanoco Group steps into solar world with Tokyo Electron joint development agreement

Nanoco Group, developer and manufacturer of quantum dots and other nanomaterials, has signed a joint development agreement with Tokyo Electron. Nanoco will develop a solar-active nanomaterial film for use in Tokyo Electron's solar cell manufacturing equipment. Nanoco will be issued upfront and milestone payments during its nine-month development phase, after which a supply and license agreement is expected to be signed.

GT Solar ships 1,000th DSS450TM crystalline ingot growth furnace

GT Solar shipped its 1,000th DSS450TM crystalline ingot growth furnace to Yingli Green Energy as part of its February 2010 contract with the company to supply the ingot growth furnaces for Yingli's Hainan 100MW manufacturing facility. Yingli Green was GT Solar's first China-based customer in 2002 when Yingli set up their



Copyright: Nanoco; Photographer Ryan Mullally

Nanoco's cadmium free quantum dots (CFQD).

Materials Order Focus

5N Plus to supply germanium feedstock to Sylarus

Germanium solar cell substrate producer Sylarus Technologies has entered into a long-term germanium feedstock supply and recycling agreement with 5N Plus. The deal is supported by 5N Plus agreeing to the subscription of a convertible debt in Sylarus, which in turn supports the substrate manufacturers' expansion plans. Sylarus and 5N Plus will also recycle various germanium-containing residues coming from the crystal-growing and wafer manufacturing activities.

GT Solar lands US$70 million-plus equipment deal with major Asian poly manufacturer

GT Solar has added to its order books with a major deal worth over US$70 million for CVD reactor equipment and related polysilicon services. The deal is with an undisclosed customer – a leading Asian polysilicon manufacturer, according to the company's release.

Meyer Burger signs CHF60m supply contract with Nexolon

Meyer Burger has signed a CHF60 million contract with Korea-based Nexolon for the supply of wire saws, ID-saws and wafer inspection systems. The order comes as Nexolon prepares to expand its production facility from 850MW to 1GW by the end of 2011. Meyer Burger and Hennecke Systems have also completed the contract held with Nexelon for the supply of slicing-sand wafer inspection-systems.

Roth & Rau to supply turnkey wafer production lines worth €92 million

An India-based c-Si cell manufacturer has placed a follow-on order with Roth & Rau for turnkey wafer production lines that are worth €92 million, which follows a previous order worth €80 million for cell production lines placed last year. The completion of the order is not expected until 2011. Roth & Rau also noted that new orders in total had now reached €250 million, up from €225.3 million at the end of the first quarter, 2010. The company had previously guided sales to reach €285 million in 2010. Roth & Rau's CEO also noted that the company had seen increased demand for its turnkey solutions, especially from Asia and that the company had deliberately expanding its expertise in the wafer production sector, which is currently undergoing a renewed capacity expansion phase.

GT Solar ships 1,000th DSS450TM crystalline ingot growth furnace

GT Solar International shipped its 1,000th DSS450TM crystalline ingot growth furnace to Yingli Green Energy as part of its February 2010 contract with the company to supply the ingot growth furnaces for Yingli's Hainan 100MW manufacturing facility.

Leshan Ledian chooses Poly Plant's CVD reactor for China plant

Leshan Ledian Tianwei Silicon-Tech formally signed its acknowledgement that it had chosen Poly Plant Project's (PPP) CVD silicon deposition Reactor for Leshan's polysilicon product plant in Leshan, China. Yingli Green was GT Solar's first China-based customer in 2002 when Yingli set up their first ingot, wafer and cell production lines at their Baoding headquarters.

Meyer Burger scores US$21.5 million equipment deal with JA Solar

Meyer Burger Technology has signed a contract worth over CHF25 million to supply wire-saw and wafer-inspection systems to JA Solar. The equipment will be used in the Chinese solar manufacturer's wafer production facility in Donghai, China, which is scheduled for completion by the end of 2010.

The wafer-slicing gear will be supplied by the Meyer Berger group, while the inspection tools will come from the Hennecke Systems unit. JA Solar is ramping capacity at the Donghai wafer plant from 120MW to 300MW.

GT Solar starts installing furnaces for GCL's wafering plant

Supporting GCL's plans to become a leading polysilicon and wafer supplier in the shortest possible time, GT Solar has started installing and commissioning its DSS450HP crystalline growth systems at GCL's new wafer manufacturing facility in China. A US$40 million contract had been signed between the two companies in January, which included furnaces. GCL recently updated its solar wafer capacity expansion plans, highlighting that it expects to reach 2GW by the end of October 2010. Previously, GCL-Poly had said this figure would be reached by the end of the year. The company also noted that wafer capacity had already reached 1.2GW. The DSS450HP furnaces are said to offer 15-20% improvement in productivity.

GT Solar gains $23.4 million order from OCI Company

OCI Company has placed a $23.4 million follow-on order from GT Solar International. The order calls for delivery of GT Solar's SDR 400 CVD, which will be used in OCI's phase 3.5 polysilicon plant expansion that will be completed in October 2011.

Tom Gutierrez, GT Solar's president and CEO, commented: "The additional throughput and cost savings of the SDR 400 CVD reactor allows OCI to further enhance their cost competitiveness."

first ingot, wafer and cell production lines at their Baoding headquarters.

Total to buy interest in AE Polysilicon

Total's subsidiary Total Gas & Power USA (SAS) has completed their acquisition of a 25.4% interest in AE Polysilicon through a reserved capital increase. In addition, Total signed a long-term agreement to buy AEP 's high-purity granular polysilicon. Currently in its commissioning stage, the polysilicon production facility will begin commercial production this year and at its full operating capacity is scheduled to produce up to 1,800 metric tons of granular polysilicon per year. Total has a technical cooperation agreement for the joint development of projects using AEP's technology, the assignment of Total personnel and creation of a joint research center.

GT Solar closes profitable fiscal year with brisk quarter, guides revenue growth for FY2011

GT Solar ended its fiscal year on a positive note, posting fourth-quarter revenues of US$194.7 million, a 12% increase over the previous period's US$173.6 million. Year end revenues came in at US$544.2 million, a slight increase over FY2009's US$541 million, with the majority of the 2010 sales – US$357.5 million – coming from the photovoltaics production equipment company's polysilicon segment. Management guidance for FY2011 calls for revenues in the US$550 million to US$600 million range.

The company posted a net income of US$33.3 million in Q410 compared to US$36.8 million in Q3. For the full fiscal year, net income was US$87.3 million, compared to US$88.0 million in FY09. Quarterly operating margin was 28.4% of revenue, compared to 33.2% in the previous period. Annual operating margin was 26.5%, on par with the number for FY09. At fiscal year-end, the Merrimack, NH-based company's backlog was US$906.2 million, with US$464.9 million in the polysilicon segment and US$441.3 million in the PV segment. Included in the total backlog was US$334.3 million of deferred revenue. The company expects to roll off US$449 million of backlog within the next 12 months. Net new orders for the quarter were US$244 million.

The company's FY2011 guidance forecasts a 75:25 split between its PV (wafering) and polysilicon segments, respectively, and that 45-50% of the fiscal-year revenues will accrue in the first half of the year. GT expects to see a gross margin in the 38-40% range. The tool manufacturer believes that polysilicon prices will range between US$45 and US$55 per kg through calendar 2011. It also sees a significant opportunity for capital equipment sales to support what the company believes will be major capacity growth over the next four years. GT also claims it can achieve <US$25/kg "all-in" polysilicon production costs for a 10,000MT/yr factory, based on best-in-class assumptions.

Taiwanese PV manufacturer DelSolar signs long-term wafer deal with GCL-Poly

DelSolar and GCL-Poly have signed a silicon wafer supply deal to establish a long-term strategic alliance. The agreement calls for GCL-Poly to provide local supplies of wafers to meet the needs of DelSolar's Wujiang, China, plant's expansion from May 2010 through December 2013. The companies said that the deal includes a mechanism by which the parties may adjust prices to better reflect prevailing market conditions. DelSolar expects the agreement to greatly enhance overall operational needs and profitability. Financial terms of the deal and specific wafer-shipment amounts were not disclosed.

Other News

Ferro increases China and Taiwan PV technology centres' capability

In a continuing effort to support the growth of the Asian marketplace, Ferro increased its capability in its Suzhou, China, and Taipei, Taiwan, PV centres. The company's Suzhou centre increase stems from the demands of the solar cell manufacturers in China. The new Advanced Technology Centre in Taiwan will reach completion by the end of this year and will be furnished with solar cell printing and firing equipment, lending both this new centre and the Suzhou centre better capability for the building of prototype solar cells. In addition, Ferro Electronoic Material will house a solar materials laboratory in Singapore at a Center for Excellence, whose focal point will be on new product development in Southeast Asia. The new facility will be located in Singapore's Science Park and perform basic research and development activities.

Silver surplus set to slide

The current 7,000t surplus in silver could start to shrink in the next few years as a number of emerging end-users gain traction in various markets, according to the Fortis Bank's 'Silver Book' report. The silver mine supply is expected to reach 22,700t this year, up from 22,000t in 2009, which will keep the surplus high. However, Fortis Bank expects a rise in investment demand later on this year, which will help lower the surpluses in the next few years and could lead to an acute undersupply by 2020. Crystalline-silicon solar cells can contain as much as 0.12 grams of silver per watt, according to the report. The solar industry is already a major silver consumer, with an estimated 18Moz consumed in 2009.

Product Briefings

Spartanics

Spartanics offers laser die-cutting applications lab for materials research

Product Briefing Outline: The new Spartanics Laser Cutting Applications Laboratory for Materials Research enables PV product manufacturers to determine if their materials can be handled by modern laser die-cutting technologies. The lab allows those seeking to use rapidly advancing laser die-cutting technology to send samples for engineering studies and analyses for evaluation.

Problem: The explosion in new materials with different properties such as tensile strengths, toughness and resilience has been especially pronounced in the last decade. During this same time period, laser die-cutting technology continues to evolve at a rapid pace largely due to more sophisticated software engineering. The speed of these developments are such that findings one might make today about whether a certain plastic, non-woven, or even nanomaterial can be adequately handled by digital die cutting is likely to have changed in just a few years.

Solution: The Spartanics Laser Die Cutting Applications Laboratory for Materials Research provides no-cost detailed engineering analyses of maximum material thicknesses that can be handled with these different substrates, including brand name materials, correlated to laser power and other variables.

Applications: A wide array of materials for laser-based production processes.

Platform: Spartanics specializes in tightly integrating advanced software engineering with sophisticated handling systems to manufacture best-in-class technology for both tool-free (laser-based), steel rule die, and male/female hard tool cutting systems, screen-printing systems and other equipment for fabricating products made from flat stock materials.

Availability: Currently available.

Coreflow

CoreFlow's wafer singulation system eliminates manual labour

Product Briefing Outline: CoreFlow has launched the 'SingFlow' wafer singulation system, which has successfully passed a number of tests at customer manufacturing sites and internal demonstrations. SingFlow is claimed to be the first automatic system that successfully deals with the delicate separation of wafers from blocks.

Problem: Solar wafer prices fell by 50% in 2009, highlighting the continued need to reduce wafer manufacturing costs. Although manual labour is used widely in low-cost regions, the need to reduce breakage, improve quality and increase throughput are key competitive requirements.

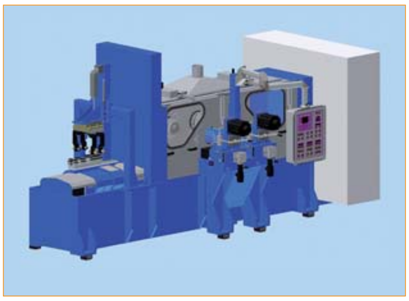
Solution: The SingFlow singulation system is based on a unique, stress-free, pure-shear singulation concept. This patent-pending approach delivers the first field-proven fully-automated production system, and improves production efficiency, throughput and yield of the manufacturing process. The modular system design supports the output to different configurations of lane-based cleaning systems, supporting five to six, or cassette loading for batch cleaning. System throughput with a two-head singulation configuration is 3,000wph with less than 0.25% breakage rate.

Applications: Crystalline solar wafer singulation process. Wafer thickness >120µm (± 30µm). Wafer size (rectangular) 156mm; 125mm (optional).

Platform: SingFlow features stress-free wafer singulation with a unique control that ensures minimal contact force on the wafer. Minimal wafer manipulations, the integration of customer-specific carrier (used in the glue-dissolving process) into the SingFlow system, as well as direct loading to clean lane or cassette enables a fully-automated singulation process.

Availability: Currently available.

Arnold Gruppe



Combined surface and chamfering grinding machine from Arnold handles low- and medium-range bricks

Product Briefing Outline: Arnold Gruppe has launched a new generation of combined surface and chamfering grinding machines. The Type 72/865 is specially designed for low- and medium-range brick production capacities up to 150MWp, which is claimed to significantly reduce production costs whilst increasing overall wafer quality.

Problem: With extensive improvements in the area of material and construction, the process reliability of this new generation of machines has been improved even further, to reduce sometimes prohibitive production costs while addressing the ever-present need of increased quality.

Solution: The 72/865 is filled with mineral cast, which provides up to a tenfold improvement in machine rigidity and increased noise suppression. A new coolant supply with a pressure of up to 25bar provides optimal process cooling and at the same time reduces the water consumption by approximately a third. In this way, optimum process reliability, shorter processing times and more precise brick production can be guaranteed.

Applications: Multi- and monocrystalline silicon blocks up to 500mm in length (wafer manufacturing chain).

Platform: For the Type 72/865, an optional addition is the database and web-browser controllable software tool ARPAT(R), which was developed by Arnold for acquisition, analysis and storage of the process data provided by the combined machine.

Availability: The machine will be introduced to the market at the EU PVSEC 2010 in Valencia, with availability worldwide from January 2011.

Tordivel Solar

Tordivel Solar's wafer inspection system tackles surface quality control

Product Briefing Outline: Tordivel Solar has introduced a new generation of optical contamination inspection solutions for mono- and polycrystalline wafers. The Wafer Surface Instrument (WSI) performs an automatic surface quality control of wafers, which can be characterized based on cosmetic surface effects.

Problem: The increased focus on cosmetic surface effects like wafer contamination is a result of higher quality awareness, and is one of the most significant contributors to wafer returns. The contamination detection instrument is a cost-effective measure to reduce wafer returns due to surface effects.

Solution: The system uses angled lighting and omnidirectional uniform illumination together with two line scan cameras per side and a PC for image collection, processing, user interface and process interface software. The special lighting removes crystals in the image and the cosmetic surface effects are clearly visible on the wafer image. The 4 MPixel images are captured using line-scan cameras with 80µm resolution. Combining the images with state-of-the-art image processing algorithms ensures higher sensitivity and selectivity. All data is fed to the central data processing unit of the Surface Inspection Master. Information is transferred by the Surface Inspection Master to the Wafer Inspection System Master (WISM), which classifies the characterized wafers based on quality class specifications, and then communicate the result to the sorter.

Applications: Mono- and polycrystalline wafers.

Platform: The system is sold as a standalone system, as part of the Surface Instrument or as part of the Tordivel Solar WIS. The characterization instrument is delivered as a one- or two-sided version. The throughput is typically one wafer per second.

Availability: Currently available.

PANalytical

PANalytical's new XRD tool is a multi-purpose research diffractometer

Product Briefing Outline: PANalytical has launched a multi-purpose X-ray diffraction (XRD) tool dubbed the Empyrean, which is used for depth profiling.

Problem: The lifetime of a PANalytical diffractometer is longer than the typical horizon of a single research program and for many scientists, an ability to accommodate change is a 'must-have' feature in their decision to invest in an XRD system.

Solution: Analysis of powder samples is a primary interest, for which the Empyrean system is claimed to deliver the highest accuracy and data quality. The system also provides for high-resolution epitaxy analysis and handles all common applications. Investigations into nanomaterials can also be performed. PDF (pair distribution function), SAXS (small angle X-ray scattering), with the ability to monitor the evolution of crystalline phases in situ with its unique slurry flow cell stage are all possible. Furthermore, the internal structure of solid objects can be studied without cutting, as the PIXcel3D detector can be used as a CT scanner for non-destructive analysis.

Applications: Depth profiling for phase identification, film thickness, thin-film stress, and epitaxial composition and relaxation.

Platform: The Empyrean comprises the X-ray source, the goniometer, new sample stages, the radiation enclosure, and a 3D detection system, the PIXcel3D. The system can measure all sample types. Users can switch between application setups using PreFIX modules without compromising on the quality of diffraction data. Dedicated hardware, software and regulatory expertise incorporated in pre-defined programs, and a customizable desktop and batch sample capabilities help make advanced functions highly accessible.

Availability: Currently available.

DuPont

Zalak 5300 seals from DuPont are specially formulated for use in plasma environments

Product Briefing Outline: DuPont Performance Polymers has introduced its Zalak 5300 high-performance seals for PV cell manufacturing. Zalak 5300 seals bridge the performance gap between standard fluoroelastomer (FKM) and perfluoroelastomer (FFKM) seals. The seals are specially formulated for use in plasma environments, such as edge isolation, ARC coating in crystalline cell manufacturing, TCO sputtering deposition, and selective a-Si PECVD applications in PV cell manufacturing.

Problem: As PV manufacturers use more aggressive and efficient chemicals to increase uptime and improve output, more strain is placed on the manufacturing process. Materials traditionally used in PV manufacturing, like silicone, fluorosilicone, and standard fluoroelastomers can degrade quickly in harsh conditions causing unplanned maintenance due to incompatible sealing materials.

Solution: Zalak seals have been designed as a cost-effective alternative in select applications where traditional sealing materials are insufficient. In addition to the plasma resistance, the seals offer good resistance to 'dry' process chemistry, as well as excellent compression set properties. They also feature low stiction and very low particle generation and are suited to static and low-sealing force applications, like chamber lid seals and gas inlet seals.

Applications: Specially formulated for use in plasma environments. A maximum continuous service temperature of 200°C is suggested.

Platform: Zalak 5300 high performance seals are said to bridge the performance gap between standard fluoroelastomer and perfluoroelastomer parts.

Availability: Currently available.

Integrated loops: a prerequisite for sustainable and environmentally-friendly polysilicon production

Sebastian Liebischer, Dieter Weidhaus & Dr. Tobias Weiss, Wacker Chemie AG, Munich, Germany

ABSTRACT
The photovoltaic market, which is dominated by polysilicon-based crystalline solar cells, has been developing rapidly, with growth rates in the double-digit range for several years. In order to meet increasing demand for hyperpure polysilicon, manufacturers need to adhere to environmentally-friendly production processes with low energy consumption. This article highlights the key processes needed to manufacture hyperpure polycrystalline silicon and explores the related challenges and solutions for sustainable polysilicon production. Our findings prove that only an intelligent interaction of all necessary process steps fulfils the requirements for minimized production residue volumes and low energy consumption. Totally integrated production loops for all essential media are prerequisite to reach these targets. Once implemented, these highly efficient production processes serve as an excellent platform technology for the continued healthy growth of the PV industry.

Introduction

Global warming and limited availability of fossil fuels have been driving the need for increased and more reliable sources of renewable energy. Due to its increasing competitiveness, photovoltaics has become the strongest-growing technology in the renewable energy sector with an impressive compound annual growth rate of 43% (2007–2014; see Fig. 1).

Although a variety of PV technologies is being explored, only a limited number is suitable for and has reached mass-production scale. Of those, crystalline-based PV is the clearly dominating technology with a share of more than 80% in 2009's PV market [2].

The basic raw material for crystalline PV cells is polysilicon. Its semiconducting properties are used to convert sunlight into electricity. Silicon is the second most abundant element in the earth's crust. Therefore, its availability is basically unlimited. Large-scale metallurgical processes are employed to convert quartz (SiO_2) into raw silicon (98-99% purity) for numerous technical applications. However, sophisticated production technology is needed to convert raw silicon into the hyperpure polysilicon needed for photovoltaic applications.

> "The deflation of the recent polysilicon price bubble has rendered many new projects uncompetitive."

Established polysilicon producers support this strong PV market growth by making huge investments to increase their capacities accordingly (Fig. 2). Unfortunately, long lead times for new capacities and exploding short-term demand may result in severe undersupply situations like that experienced in 2007/2008. The resulting price bubble has attracted many new market entrants. However, only suppliers with state-of-the-art technology and cost structures will be competitive in the long run. Consequently, the deflation of the recent polysilicon price bubble has rendered many new projects uncompetitive in terms of quality and cost. A highly efficient use of energy and raw materials is vital to achieving state-of-the-art cost structures and an environmentally-benign polysilicon production process.

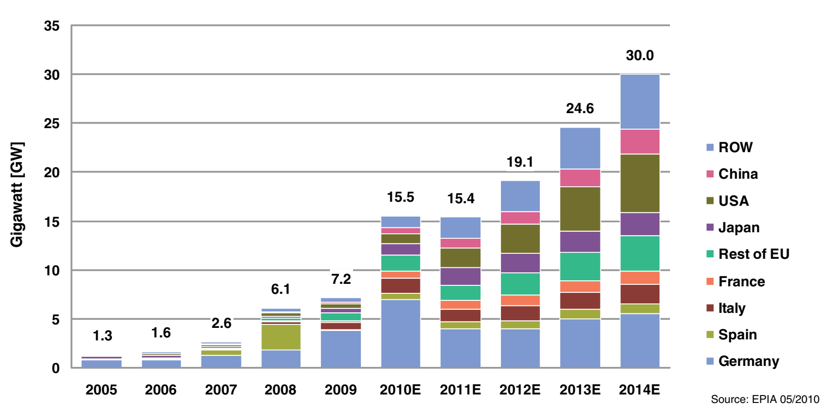


Figure 1. Historical annual PV market development and forecast from 2005 to 2014 [1].

Integration levels of polysilicon production

By far the most common approach to producing polysilicon globally is the so-called 'Siemens process', which involves the deposition of polysilicon from trichlorosilane (TCS). TCS and hydrogen are fed to heated silicon rods within special reactors. A pyrolysis reaction takes place at the hot silicon surface and elemental silicon is deposited on the rod's surface. In this process, two main reactions of TCS have to be considered:

$$4\,SiHCl_3 \rightarrow Si + 3\,SiCl_4 + 2\,H_2 \qquad (1)$$

$$SiHCl_3 + H_2 \rightarrow Si + 3\,HCl \qquad (2)$$

TCS as feedstock is obtained by chlorination of metallurgical silicon. The corresponding process is carried out in fluidized bed reactors, in which finely-ground metallurgical silicon reacts with hydrogen chloride (HCl):

$$Si_{mg} + 3\,HCl \rightarrow SiHCl_3 + H_2 \qquad (3)$$

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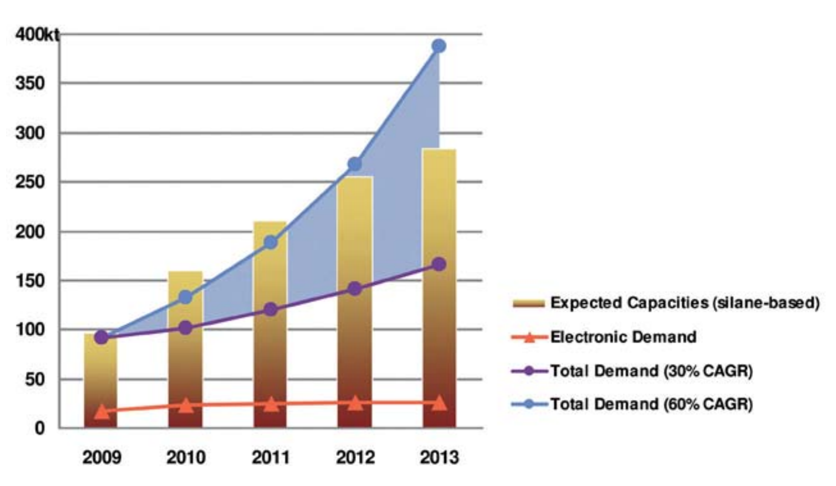


Figure 2. Global polysilicon supply and demand [3].

purity for deposition feedstock.

Following Equations 1 and 2, up to three-quarters of the TCS is converted to tetrachlorosilane (STC) and does not contribute to polysilicon deposition. Consequently, a maximum of about 18kg of STC is generated per kg of deposited polysilicon. It goes without saying that an economic recovery method is necessary for this by-product – a fact that unfortunately has not been taken properly into consideration by all newcomers in the past [4].

Established polysilicon producers are utilizing several methods of STC recovery. One option is to use STC as feedstock for the value-adding production of pyrogenic silica:

$$SiCl_4 + 2\,H_2 + O_2 \rightarrow SiO_2 + 4\,HCl \quad (4)$$

If this is the only possible route for STC, the production of polysilicon and pyrogenic silica are coupled, which can quickly lead to restrictions. Therefore, the conversion of STC back to TCS by hydrogenation is mainly used to recover the STC for the production of polysilicon:

$$SiCl_4 + H_2 \rightarrow SiHCl_3 + HCl \qquad (5)$$

In either case, production of pyrogenic silica or STC conversion, HCl is generated as a by-product which can be fed back into the TCS synthesis.

Besides STC, there are further chlorosilane by-products generated during TCS synthesis and polysilicon deposition. The expense of processing these by-products can be minimized by linking the polysilicon production with that of organofunctional silanes, silicates and silicones. Predetermined loss of material can be converted into value-adding products if this is done properly. Fig. 3 shows a corresponding closed-loop production system in operation at WACKER POLYSILICON's Burghausen site.

In a standalone polysilicon production process as shown in Fig. 4, approximately 100% of the STC can be recycled to TCS for polysilicon production. The major challenge of such a plant is the optimization of each single process step and the steps' interaction to minimize all kinds of chlorosilane by-products which are not usable for polysilicon deposition.

In any case, a highly integrated closed-loop production process is a prerequisite for a sustainable and economical production of polysilicon. Energy-efficient processes and the minimization of residue are further technological factors that can contribute to a highly efficient polysilicon production process. The following section discusses some aspects of this task in detail.

Challenges in production of trichlorosilane

As noted above, metallurgical-grade silicon is used as a feedstock to synthesize solar-grade TCS. Impurities in the silicon metal significantly impact TCS quality and the productivity of the production process. Many earlier investigations were generally limited to the influence of metallurgical-grade silicon on TCS selectivity. However, in addition to this very important aspect, there are still many other issues that influence cost, quality, safety and environmental impact. Fig. 5 shows in detail the process for manufacturing TCS.

Chlorosilanes are obtained by reacting metallurgical-grade silicon with HCl. This reaction can be carried out in a fluidized-bed reactor at temperatures of 300-400°C. The reaction conditions in the fluidized bed are influenced by reactor design, particle size distribution of the silicon feed, and HCl flow.

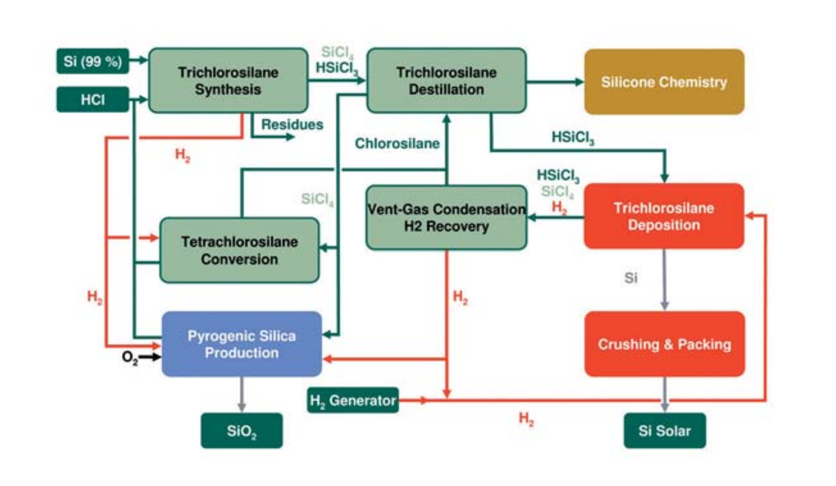


Figure 3. Integrated product flow at WACKER POLYSILICON's Burghausen site.

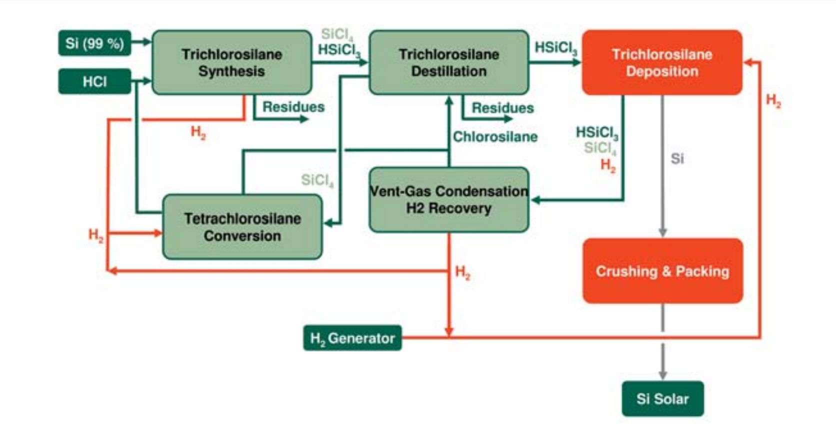


Figure 4. Standalone polysilicon production.

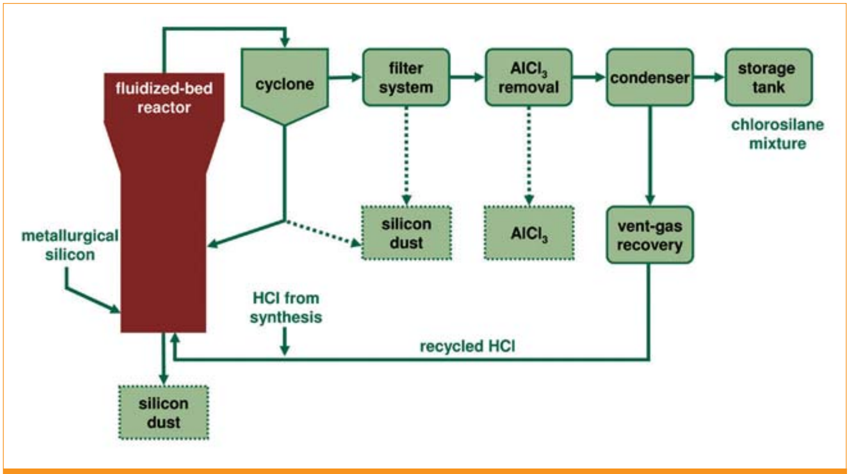


Figure 5. TCS synthesis.

At an integrated closed loop production site, the TCS production should be continuously optimized towards minimizing the amount of by-products. The HCl first-pass yield should reach almost 100% and the TCS selectivity might be up to 90%. The result is a small loop of HCl and only a small formation of STC which saves energy in vent-gas recovery and in STC conversion. Furthermore the use of metallurgical-grade silicon with a well-selected composition of non-silicon metals (Fe, Al) reduces the production of undesired high and low-boiling chlorosilanes and metal chlorides.

Silicon metal wastes

Together with the metallurgical-grade silicon, impurities such as slags, calcium, aluminium and iron compounds are introduced into the reactor. Some of these are elutriated from the reactor as fines with the product gas stream; others remain with the bulk material in the reactor where they accumulate. These are two methods of producing silicon-containing wastes.

> "If a particular impurity level is exceeded, the reactivity of the bulk material decreases."

On the one hand, dust particles are continuously elutriated from the reactor. A first dust fraction is separated by a cyclone in order to be fed back to the reactor. A second dust fraction, which is collected by filters, is even finer than the first fraction and contains a high concentration of impurities. On the other hand, impurities accumulate in the reactor during the continuous TCS synthesis. If a particular impurity level is exceeded, the reactivity of the bulk material decreases, which can even lead to a shutdown of the reactor. At this point, the bulk material has to be removed from the reactor.

An important feature of a properly designed reactor system is the selective control of bulk material impurity levels and silicon loss minimization, both controlled by fines discharge [5]. Benefits are high reactor productivity and low amounts of silicon-containing residues. There are two methods of disposal of such residues, the first of which is treatment with lime, which transforms the residues into innocuous substances that can easily be land-filled. However, this procedure entails a certain amount of effort and cost. The second option is to sell the previous by-products to metallurgic and cement industries – an economically and ecologically sound and reasonable option as the substances can then be used for other processing purposes.

$AlCl_3$ removal

Under TCS synthesis conditions, most of the aluminium contained in metallurgical-grade silicon reacts with hydrogen chloride. The resulting $AlCl_3$ sublimates at temperatures over 150°C and passes through the filter system along with the gaseous silanes. However, if the gas temperature drops below 150°C, $AlCl_3$ desublimates and is deposited on the inner walls of the equipment or the piping.

Therefore, it is extremely important to have an effective method for separating $AlCl_3$ completely from the product gas and then removing it from the process; otherwise the $AlCl_3$ would be deposited on downstream equipment like pipes, tanks and even distillation columns. Cleaning of contaminated equipment can lead to a severe safety problem due to the high reactivity and exothermic potential of $AlCl_3$. Methods for removing $AlCl_3$ from the process have been described in different publications [6,7].

Despite the problems associated with $AlCl_3$, a certain level of aluminium in the bulk material is necessary to achieve a high reactivity and TCS selectivity. However, an excessive amount of aluminium quickly increases the costs of $AlCl_3$ workup and disposal. The challenge therefore is to optimize the aluminium content and the operation mode of the reactor in such a way that the reactivity does not decrease, but less $AlCl_3$ is produced. The removed $AlCl_3$ can be treated in the same way as silicon metal residues. Due to the potential high purity of re-sublimated anhydrous $AlCl_3$, this by-product can also be recovered and sold, e.g. as a catalyst.

Condensation and vent-gas recovery

Downstream of TCS synthesis, dust separation and $AlCl_3$ removal, the gas stream is condensed and separated into a liquid fraction (crude silane) and a gaseous fraction that contains mainly hydrogen and a small amount of HCl and non-condensed chlorosilanes. The liquid chlorosilane fraction is stored in tanks and is subsequently distilled. The gaseous

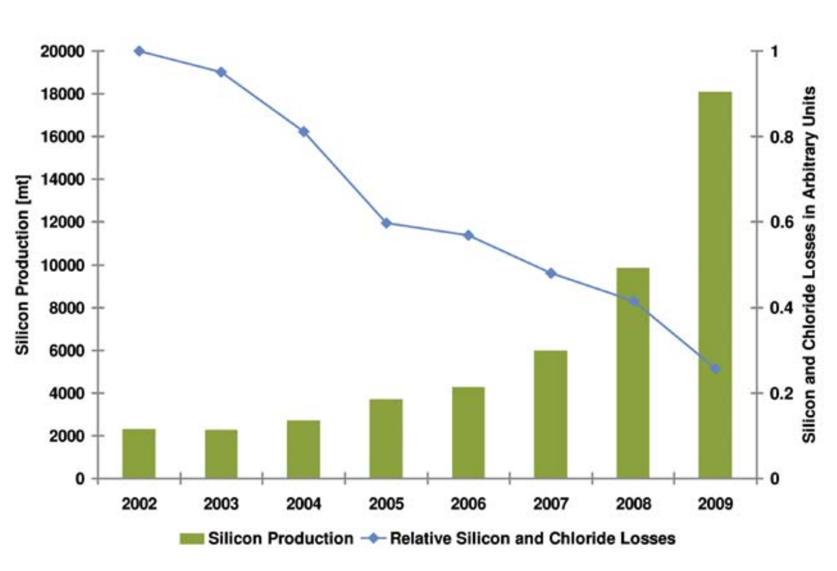


Figure 6. Development of residues at WACKER POLYSILICON in comparison to the correlating polysilicon output.

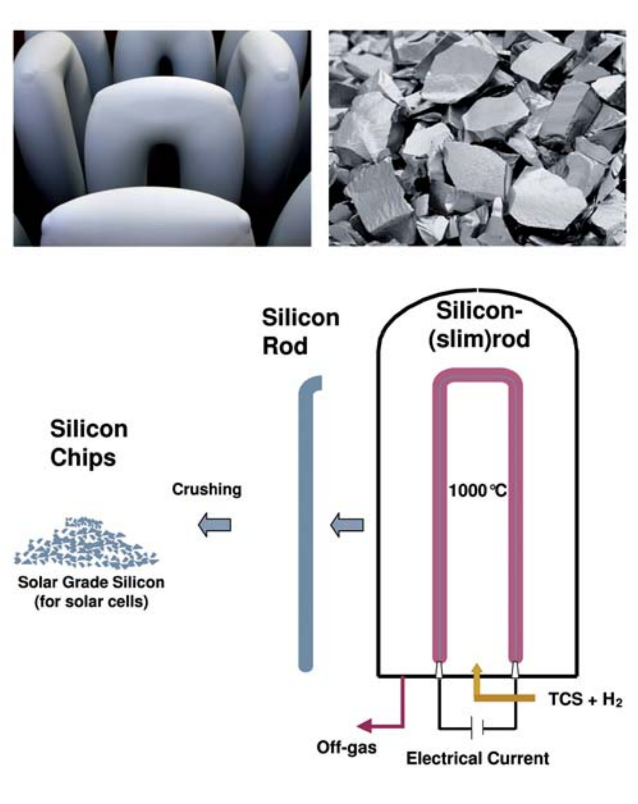


Figure 7. Schematic representation of the rod deposition process.

fraction is purified in a gas recovery unit. Hydrogen chloride is then fed back to the TCS synthesis, while chlorosilanes are condensed and recovered for distillation. Hydrogen can be recovered with high purity, suitable for use in STC hydrogenation. By using an appropriate vent-gas recovery, the disposal of residues can be avoided.

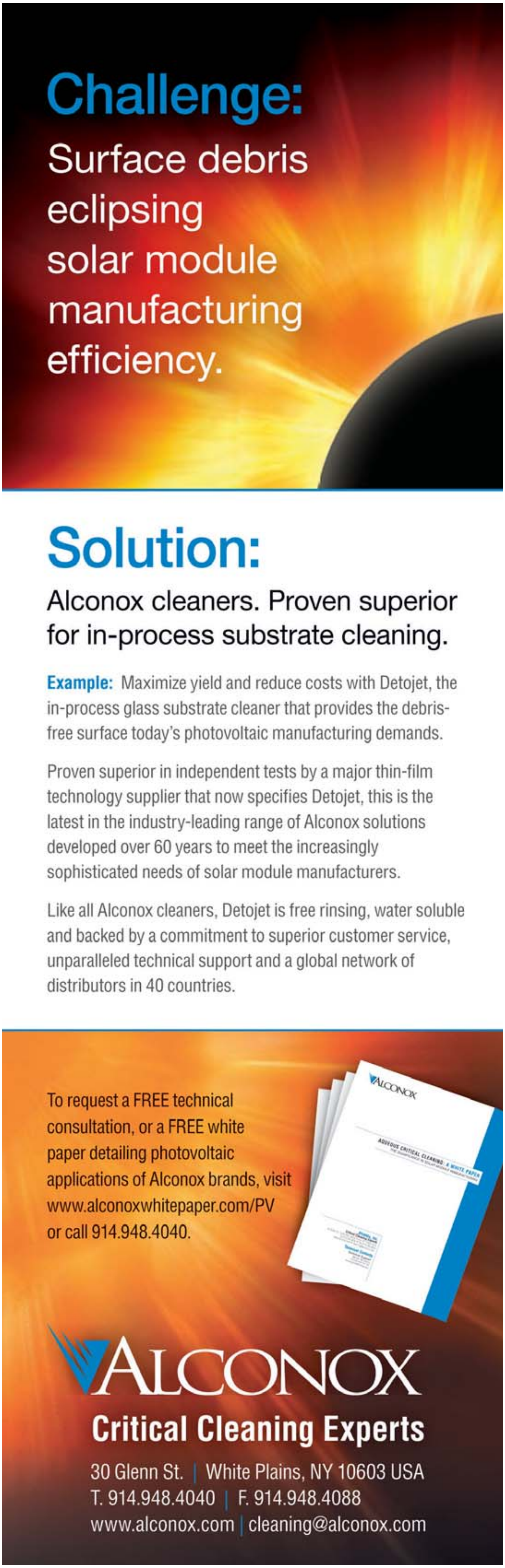
Chlorosilane distillation residues

The distillation of hyperpure TCS separates chlorosilane fractions that are enriched with certain impurities, for example, boron and carbon-containing compounds, which can be found in low and high-boiling fractions. As a matter of principle, these fractions enriched with impurities have to be discharged from the distillation system to achieve the high quality standards required for hyperpure TCS. If precautionary measures are not taken, the disposal of these contaminated fractions is associated with high silicon and chloride losses.

> "Small fractions with impurities have to be discarded for achieving the high purity of TCS."

Within an integrated chemical production site, all these fractions can be recycled and thus do not require disposal measures. Depending on the main component of the respective fraction – dichlorosilane, TCS or STC – and the concentration of the impurities, customized solutions can be developed to utilize these fractions. This significantly reduces the loss of silicon and chloride equivalent, which in turn means lower disposal costs, low environmental impact and low production costs of the main product, hyperpure TCS.

In a standalone polysilicon plant, the by-products formed in the TCS reaction have to be avoided. This can be done as noted by using appropriate metallurgical-grade silicon and an optimized operation mode of the TCS reactor. Secondly, the amount of discharged chlorosilane fractions from the distillation has to be reduced to a minimum by concentrating the impurities in the



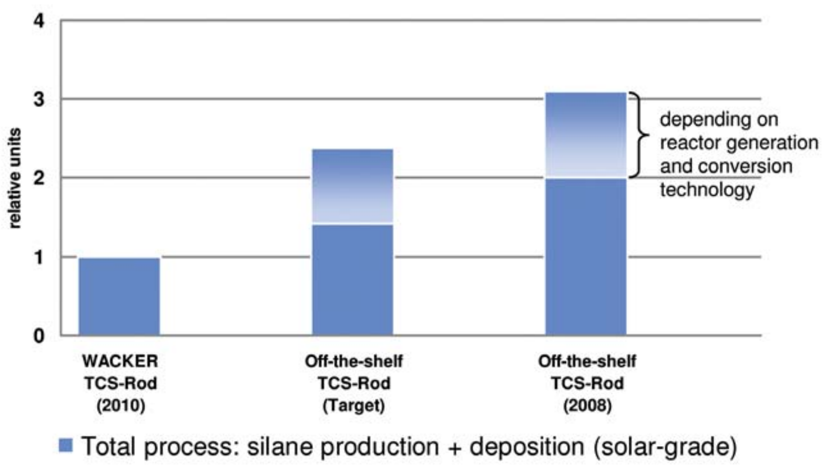


Figure 8. Specific energy consumption of various technologies for the production of polysilicon [3].

discarded streams to a maximum level. The high-boiling fraction of chlorosilanes can be recovered in several ways, for example by feeding it back to the fluidized bed reactor [8]. Low-boiling chlorosilanes can be chlorinated to TCS, which can be recycled and used for polysilicon deposition [9].

However, small fractions with impurities have to be discarded for achieving the high purity of TCS. The streams containing these highly concentrated impurities can be treated in a caustic scrubber system where the chlorosilanes react to NaCl (cooking salt) and silica (SiO_2), both of which are non-toxic and can be disposed of properly. Despite the exponential growth of production capacities, the relative amount of silica and salt discharged has decreased significantly in the last few years due to the use of advanced technologies (see Fig. 6).

STC conversion

Another key component of a closed-loop system is STC conversion. Besides the hydrogenation gas phase process as described in Equation 5, the fluidized bed hydrochlorination process is an alternative conversion path:

$$3\,SiCl_4 + Si + 2H_2 \rightarrow 4\,SiHCl_3 \qquad (6)$$

Comparing these two processes, it can be said that there are no silicon or chloride losses in the conversion of STC by hydrogenation. A further advantage is that compared to the hydrochlorination process, there is no need for a copper catalyst to be used – as a result, no copper-containing residues are created when utilizing conversion by hydrogenation [10].

Polysilicon deposition

The deposition of polysilicon takes place in special deposition reactors. During the batch process, pure silicon grows on electrically heated silicon rods. After reaching a predetermined diameter, the batch process is stopped; the rods are removed from the reactor and crushed for further use in the solar industry (see Fig. 7).

In principle, the deposition step produces no chemical waste that needs careful handling, because the vent gas of the deposition reactors is collected and recycled for re-use. Therefore, highly-integrated vent gas recovery systems are beneficial, not solely for environmental protection regulations, but also for economic reasons as the price for key raw materials such as metallurgical-grade silicon and hydrogen is increasing continuously.

The main focus in polysilicon deposition is on the reduction of energy consumption by optimizing the deposition reactors continuously. In public, the production of solar-grade feedstock via gas phase deposition has frequently been criticized for being too costly with regard to the high energy consumption of the deposition process [11]. This criticism is based on the belief that high temperatures in chemical processes basically lead to high energy consumption, a belief that is misleading in the case of polysilicon deposition. In principle, the deposition of polysilicon does not consume energy at all: the level of energy demand during deposition is mainly influenced by energy losses and not by the reaction itself.

Much effort has been put into the design of the reactor with the aim of reducing energy losses of polysilicon deposition. The major principle – the topic of many articles and patents to do with deposition reactors – is 'economy of scale' [10,12]. As a rule of thumb, there are three ways of increasing the output of deposition reactors, the most common of which is by increasing the number of rods in the reactor. As a consequence, polysilicon can grow on more rods, increasing the output per batch process significantly. An increase in rod length has a similar effect, while the third approach of increasing the predetermined rod diameter can also lead to decreases in specific energy losses.

Besides improving the reactor's design, optimizing the deposition process also enhances efficient raw material usage and reduces energy consumption. One of the key parameters in this process is the deposition temperature. A higher deposition temperature increases the deposition rate and reduces deposition time without loss of reactor output. This reduction of deposition time is by far more effective for decreasing energy losses than running the deposition process at lower temperatures. This means that, within a certain range, high temperatures in polysilicon deposition can even support energy savings and are thus a prerequisite for a sustainable polysilicon production. As a result, the task of an optimized deposition process is to reduce the deposition time in order to minimize energy losses and to achieve the highest possible reactor output and highest polysilicon quality simultaneously.

Most of the energy for polysilicon production is used during the deposition process. Nevertheless, for a complete overview, it is useful to look at the whole specific energy consumption per kg of polysilicon. Fig. 8 illustrates this consumption, highlighting the potential differences between polysilicon producers as an immense diversity of applied technologies with significant differences in energy consumption is currently available.

> "Optimizing the deposition process also enhances efficient raw material usage and reduces energy consumption."

As a result of all these time-consuming developments, customer-orientated products and a sustainable polysilicon deposition process with high output, yield and quality can be achieved and by-products and residues can be minimized.

After harvesting, the silicon rods have to be crushed as shown in Fig. 7. This crushing system requires a great deal of effort in order to minimize the loss of polysilicon – especially in regard to the unavoidable dust formation. New high-quality crushing systems that allow the use of all polysilicon fractions have appeared on the market. These systems do not contaminate the polysilicon and are optimized in such a way that even the smallest fractions and polysilicon dust are of highest purity. Essentially, it is possible to prevent polysilicon loss during crushing.

Summary

It has been shown that the trichlorosilane-based production of silicon feedstock for the solar industry is sustainable and highly efficient if designed and implemented properly. The process does not generate any permanent, environmentally toxic residues. Implementing a closed-loop product flow enables the safe handling of all main reactants. Moreover, at an integrated production site, almost all by-products can either be recycled or used for other purposes. Ongoing process development continuously minimizes residues and energy consumption and improves product yield significantly. Thus, avoiding waste and recycling by-products is not only an ecological, but also an economical asset as resources such as silicon metal or electrical energy can be used more efficiently. A sustainable, cost-effective production of silicon feedstock will also be possible in future large-scale plants.

Acknowledgement

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Separation of wet wafers after sawing

Kevin Reddig, Fraunhofer IPA, Stuttgart, Germany

ABSTRACT

"Handle with care" – this world-renowned warning sign is inherently printed on every wafer until it is safely wrapped into a finished module – and for good reason. Despite the declining price of silicon and the improved manufacturing methods, the raw wafer still has a major share in the overall cost of a module. If we assume an average wafer price of €2.70 for a 156mm multicrystalline wafer, the finished cell will cost about €4. Adding in the module manufacturing costs, a cell in a typical module will cost €5. Hence, the wafer accounts for more than 50% of the total manufacturing costs, and as such is key to optimizing the costs in the solar value chain for crystalline photovoltaic products. This paper offers some guidelines on the wet wafer separation process that are intended to aid in minimizing the cost associated with wafer breakage.

Wafer manufacturing is key to optimizing the costs incurred in crystalline photovoltaic product manufacturing. However, before a wafer first sees the light of day, it has to undergo numerous process steps that include mechanical cutting, heating and pressing of the wafer as well as several more stressful operations including wafer handling. So it is not surprising that wafer breakage is still a major concern in the process chain. The main manufacturing steps through which a wafer has to pass are wafer manufacturing (production of the raw wafer), cell manufacturing (the wafer is processed into a photovoltaic cell) and module manufacturing (the cells are interconnected in a larger module).

"The tricky part is the separation of the sawn ingot into individual wafers."

Compared with the (usually) cleanroom-centric cell manufacturing process, the wafer manufacturing process is very dirty. Wafers are cut out of an ingot using a wire saw, and then an abrasive slurry (mainly based on glycol and silicon carbide) is applied. Before sawing the ingots, one or more such ingots are glued to a plate, the so-called 'beam' (usually made of glass), which in turn is glued to a re-usable dovetail-shaped carrier. This carrier is then clamped into the wire saw. After the wafers are cut out, they are still glued to the beam (see Fig. 2). The tricky part is the separation of the sawn ingot into individual wafers which are then cleaned, characterized and packaged.

Figure 1. Wafers are prone to damage due to their fragile nature.

Wafer separation at a glance

Though wafers might undergo separation several times during the whole manufacturing process, the only time they are wet and laden with residues is in the manufacturing of the wafers themselves. Dry and clean wafers can be separated by directing pressurized air between them, then gripping the topmost one with a vacuum or Bernoulli gripper. This principle can most definitely not be applied within the wafer manufacturing step because the wafers are wet and laden with remains from the slurry at this stage in the production.

In the past, wafers were separated by hand – an approach that is still used in some manufacturing facilities. The operator collects a number of wafers and carefully removes it from the beam. The wafers are then separated one by one from this package and sorted into a carrier or placed on a conveyor belt for the cleaning process. Because of the size of the average human hand-span, this manual separation was a lot easier with the former 125mm wafers than it is now with the current 156mm wafers. In terms of the throughput and the yield, automating this step is highly preferable, leading to considerable R&D investment and effort on the part of equipment and wafer manufacturers to ensure an automated wafer separation.

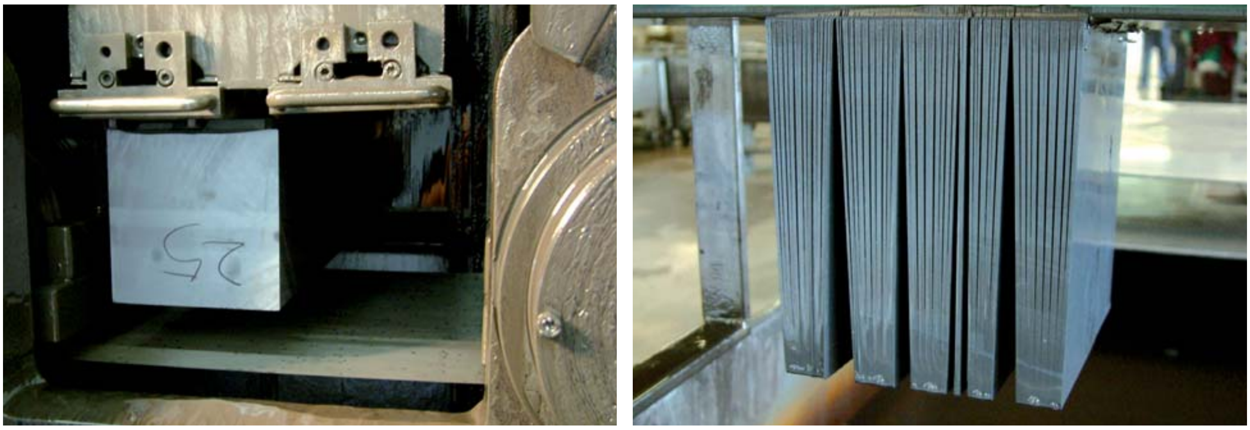

Figure 2. Wafers in a wire saw (left). After sawing, the wafers are clustered into packages (right).

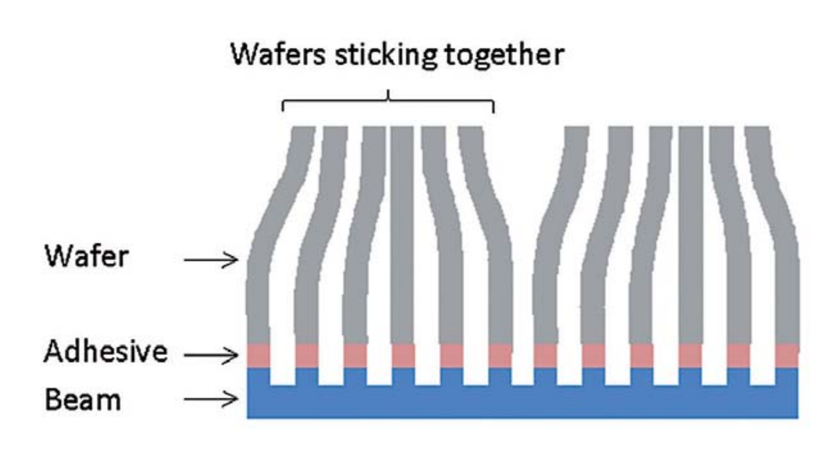

Figure 3. Unproportional schematic sketch of wafers after sawing (bow of wafers is exaggerated).

Due to the fact that companies usually do not wish to divulge too many details of their hard-earned knowledge, scientific and technical publications on wafer separation are quite hard to find. Nevertheless, a good overview on both proposed and implemented solutions can be gained by analyzing existing patents describing automated separation techniques. About 12 relevant patents have been analyzed that give a good picture of possible solutions. One viable option is to separate the wafers directly from the beam while the wafers are still adhered to it. A further option is to unglue the whole sawn ingot and collect the wafers in a special carrier or in packages for further processing steps.

Both approaches have advantages and disadvantages: if the wafers are separated directly from the beam (option 1) they are in a defined position and usually do not need any additional support. Ideally, each wafer stands on a thin bar of glue as the saw also cuts the beam (see Fig. 3). However, in a manufacturing environment some wafers might already be dissolved from the glue, and thus can form an obstacle to the separation. Additionally, the adhesive force of the glue can vary widely, which can require larger mechanical forces to dissolve the wafers.

The other approach (option 2) requires the dissolving of the entire wafer stack from the beam as well as the collection of the wafers for the separation process. The dissolving can be achieved by using warm water or a chemical solvent, depending on the type of glue. As soon as the wafers are collected, they are arranged in a defined and secure manner. This transfer requires an extra handling step in which the wafers are gripped or clamped at the edges. Even though this is an additional hazard to the material integrity, the advantages of this latter approach seem to outweigh the disadvantages as most known solutions offered on the market have chosen this approach. One reason for this decision is that it better suits the typical manufacturing environment scenario.

Typical characteristics of a sawn ingot

The decision as to whether the wafers should be separated directly from the beam or dissolved and collected in a stack is fundamental. Therefore, numerous experiments have been conducted in a manufacturing environment to determine the adhesive force of the adhesive bar which connects the wafer with the beam.

In these experiments, the ingots were processed using a set of different process parameters. After the sawing of these ingots, the wafers are drawn from the ingot by means of experimental equipment that features a vacuum pad. This equipment grips the wafer on the entire surface and records the force that is needed to dissolve the wafer from the beam with a load cell. Several experiments were performed by testing a number of silicon ingots with different manufacturing parameters. These parameters include the adhesive type, the duration of placement in a cleaning solvent and the angle of the vacuum pad. Three different types of two-component epoxy adhesives were used. Ingots were placed in a hygroscopic cleaning solvent that consists of an aliphatic compound, which usually has a disintegrating effect on the epoxy adhesive.

In the experiments, no correlation could be observed between the variegated parameters. Instead, the adhesive forces were seen to vary significantly. In some experiments, all wafers were dissolved from the beam by the cleaning agent, whereas other experiments showed no influence of the cleaning agent on the adhesive forces. The adhesive forces, however, do not only differ within experiments but also from ingot to ingot. A typical graph of such an experiment is depicted in Fig. 4. In this experiment, the wafers were drawn orthogonally from the beam; some wafers were already dissolved (force = 0) while others were still attached tightly to the beam, requiring a force exceeding 100N for separation in some cases.

In order to reduce the high adhesion forces required in this step, a subsequent series of experiments involved tilting the wafers by 10°, after which the wafers were gripped and drawn by the vacuum pad. This has a tremendous effect on the stability of the adhesive bar, reducing those adhering forces not exceeding 40N by an average of 20N. A separation system treating adhered wafers should therefore always grip tilted wafers.

Nevertheless, the tilting of the wafers cannot be achieved without increasing the mechanical stress, especially in the region close to the glue bar, and does not solve the problem of wafers that are already dissolved within the ingot. These wafers cannot be separated easily from their respective neighbours. Moreover, such wafers could shift and lead to breakage because the gripping mechanism would obstruct a continuous and reliable processing. Therefore, all known solutions on the market work with a completely dissolved stack of wafers.

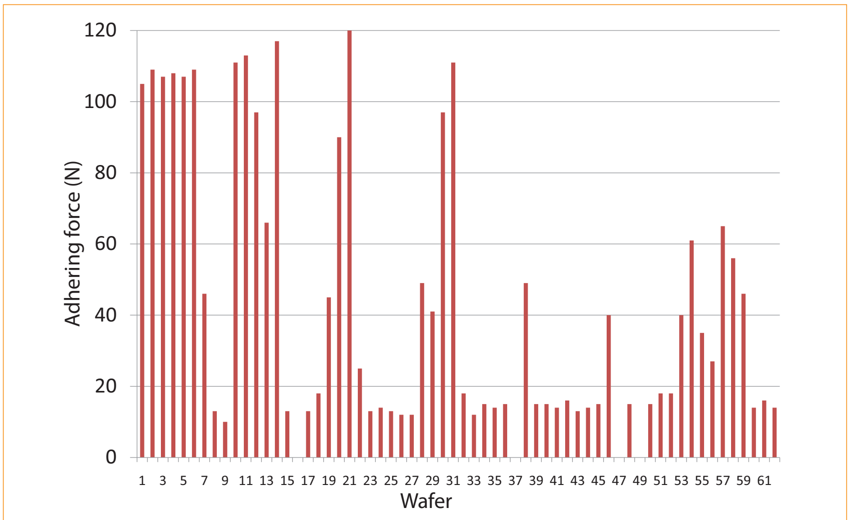

Figure 4. Typical adhesion forces of wafers to the beam.

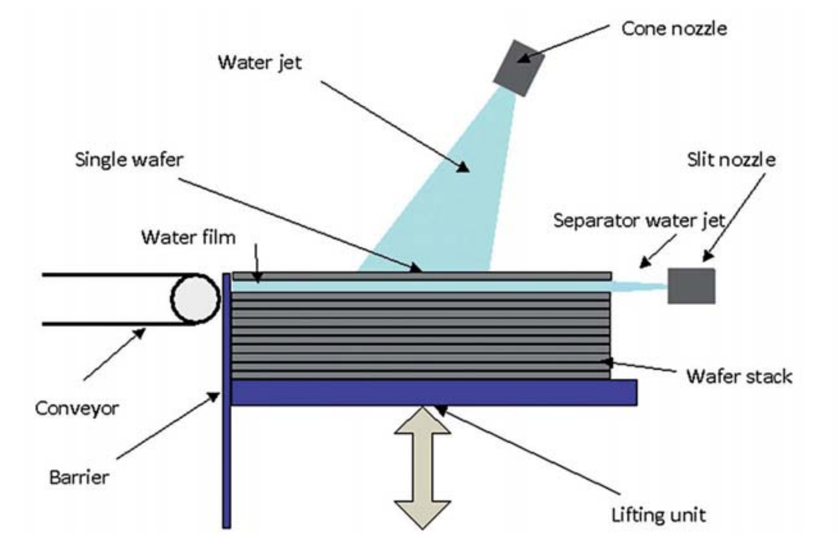

Figure 5. Fluid jet wafer separation principle.

Separation from a stack of wafers

Several approaches to the separation of wafers from a stack are in use or are described in patents. The main difference between the methods is the orientation of the stack. Some solutions clamp the wafers vertically into the stack in order to be able to process all wafers on the beam in one run; other solutions use horizontally stacked wafers. As a consequence, these stacks are limited in height because the tolerable weight on the lowermost wafers is limited. Again, both approaches have their advantages and disadvantages. The clamping mechanism for the vertical presentation of wafers is more complex and requires precautions in order to avoid harming the wafers. The horizontal stacking of wafers allows the use of comparatively simple cassettes but limits the amount of wafers in such a cassette and therefore requires a constant re-loading of the separation unit.

The known separation methods comprise different approaches. A well-known solution from other industries is the placement of a stack of wafers on synchronously powered rolls which separate a wafer by conveying it beneath a separator. Other solutions use grippers or conveyor belts to transport separated wafers from a vertically-aligned stack. In such solutions, water jets are sometimes used to support the separation of the wafers.

Wafer separation with fluid jets

At the Fraunhofer IPA, a method for separating wafers on the basis of fluid jets has been developed and analyzed. With this method, fluid jets are directed to move the separated wafer over a barrier. A stack of wafers is placed on a platform which can be traversed vertically. The wafer at the top of the stack is moved into the fluid jet, which separates it from the rest and moves it over a barrier. A conveyor belt transports the wafers to further processing stages, usually to an inline cleaning tool or an indexer that collects the wafers in a carrier. The principle behind this separation is depicted in Fig. 5.

> "The wafer at the top of the stack is moved into the fluid jet, which separates it from the rest and moves it over a barrier."

The procedure was developed with the intention to minimize the mechanical stress on the wafer. However, the force of the water jets can also reach a level that might harm the wafers. Additionally, the quality of the separation process is dependent on other parameters such as the location and the angle of the water jets. Therefore, an experimental set-up was constructed in which the top wafer is separated but not carried away. Instead, the elevation of the wafer is constantly monitored by a special configuration of four laser distance sensors, which allows the measurement and recording of the influence of the water jets on the elevation, the tilt and the vibration of the wafer. By means of this set-up, several experiments were executed and an optimal range of the parameter values was determined, which was in turn applied and adapted to a prototype. The advantage of this approach is that it provides an opportunity to study the effects of the adjustment of the changing parameters, which is not possible if the wafers are carried away.

Set-up for the experiments

Separation is achieved by using slit nozzles aligned at the rear, opposite to the barrier. About four or five nozzles are evenly spaced along the length of the wafer, tilted at an angle of -25° and +25° to the wafer. The upper nozzle emits a cone-shaped jet and can be tilted to add an additional momentum to the wafer. The main purpose of the upper nozzle is the generation of a force that partially neutralizes the vertical momentum of the wafer, which otherwise might be thrown in an undefined position by the separation effect of the rear nozzles. This also suppresses the vibrations, and without this upper nozzle, the wafer could flap uncontrollably, likely leading to wafer damage.

Nowadays, deionized water (DI-water) is used in manufacturing processes for cleaning or as a medium for the interim storage of wafers, so it makes sense to employ the same medium for the separation process. The water is collected in a basin underneath the separation unit and pumped with a multi-stage rotary pump to the nozzles. The pressure for each nozzle unit can be adjusted to a maximum pressure of 10 bar, whereas the separation process is accomplished with much lower pressure rates.

Distance sensors based on laser LEDs are used for measurement of the wafers' elevation and vibration. The sensors have a theoretical resolution of 2μm, but realistically, about 10μm can be achieved. Without any precautions, the water jets would render the optical distance measurement useless as the water droplets and spray would block the signal path. Furthermore, droplets would accumulate at the sensor and in this way blur the laser beam. Therefore, a special housing was constructed of acryl glass tubes to shield the signal path. In order to prevent the spray from entering the tubes, they are constantly charged with compressed air (see Fig. 6). Four sensors were used to determine both the elevation of the wafer and the roll and pitch angles.

Experimental results

This section presents the principal results of the experiments conducted. Most of the experiments were designed using the ceteris paribus principle. The pressure at one of the nozzle units was varied during one experiment; other parameters included the angle of the rear nozzle unit, the location and the angle of the upper nozzle as well as the usage of nozzles at the side of the wafers.

The first run of experiments investigated the influence of the upper nozzle. The graph in Fig. 7 represents a typical result of such an experiment, showing how the average relative elevation of a wafer changes with the increase in pressure on the upper nozzle. The fluctuation of the wafer elevation (vibration) diminishes as the general elevation of the wafer itself is decreased. The subsequent carry-off of the wafer should ensure a clear separation in order to guarantee a minimum elevation. The reduction of the vibration is necessary to reduce the potential damage of the wafer. Therefore, a good setting for the upper nozzle is around 3 bar. The experiments on the rear nozzle unit concentrated on the angle in relation to the wafer plane and the pressure on the nozzles. The angle is categorized into three ranges as depicted in Fig. 8.

Suboptimal results in terms of the separation quality were achieved by applying a positive angle, although the initial assumption suggested a good separation effect with the water jet detaining the following wafer. A neutral angle showed the same drawback as the width of the water jet expanded and seized the next wafer as well. The best separation result is achieved by a negative angle as the water jet can be adjusted in such a way that only the top wafer is affected and separated from the rest of the stack.

The pressure of the rear nozzles was varied in a range of 1 to 7 bar. Depending on the angle of the rear nozzle unit, a pressure of 3-4 bar was sufficient for a good separation. In all experiments, the vibrations of the wafer increased with rising pressure, a factor that must be closely monitored because of the potential harm to the wafer. Fig. 9 shows a close-up of the resulting vibration. The frequency of the wafer elevation was 10Hz, which fluctuates at a frequency of roughly one second with a peak-to-peak amplitude of about 1mm. Such a scenario is a typical result of application of pressure of more than 4 bar on the rear wafer nozzles.

The presentation of the wafer stack in relation to the separation unit has a large influence on the separation process itself; to prevent lateral dislocation, the wafers are guided at the sides. Alternatively, a cassette can be used with which the wafer stack is inserted into the separation unit. The usage of a cassette proved not only to be advantageous because of a simplified loading, but also served as a method of optimizing the separation procedure. By enclosing the wafer stack, the liquid volume underneath the separated wafer is enlarged and stabilized, thus facilitating the separation and the transport of the wafer.

Figure 6. Compressed air is used to clear the signal path of the distance sensors.

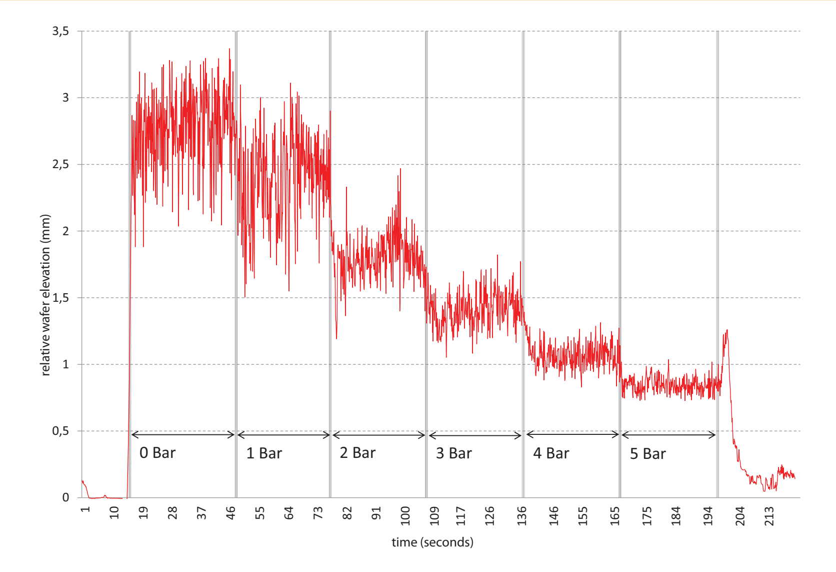

Figure 7. Average elevation of the wafer at increasing upper nozzle pressure.

Implementation of results in a prototype

The results garnered from the experiments were transferred and implemented into the prototype depicted in Fig. 10. Additional adaptations to the previous settings were made to optimize the separation and the transport of the wafer. The pressure on the nozzles can be decreased without impairing the quality of the separation. However, the transport of the wafers still needed additional attention. Directing the water jets of the rear nozzle from slightly underneath the wafer plane reduced the initial velocity required of the wafer to pass the barrier. It is therefore advantageous to somewhat split the responsibility for the separation and the initial transport by introducing a special nozzle that is solely responsible for vertical movement. The nozzle adds some velocity to the wafer after separation and starts the wafer on its way past the barrier. Wafers with thicknesses of 210µm and 180µm were used in these experiments; thinner wafers will also be tested in the future.

Conclusion

The separation of wafers from a stack by means of water jets proved to be a feasible approach. Future work will focus on increasing the speed of the process as well as on further researching the effects of separation on the mechanical stability. During the separation process no immediate wafer breakage could be

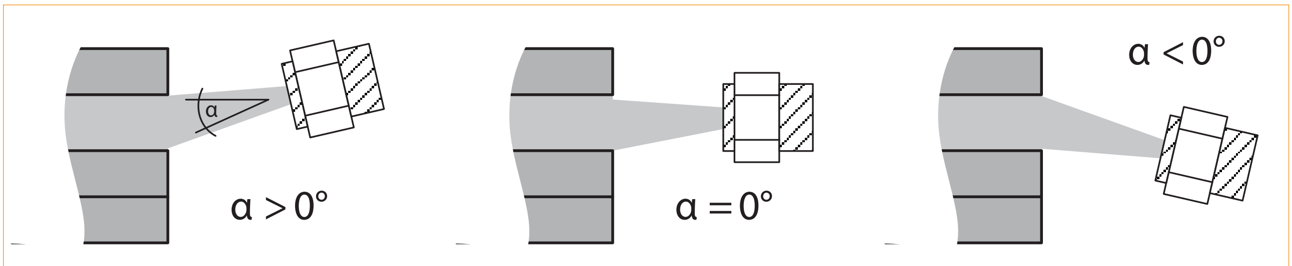

Figure 8. Angle ranges of the rear nozzle unit.

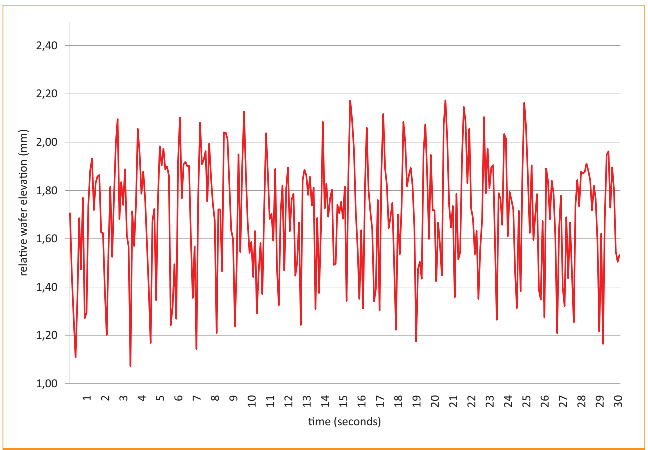

Figure 9. Details of vibration caused by the separating water jets.


Figure 10. Prototype of the separation unit.

observed; however, the reuse of the same wafers in the separation unit increases the danger of wafer breakage. Therefore, wafer breakage can either be caused by manual handling and the insertion of the wafer stack or by micro-cracks in the wafer which can arise during the separation process, a result of vibrations or edge damages, for example. The next step in addressing this issue should be a more detailed characterization of wafers prior to separation by detecting possible micro-cracks and by using a subsequent cycle of repeated separations and qualifications of the same wafers in several runs.

About the Author

Kevin Reddig is a team leader at the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) which he joined in 2002. He received an M.S. degree in industrial engineering at the University of Karlsruhe (TH), and works in the field of factory planning and automation including equipment automation, material flow solutions and data modelling and processing. Kevin has experience in both hardware and software automation projects in both the photovoltaic and semiconductor industries.

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Purifying UMG silicon at the French PHOTOSIL project

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ABSTRACT
This paper gives an overview of the French PHOTOSIL project that deals with the purification of metallurgical-grade (MG) silicon via different stages of upgraded metallurgical-grade (UMG) silicon to finally arrive at a purity level that is compatible with the requirements of the silicon-based PV industry. However, purified UMG silicon in general and by definition does not reach the ultra-high purity levels of electronic-grade (EG) silicon. Based on the PHOTOSIL project, this paper presents the typical technical challenges and problems encountered with less pure purified UMG silicon and how they were resolved, both during silicon purification and crystallization and the processing of solar cells.

EG silicon is obtained by gas phase purification, applying Siemens-type or related simplified processes and most widely used by the silicon-based PV industry at the moment. The ultra-high purity levels of EG silicon and its reproducibility almost automatically guarantee high PV performances in a controlled and reliable way. The challenge for purified UMG silicon therefore is to close the gap with EG silicon as much as possible by arriving at quality levels that allow for sufficiently high solar cell performances, while at the same time putting forward its potential economic advantages in terms of reduced costs and higher material availability. Ultimately, the goal for purified UMG silicon is to bring the cost per watt of converted energy further down towards €1/W, towards grid parity and to give crystalline silicon-based photovoltaics a long-term perspective alongside other emerging second- and third-generation techniques.

The results and data contained in this paper were obtained from members of the PHOTOSIL consortium: FerroPEM, CEA-INES, CNRS-SiMAP and APOLLONSOLAR. At present, the PHOTOSIL project is in an advanced industrial pilot line stage, working on batch sizes of 90kg for the different purification operations and 120kg for the crystallization of multicrystalline silicon ingots.

"The distinctive major advantage of PV is the quasi unlimited supply of solar radiation arriving on the earth's surface."

PV energy conversion will play a major role for the world's future long-term energy supply. The distinctive major advantage of PV is the quasi unlimited supply of solar radiation arriving on the earth's surface. In a simplified but striking comparison, the energy 'consumption' of the human civilization per annum corresponds roughly to one hour of incoming solar radiation on the entire surface of the earth [1]. PV energy conversion can therefore be regarded as a truly sustainable form of energy supply. In addition and contrary to other currently used forms of energy conversion based on fossil fuels for example, PV energy conversion is pollution- and noise-free, and no moving particles are involved.

For these reasons, PV plays a major role in studies and projected scenarios on how to meet the constantly increasing primary energy requirements of the earth, as shown in a study by the German Advisory Council on Global Change (WBGU) [2]. The scenario in this example concludes that by 2050, 25% of the global primary energy supply will be provided by solar energy, which rises to 64% in 2100 (see Fig. 1).

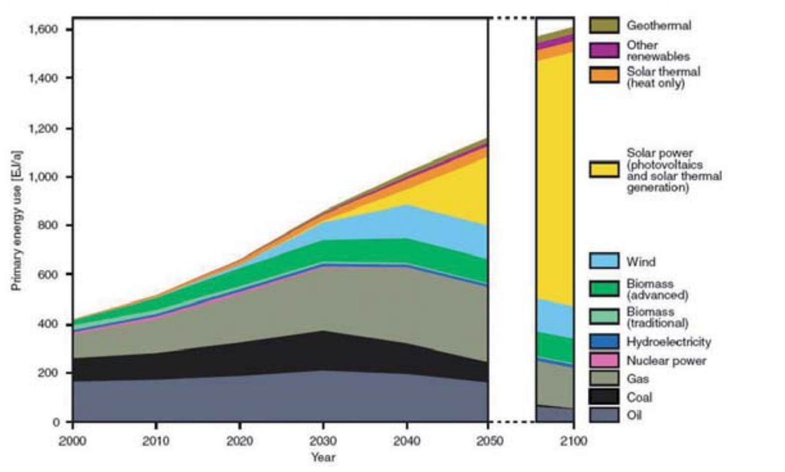

Figure 1. "Exemplary Transition Scenario" – Study by the German Advisory Council on Global Change on the future global primary energy supply (WBGU).

Although the PV industry continues to show impressive annual growth rates of 60% in average for grid-connected PV systems and 102% on average for large utility-scale installations between 2004 and 2009 [3], its share of the total energy production is still marginal. In 2008, PV energy conversion systems contributed only 0.2% to the total global electricity production [3]. However, to be able to contribute to the future global energy supply as implied by the aforementioned WBGU study, the PV industry needs to further accelerate its growth and innovation rates, while also bringing down the costs per produced watt further to achieve grid parity.

Regarding the PV industry, crystalline silicon as a base material for PV cells and modules plays by far the dominant role and is expected to keep this important role for some time. Although second-generation thin-film technologies are expected to gain more important market shares in the future, last year (2009) saw 78% of the worldwide PV production capacity based on crystalline silicon technology, with the remaining 22% comprising thin-film technologies [4].

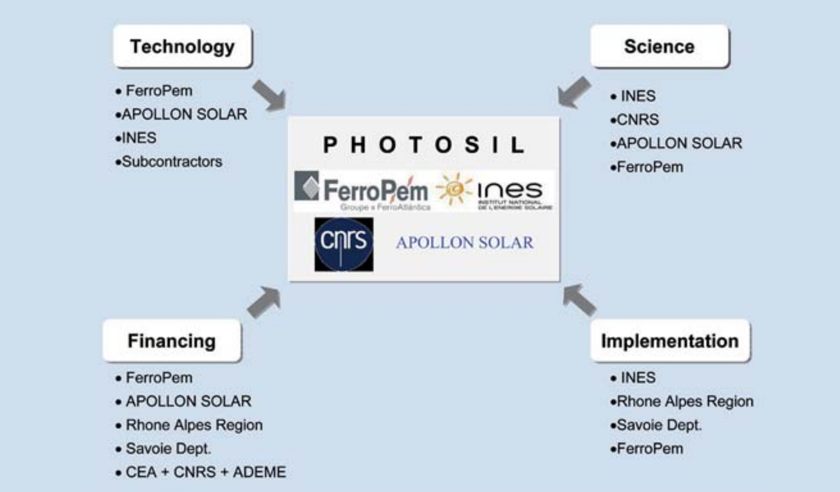

Figure 2. The PHOTOSIL Consortium and project organization.

Silicon feedstock, the raw material for crystalline silicon-based PV solar cells and modules, plays a key role for the future expansion of this branch of the PV industry – specifically its availability and cost. Although silicon is the most abundant element on the earth, it still needs to be reduced from SiO_2 and further purified. Depending on the applied technology and the market situation, the costs of silicon feedstock can comprise between 20 and 30% of the total PV module's costs. Traditionally, the crystalline silicon-based PV industry has used high purity EG silicon as feedstock for mono- and multicrystalline ingot and wafer production. Due to the accelerating growth of the PV industry, which began in the late 1990s, the classical silicon feedstock sources for PV became more and more limited, resulting in drastic price increases for EG silicon feedstock.

This situation has triggered a dual reaction (see [5] for more details): (i), an increase of production capacities for EG silicon using the chemical purification route based on gas phase purification (for example, the Siemens process); and (ii), direct purification of widely available MG silicon.

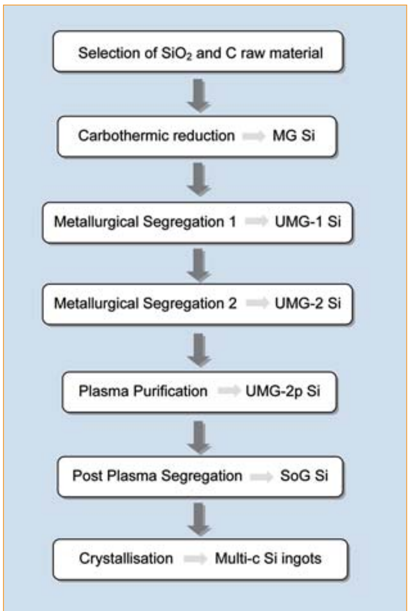

Figure 3. PHOTOSIL process flow.

"The production of solar-grade silicon via the metallurgical route is attractive due to its low cost potential."

The production of solar-grade silicon via the metallurgical route is attractive due to its low cost potential, a result of the fact that capex for production facilities and energy costs are much lower than those incurred by the chemical purification route. However, solar-grade silicon from this route needs to have quality levels that are compatible with the requirements of the PV industry in terms of solar cell performance, material yield and reproducibility.

The PHOTOSIL project

The PHOTOSIL project is part of the metallurgical route taken to directly produce solar-grade silicon from MG silicon. The diagram in Fig. 2 shows PHOTOSIL's partners and their main roles within the consortium. The project started in 2004, inspired by early encouraging results from the European ARTIST project [5], which also dealt with the purification of MG silicon. Development work on pilot-plant level started in 2006, and in 2009 operations ran on a continuous level using the first-generation pilot equipment, which led to the development of second-generation equipment – currently in the design phase – that will be used for industrial production.

In order to industrially exploit the PHOTOSIL technology, the company PHOTOSIL INDUSTRIES was created in 2009 by FerroPEM and APOLLONSOLAR.

The technico/economical objectives of the PHOTOSIL project can be summarized as follows:

- Solar-grade silicon feedstock costs of €15/kg and multicrystalline ingots at €35/kg
- Crystallization yield of >85% (usable p-type ingot part)
- Sufficient high purity and crystal quality for solar cell efficiencies >15.0% on average
- Use of 100% PHOTOSIL silicon – no blending with EG silicon
- Ready-to-use silicon feedstock – no additional doping required.

PHOTOSIL technology: standard purification process and results

Looking at the generic flow of the PHOTOSIL process as depicted in Fig. 3, one important point of note is the process's complete vertical integration, starting with the selection of raw material (quartz and carbon reductant) for the reduction of MG silicon and ending with the crystallization of multicrystalline silicon ingots from purified silicon. Effectively, the process combines metallurgical segregation processes with an inductive plasma treatment.

The vertical process integration brings two major advantages: (i), the transfer of silicon in its liquid state between certain purification steps, thus conserving the melting enthalpy; and (ii), the possibility of recycling silicon rejects after different purification steps. Both points allow for improved material yields and process times, and consequently lower processing costs. In the following section, the different purification process steps will be described in chronological order, followed by a review of obtained results.

The first three steps – selection of raw material, carbothermic reduction of silica to produce MG silicon and a first segregation of this MG silicon – take place under the operation of FerroPem outside of the proper PHOTOSIL facilities. This relocation is basically to simplify logistics and to benefit from existing production facilities and know-how. The great advantage of this approach is that the process is started with a lower impurity content – which can be a problem, especially regarding difficult-to-remove impurities like the major dopants, boron and phosphorous. The special selection of the two raw materials, quartz and carbon reductant, reduces MG silicon using dedicated electrical arc furnaces of FerroPEM. The silicon is directly transferred in its liquid state to the first segregation process that allows the reduction of impurities with a low segregation coefficient, which includes all metals but also phosphorous to a certain extent. The impurity characteristics of

Element	B	P	Fe	Al
	ppm_w	ppm_w	ppm_w	ppm_w
PHOTOSIL UMG-1 Silicon	7-8	10-12	150	30

Table 1. UMG-1 silicon characteristics.

Figure 4. UMG Si segregation unit.

the resulting UMG-1 silicon are shown in Table 1.

The UMG-1 silicon is subjected to a second metallurgical segregation treatment to further reduce metal and phosphorous concentrations, as depicted in the photos in Fig. 4. This is the first of several operations that take place within the PHOTOSIL facilities. The UMG-1 Silicon is first re-melted in an induction furnace and then transferred into a specially designed segregation vessel, in which a large volume of the silicon solidifies in a controlled way. The remaining liquid part in which metals and phosphorous have segregated is then poured into a waste container.

In a following purification step, the solidified UMG-2 is re-melted inside a graphite crucible by induction and submitted to an inductive plasma purification process, described in more detail elsewhere [7]. This crucial process, which mainly serves to reduce the boron concentration, consists of an argon plasma gas being projected towards the surface of the melted silicon. The argon plasma gas contains reactive species via injection of oxygen and hydrogen gases that are activated by high-frequency induction.

At the surface, which is constantly renewed by electromagnetic stirring of the melted silicon, the reactive species from the plasma gas react with the boron at the surface of the silicon bath and render it volatile (see Fig. 5). The progress of the boron volatilization is monitored by taking samples from the liquid silicon and performing resistivity- and conductivity-type measurements. This method turned out to be the simplest and most reliable one for monitoring this crucial process step.

“The progress of the boron volatilization is monitored by taking samples from the liquid silicon and performing resistivity- and conductivity-type measurements.”

Once the target resistivity is reached, the purified liquid silicon is either transferred into a cooling unit, where it randomly cools, or to another controlled segregation step. In fact, as the PHOTOSIL project progressed, it was found that this additional post-plasma segregation is necessary, since the plasma treatment introduced oxygen (from the plasma gas), carbon (from the graphite crucible) and aluminium (from the thermal insulating material) into the silicon. These three elements are present in stable compound form at the temperature in question, around 1500°C, and were found to segregate well.

Impurity concentrations for selected impurities following this entire PHOTOSIL purification process are listed in Table 2. The chemical analysis technique used for the determination of the concentrations of these impurities was GDMS and the metal concentrations were below the detection limit. These data reflect the status of the PHOTOSIL project in 2008/09 using the consolidated base purification process.

It can be seen that the boron and phosphorous concentrations are still relatively high; however, acceptable results were still achieved after crystallization of multicrystalline ingots from this silicon and processing of solar cells from this material. In total, 10 multicrystalline ingots of 60kg each have been crystallized with the intention of verifying the reproducibility of the entire process chain. The crystallization process and equipment used for the these ingots feature some innovative aspects in terms of heat management, high thermal gradients at the crystallization interface and time cycles for the crystallization operation [7].

Detailed characterization results from these 10 ingots are available [8]. Among other data, this publication gives a detailed analysis of the carbon and oxygen concentrations and their influence on the material quality after crystallization. In summary, the average

Element	B	P	Fe	Al	Ti	Cu
	ppm_w	ppm_w	ppm_w	ppm_w	ppm_w	ppm_w
PHOTOSIL SoG Silicon	1.5	4.0	<5.0	<2.0	<2.0	<2.0

Table 2. GDMS chemical analysis data of characteristic impurities in the silicon obtained through the standard PHOTOSIL process.

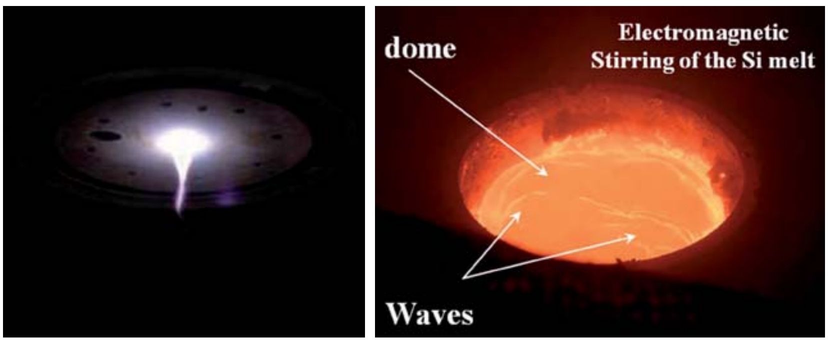

Figure 5. Photos of the inductive plasma gas (left) and the surface of the molten silicon inside the graphite crucible used during plasma purification. The visible waves at the surface of the silicon are an indication of the electromagnetic stirring.

Element	B	P	Fe	Al	Ti	Cu
	ppm_w	ppm_w	ppm_w	ppm_w	ppm_w	ppm_w
PHOTOSIL SoG Silicon	~ 0.3	~ 1.0	<2.0	<2.0	<2.0	<2.0

Table 3. GDMS chemical analysis data of characteristic impurities in the silicon obtained by the optimized PHOTOSIL process in 2010.

	h (%)	V_{oc} (mV)	I_{sc} (mA/cm^2)	FF(%)
Average	17.4	617.5	35.5	79.5
Best cell	17.6	619.3	35.5	79.9

Table 4. IV characterization results of the solar cells processed from the monocrystalline ingot, made from ultimately purified PHOTOSIL silicon.

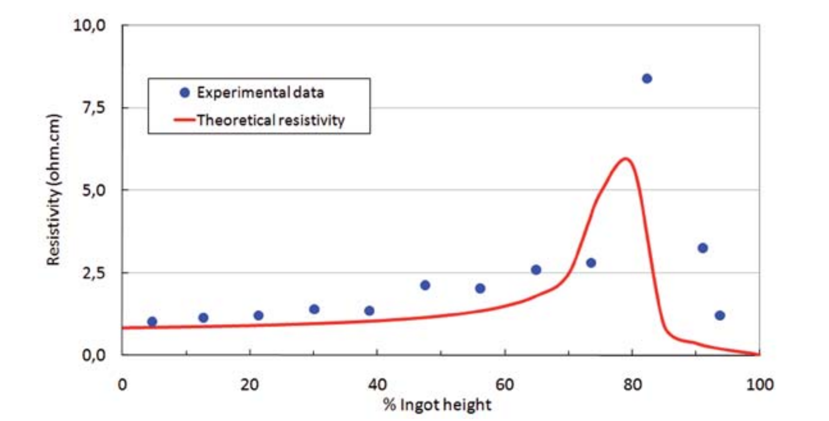

Figure 6. Resistivity distribution of the multicrystalline silicon ingot crystallized from ultimately purified PHOTOSIL silicon.

usable p-type part of the ingots with a resistivity range between XΩcm and YΩcm was 82% – very close to the objectives of the PHOTOSIL project. The change in conductivity type at a certain ingot height is due to the difference in segregation coefficient of phosphorous (0.35) and boron (0.8) and the fact that both are present in important concentrations in the starting material prior to crystallization. The more efficient segregation of phosphorous leads to its accumulation towards the upper part of the ingot and at a certain point to compensate for the boron concentration.

Using a standard industrial-type screen-printing process at the INES Restaure platform, cell efficiencies obtained reached 14.5%, with top efficiencies exceeding 15.5% – also satisfying the PHOTOSIL objectives. However, due to the presence of boron and oxygen in this material, some of the cells showed light-induced degradation in the range of 1% absolute.

PHOTOSIL: optimized purification process and results

In order to demonstrate the potential of the purified metallurgical silicon obtained using the PHOTOSIL process, all of the various processing steps of the generic process flow presented in Fig. 3 underwent optimization in 2010 with first-generation pilot line equipment. This work also gave valuable input for design of second-generation purification equipment, which is currently underway. One important goal of this purification campaign was to demonstrate the competitiveness of PHOTOSIL-purified metallurgical silicon. Table 3 summarises the chemical analysis data, again obtained by GDMS of the ultimately purified PHOTOSIL silicon. Comparison of the values in Tables 2 and 3 shows that clear progress has been made on these standard values from 2008/09.

This ultimately purified silicon was again used to crystallize a 60kg multicrystalline ingot as well as a 15kg, 6-inch CZ ingot, neither of which had additional dopants applied. Both ingots were cut into 125 x $125mm^2$ wafers (pseudo-square in the case of the CZ ingot), which were electrically characterized and processed into solar cells, again at the INES Restaure platform, detailed results of which have been published recently [10]. The most important results are summarized here, starting with the multicrystalline ingot, whose resistivity distribution as a function of ingot height is shown in Fig. 6.

As shown in the graph, the obtained resistivity in the p-type part is around 1.0Ωcm and above; the conductivity type change from p-type to n-type occurs at around 80% of the ingot height.

Three different processes were applied to the solar cells at the INES Restaure platform, all using screen-printed metallization – a standard one and two specially adapted to UMG-type silicon. Efficiency results from all three processes are summarized in Fig. 7, showing top efficiencies of 16.2%. Furthermore, these cells proved to be almost free of light-induced degradation, which came in at less than 1% relative.

From the same ultimately purified PHOTSIL silicon, an entirely monocrystalline CZ ingot was obtained, which is in itself already a material quality indicator of very low impurity content. The impurities effectively act as nucleation centres during crystallization and can lead

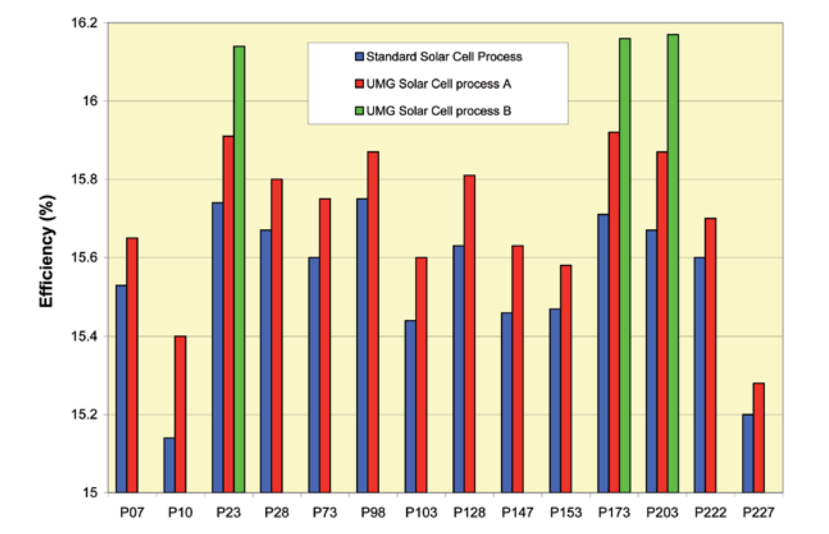

Figure 7. Efficiency distribution as a function of ingot height of solar cells obtained from the multicrystalline silicon ingot from ultimately purified PHOTOSIL silicon.

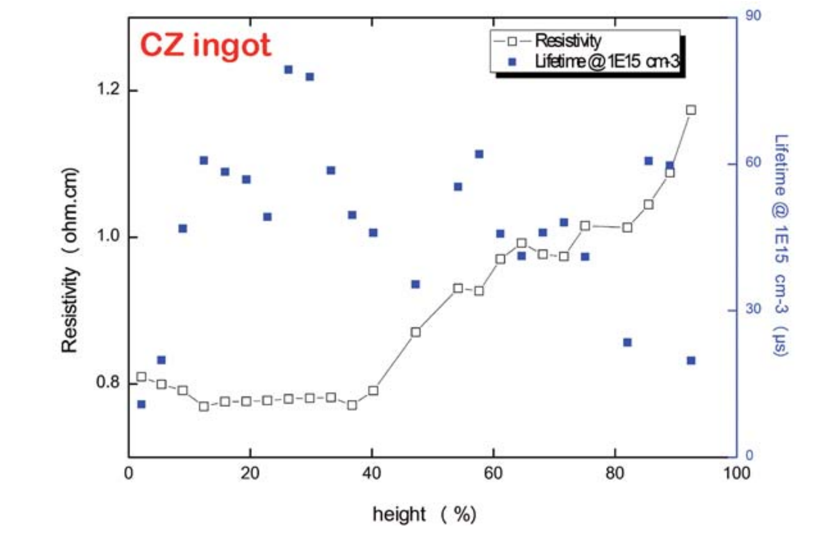

Figure 8. Resistivity and carrier lifetime data as a function of ingot height from the monocrystalline CZ ingot, crystallized from ultimately purified PHOTOSIL silicon.

to the appearance of dislocation and grain boundaries at certain stages.

Looking at the electrical characterization results in Fig. 8, one can see a resistivity between 0.8 and 1.2Ωcm throughout the ingot and considerably higher lifetimes in the order of 50 to 60µs. Solar cell data are summarized in Fig. 9 in terms of efficiency distribution as a function of ingot height, and more detailed IV data are presented in Table 4. The cells were again processed at the INES Restaure platform using screen-printed metallization and an industrial-type process.

As shown in Fig. 9, the efficiency distribution throughout the entire ingot is very uniform at high absolute values, far exceeding 17.0%. The IV data in Table 4 show that the average efficiency is 17.4%, with a best solar cell reaching 17.6%. To the authors' knowledge, these values are among the highest so far reported for solar cells processed on wafers of purified metallurgical silicon.

Conclusions

The quality and performance potential of PHOTOSIL silicon obtained by purification of metallurgical-grade silicon can be demonstrated by an optimized purification process. These encouraging results are in line with a recently published analysis of the economical viability of purified UMG silicon [11], provided the cost objectives of the PHOTOSIL projects are reached. The study defined economical breakeven points by relating solar cell efficiencies on purified UMG material to cost advantages of this material compared to solar-grade silicon obtained from the chemical purification route. To render it economically viable, purified UMG silicon that yields 15% solar cell efficiencies needs to be at least 12% lower in cost than chemically-purified solar-grade silicon.

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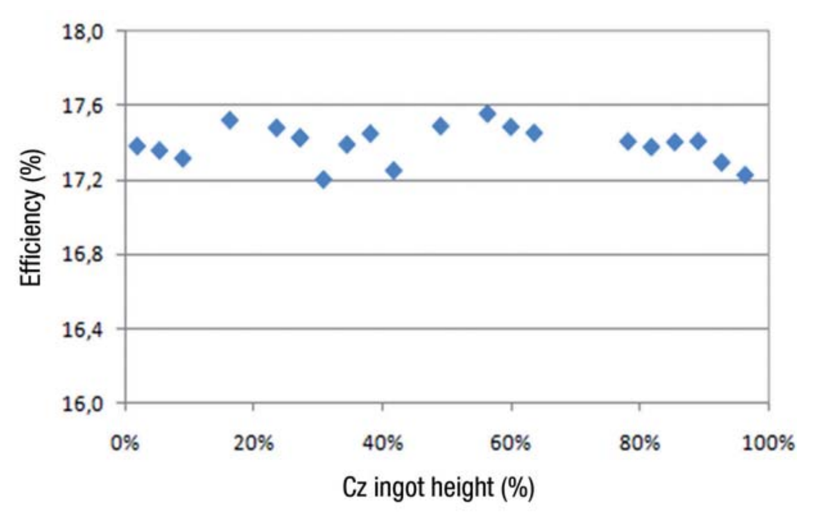

Figure 9. Solar cell efficiencies as a function of ingot height in case of the CZ ingot, made from ultimately purified PHOTOSIL silicon.

About the Authors

Roland Einhaus joined Apollonsolar in 2002, and currently holds the role of R&D Director. He has been working in PV research since 1994, focusing on the various steps of the silicon-based PV value chain from silicon purification and crystallization to silicon solar cell processes, characterization and PV modules. Before joining Apollonsolar, he worked at Photowatt, IMEC and the UNSW.

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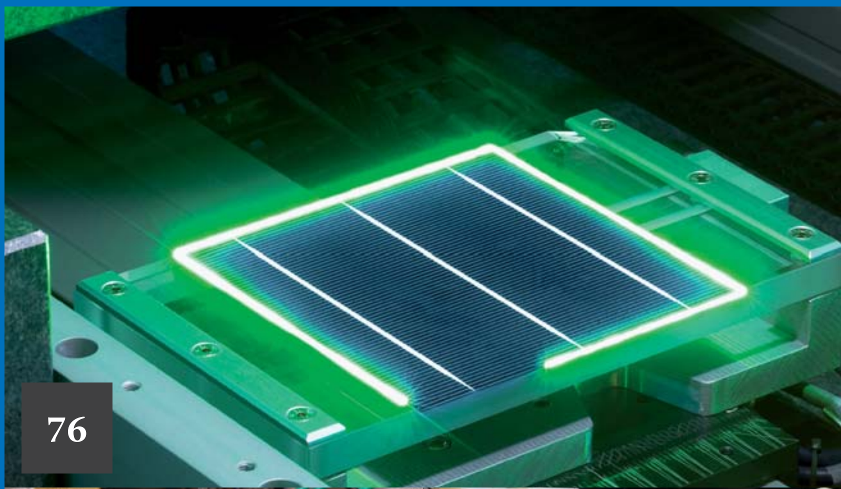
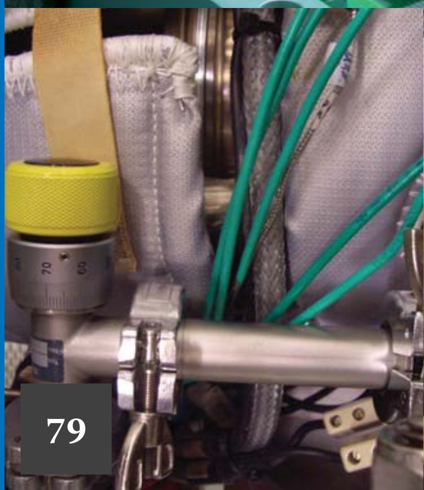
Cell Processing





SunPower pushes c-Si solar cell efficiency record to 24.2%

Produced at its solar cell plant in the Philippines, SunPower has had a full-scale solar cell verified by NREL (U.S. Department of Energy's National Renewable Energy Lab) with a conversion efficiency of 24.2%. This is a new world record for c-Si cells. SunPower did not disclose any processing details that enabled the new record efficiencies or when such cells would enter volume production.

SunPower also noted that it had increased its cell efficiencies a full four percentage points over the last five years. However, although the company also touted it had radically reduced manufacturing costs during the same period, SunPower has also entered into a joint manufacturing partnership with Taiwan-based AUO to drive down manufacturing costs of its next-generation cells.

SunPower's proprietary all-back contact cell.

Yingli Green, JA Solar join Innovalight on cell efficiency mission

Joining the likes of JA Solar, on its mission to quest solar cell efficiency, Yingli Green has signed a technology, research and production collaboration agreement with Innovalight - the privately-held firm selling a platform of silicon ink-based high efficiency solar cell materials and technology.

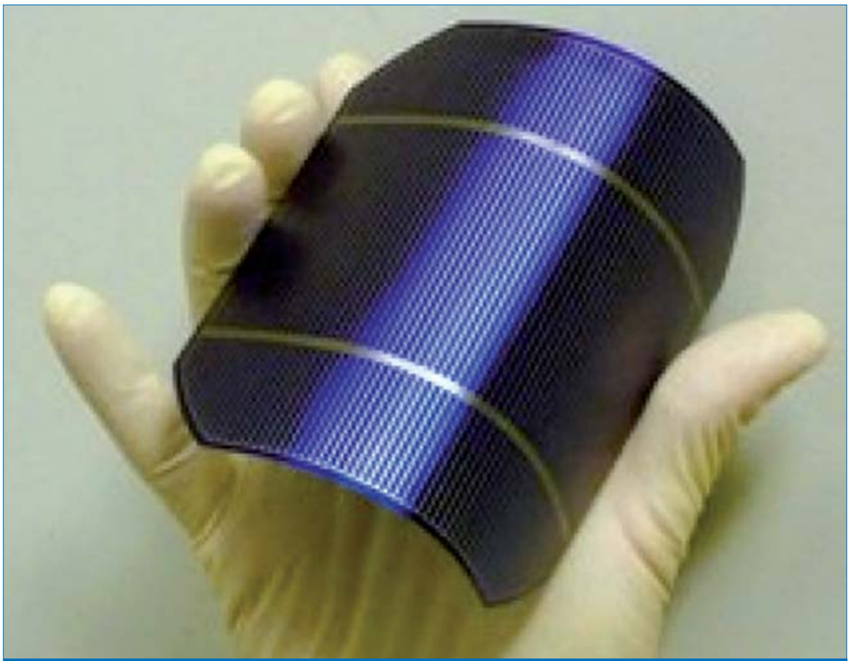
Innovalight will also be working with Chinese cell manufacturer JA Solar to push cell conversion efficiencies past 20% for JA Solar's recently introduced Secium high efficiency solar cells. The cell manufacturer has already achieved conversion efficiency of 18.9% using Innovalight's nanotechnology-based silicon ink. Development work will be performed at both Innovalight's headquarters in California and at JA Solar's R&D center in China with the new agreement lasting three-years.

RASIRC and Fraunhofer present research paper on purified steam at IEEE conference

During IEEE's 35th PV specialist conference, RASIRC and the Fraunhofer Institute for Solar Energy Systems presented their research on using purified steam in the solar cell fabrication process with their paper, "Purified Steam for Industrial Thermal Oxidation Processes." The paper compares purified steam with pyrolytic team for silicon solar cell fabrication.

Thermal silicon oxides are known to passivate silicon surfaces and have been used for the fabrication of efficient silicon solar cells. In most cases, the steam used for wet oxidation is produced by pyrolysis of highly purified hydrogen and oxygen gases. A new approach for direct steam delivery is to purify vaporized deionized water, wherein the process decreases costs for expendables, eliminates hydrogen gas from the facility and improves safety. Increased saturation with steam in the process atmosphere results in a higher cell growth rate during oxidation.

The research paper compares the two steam-generation technologies, analyzes the physical properties of purified steam grown thermal oxides and implements a direct steam-based oxidation process into an industrial fabrication sequence for rear-surface passivated solar cells. Results have shown that by using industrial equipment for wet chemical cleaning and thermal oxidation, high effective carrier lifetimes of ~400μs on 1Ω/cm floatzone wafers for both steam sources were achieved.



Innovalight's silicon ink-based solar cell.

DEK Solar presents latest advances in PoP technology to ECN delegates

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

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

VLSI Standards adds ISO-17025 to its solar cell certification services

In a move to help solar cell manufacturers meet metrology quality requirements, VLSI Standards has enhanced its portfolio to include accreditation to the ISO-17025 standard for cells of up to 156mm x 156mm in size. Production cell measurements will continue to be serviced from VLSI's calibration laboratory in California.

VLSI's solar cell certification service offers traceable measurements of production cells of short circuit current (I_{sc}), open circuit voltage (V_{oc}), maximum power (P_{max}), cell area, spectral response (or quantum efficiency), fill factor and cell efficiency. Measurements will be performed under STC with an option to have temperature dependence measurements.

IMEC achieves new record efficiencies for large-area epitaxial thin-film silicon solar cells

IMEC has achieved large-area (70cm^2) epitaxial solar cells with efficiencies reaching 16.3% on high-quality substrates. Efficiencies of up to 14.7% were attained on large-area low-quality substrates. IMEC accomplished 20μm-thick high-quality epitaxial silicon stacks on top of a highly-doped high-quality substrate and low-cost upgraded metallurgic-grade (UMG) type, multicrystalline Si substrate.

The p^+-type surface field (BSF), the p-type base and the n-type front-side emitter were developed with chemical vapour deposition. The light-trapping method uses plasma texturing of the front surface combined with an internal porous silicon Bragg reflector at the epitaxial/substrate interface. The cells on the high-quality substrate are contacted with copper plating. Those cells made on low-quality substrates achieved metallization with screen-printing, the last step after the formation of the diffused front surface field (FSF) and the silicon nitride antireflection coating. The epitaxially-grown wafer equivalent substrates are completely compatible with standard

industrial solar cell processing.

Trina Solar and SERIS to collaborate on wafer solar cell

Trina Solar announced its recent research agreement with the Solar Energy Research Institute of Singapore (SERIS). Their collaboration will be for the development of an all-back contact high-efficiency silicon wafer solar cell with Trina Solar's monocrystalline wafers. Trina will cover the cost of the research project in exchange for the intellectual property rights. Trina Solar and SERIS will work together to produce the high-efficiency solar cell by printing contacts on the back of the cell to increase front surface exposure to sunlight. Trina Solar is anticipating a 21.5% production efficiency and 23.5% laboratory test efficiency with the project completed in the next three years.

SpectraWatt receives research grant via NSF

The Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) program of the National Science Foundation has chosen SpectraWatt as its recipient for a US$150,000 research grant.

The grant will go towards Phase 1 of the company's project, which focuses on achieving panel efficiencies of over 20% from a combination of multicrystalline silicon and other materials. Commencement on SpectraWatt's project will start later this year at their Hillsboro, Oregon research facility. Dr. Juanita Kurtin, director of R&D, will supervise the project.

Cell Production News Focus

Hyundai Heavy Industries to nearly double cell, module capacity to 600MW by 2011

Hyundai Heavy Industries said it plans to double its annual module and cell production capacity from the current levels of 320MW and 370MW, respectively, to 600MW by early 2011. The company will complete the near-doubling of its capacity through the expansion of its solar power factory in Eumseong, north Choong-cheong province, by early 2011 and start full-scale production from the second quarter of the same year. Hyundai Heavy has also been processing 3000 tons of polysilicon prototypes at Korea Advanced Materials, a company jointly established with KCC.

LG Electronics begins PV cell production with two centrotherm crystalline manufacturing lines

centrotherm photovoltaics has concluded the ramp-up of two crystalline solar cell manufacturing lines at LG Electronics, which enters the photovoltaics manufacturing industry with one line for monocrystalline and one line for multicrystalline solar cells. centrotherm photovoltaics will manage its customer relationship with LG Electronics from its Korean branch, established in 2009.

Business News Focus

China Sunergy, REC Wafer dispute continues

The ongoing dispute between China Sunergy and REC Wafer continues as the former reveals that it is considering appealing against the decision made in favour of the Norway-based wafering company. The ruling by the Norwegian District Court on July 5th, which took the side of REC, is now set to be contested by China Sunergy, meaning that the US$50 million bank guarantee is currently still blocked from being withdrawn by REC Wafer.

Integrated Materials is acquired by U.S.-based Ferrotec

Ferrotec, the U.S.-based global supplier of materials, components, and precision system solutions, has purchased Integrated Materials. The sale includes the acquisition of Integrated Materials' patented SiFusion process for manufacturing polysilicon furnaceware. Full terms of the transaction were not disclosed.

Q-Cells and Innotech engage long-term strategic partnership

In accordance with the newly-signed long-term strategic partnership between Q-Cells and Innotech Solar, Q-Cells will sell all of its non-prime solar cells to ITS for conversion into PV solutions under the ITS name. All visual and electrical non-prime solar cells will be supplied to ITS under a multi-year agreement. Additionally, Q-Cells and ITS agreed to transfer of individual reworking assets and staff from the Thalheim Q-Cells site to help ITS's expansion capabilities.

ISRA Vision completes acquisition of Graphikon

ISRA Vision has completed its acquisition of Graphikon, Gesellschaft für Bildverarbeitung und Computergraphik, based in Berlin. Graphikon's product range includes wafer-based solar cell and glass tube inspection tools. ISRA will also obtain the company's client list which includes the likes of aleo solar, Q-Cells, Würth Solar, Solarwatt, Schott, Evergreen Solar, Epcos and Solarworld.

By the end of 2010, Graphikon plans to achieve a total output of more than

REC's cell production in Narvik, Norway.

Source: REC


bundle of energy loves regeneration
Innovative solutions from BASF ensure that solar panels remain full of energy even if the sun doesn't shine for brief periods. Our solutions and expertise cover the entire solar cell production process from wafer cutting to module framing. Sunlight can be efficiently turned into energy. At BASF, we create chemistry.
solar-cells@basf.com
BASF
The Chemical Company

Cell Processing Order Focus

Singulus supplies cell manufacturer with Linea texturing, inline coating machine

Stangl, the subsidiary of Singulus, has delivered one of its Linea texturing and inline coating machines to an unnamed European solar cell manufacturer. This order marks Singulus' first installation of a front-end system, with the combination of phosphor cleaning and anti-reflective coating. This installation and commissioning of a combined Singulus and Stangl production machine for silicon solar cells is an important integration step for the automation and cost reduction of modern cell manufacturing.

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

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

Tempress Systems receives US$20 million in new orders

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

Amtech's order backlog tops US$80 million: reports record revenue

Amtech Systems said that for its fiscal third quarter, sales in solar reached US$42 million in total, a new quarterly revenue record. For the first nine months of the year, Amtech said it recorded over US$135 million in total orders, exceeding all previous full fiscal-year bookings. Amtech's total order backlog at June 30, 2010, was approximately US$80 million.

centrotherm photovoltaics receives first upgrade order from Taiwanese customer

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

"Our strategy of upgrading existing production lines with selective emitter technology is proving highly successful. The market is showing great interest in such products," said Dr. Peter Fath, CTO at centrotherm photovoltaics.

Manz gets first selective emitter orders from Yingli Green, Bosch and Conergy

Many c-Si solar cell manufacturers are developing various selective emitter processes that place emitters underneath the front contacts of cells to boost conversion efficiencies. However, Manz Automation may be taking the lead in announcing that its laser-based production technology has been selected by Yingli Green, Bosch, and Conergy.

The company said that its 'OneStep' selective emitter technology will be implemented at pilot production lines over the coming months with the aim of production verification as soon as possible. Various studies have indicated that the process technology could provide a 0.5% increase in cell conversion efficiencies.

Manz uses a high-precision printer (HAP2400) and the OneStep selective emitter laser line to produce the SE structure.

€3.5 million. The acquisition price, approximately 75% of the current revenues, also includes an earn-out and share component. An appreciable contribution from Graphikon to the consolidated revenues and earnings of the ISRA group is expected in the new fiscal year 2010/2011.

KMSA introduces full line of PV measurement, characterization instruments for the U.S. market

Konica Minolta Sensing Americas (KMSA), the industrial colour, light and shape measurement company, has announced plans to introduce a full line of photovoltaic measurement and characterization instruments to the U.S. market.

The new line is a product of cooperation between Konica Minolta Sensing and the National Institute of Advanced Industrial Science and Technology (AIST) of Japan. A reference cell is used as a standard point of calibration to ensure consistent measurements of newly-developed photovoltaic cells.

"Our pseudo reference cell is specifically designed to adjust the illumination of solar simulators for multijunction solar cells. Multijunction solar cells are sensitive to a greater portion of the light spectrum," said Bryan Bond, photovoltaic business manager for KSMA.

KMSA's entry into this new market stems from a US$20 million capital investment by Konica Minolta Holdings and Konarka Technologies to develop and distribute thin-film photovoltaics.

Konica Minolta's San-ei XES-301S solar simulator.

Spire receives DOE grant for development of microcrack detection in solar cells and wafers

Spire welcomed the recent news that the U.S. Department of Energy (DOE) will be providing a grant to the company for the development of a micro-crack detection system for solar cells and wafers. Currently, a large proportion of PV cells have microcracks that spread through the cells and can cause power loss and cell breakage. The cracks are hard detect with current technology, but Spire aims to develop a non-contact photoluminescent technique to image the cracks, which will be integrated into high-speed crack detection cell test equipment in cell and module assembly lines.

"We are pleased that the DOE is supporting our efforts to develop this critical capability," said Roger Little, chairman and CEO of Spire. "The early detection of microcracks in wafers and cells will reduce scrap, improve production yield, and increase the lifetime of installed modules, thereby reducing total energy generation cost."

By Mark Osborne, News Editor, Photovoltaics International

At Intersolar Europe 2010, Samsung Electronics, a powerhouse of the semiconductor industry, exhibited for the first time. However, based on their manufacturing strategy and plans, it looks like they will be attending many other major events for years to come.

Changsik Choi, executive vice president of Samsung Electronics' Solar Energy Business Team at Intersolar Munich, 2010.

Typically, the Korean-based memory manufacturer has revealed little about their solar manufacturing strategy, especially capacity and capital spending plans. However, PV-Tech was granted an exclusive interview with the head of its new Solar Energy division, Changsik Choi, Executive Vice President of Samsung Electronics.

Although it may be early days for Samsung Electronics' foray into the solar industry, it becomes instantly clear on speaking with the executive that the company is taking its entry into the market seriously, with potential to become a major player.

"Currently, we are focusing on the crystalline silicon business, especially monocrystalline silicon," noted Choi.

He continued to say that Samsung is targeting the high-efficiency cell space but instead of offering a premium priced product, it has focused on tapping into its LCD and semiconductor processing know-how to produce high-efficiency cells at lower costs.

The Samsung Electronics executive made it clear that its focus for 2010 would be to gain acceptance from key customers for its cell technology.

Choi said the company plans to spend US$6 billion over the next 10 years to build and expand manufacturing capacity to "several gigawatts in the near future," – although he refused to be more specific.

Currently, pilot production of mono-c-Si cells is at the low megawatt level as it gains customer acceptance, but Choi made it clear that the gigawatt ramp is a priority.

Despite Samsung's expertise as the largest TFT-LCD producer, Choi noted that the company is still evaluating its thin-film solar options and that definite plans will be made in the "near future."

Samsung Electronics may not be in a rush to enter the thin-film market just yet, but its move to produce high-efficiency cells at low cost is a major disruptive move. The company is noted in the semiconductor industry as an aggressive driver in manufacturing cost reduction, and it invests heavily in new process technologies and manufacturing capacity.

In solar, Samsung has seen weaknesses in manufacturers supplying the high-end efficiency market, primarily due to the 'premium' price tag attached. It is well known that SunPower has the highest cell efficiencies but has struggled to cut manufacturing costs, leading to its recently announced partnership with AUO to drive down cell production costs, while expanding capacity to gain the economies of scale.

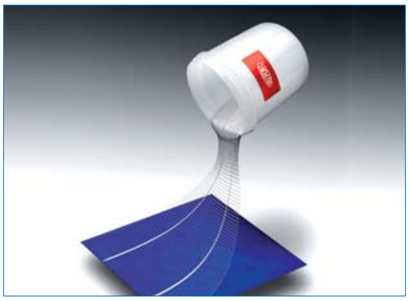
JA Solar is also targeting high-efficiency cells and modules via its OEM module business, cutting the cost and 'premium' price advantage held by the likes of Sanyo and SunPower.

The battleground is rapidly taking shape to establish the future dominant high-efficiency low-cost cell producer, and Samsung's entry only raises the stakes for more established players.

Samsung is set to enter the high efficiency c-Si cell manufacturing fray.

Product Briefings

DuPont



Solamet PV16x series metallization pastes from DuPont can raise solar cell efficiency by up to 0.4%

Product Briefing Outline: DuPont Microcircuit Materials (MCM) has introduced its newest generation of front-side metallization pastes for crystalline silicon solar cells. The Solamet PV16x series photovoltaic metallization pastes are claimed to deliver up to 0.4% greater conversion efficiency for solar cells, and are suited to a wide range of printing line widths and processes.

Problem: The front-side conductor is responsible for absorbing light and generating most of the electrical carriers. Smaller line widths can boost cell efficiency as more surface contact area is available. However, low contact resistance is required as well as high conductivity, especially on large substrate sizes, requiring quality products to achieve desired results. The material properties and functional requirements of the front- and back-sides of PV wafers dictate significant differences in the functionality of photovoltaic metallization.

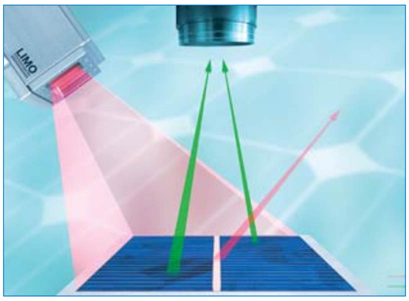
Solution: DuPont's new pastes are said to provide up to 0.4% greater efficiency, and feature low-contact resistance. The enhancements are achieved through advanced chemistry, which provides lower contact resistance to the Si, as well as through reduced bulk resistivity of the paste, which yields higher gridline conductivity. They are available in a range of options suitable for various printing requirements, including fine lines (less than 80μm) with high aspect ratio patterning, to improve line conductance. Capable of contacting shallow emitters of up to 85Ω/sq and deep emitters, the Solamet PV16x metallization pastes have undergone extensive customer testing.

Applications: c-Si solar cell metallization.

Platform: DuPont's Solamet pastes are available in a large range of options for a variety of printing requirements.

Availability: Currently available.

LIMO



Fast in-line solar cell inspection with asymmetric homogeneous diode laser illumination from LIMO

Product Briefing Outline: LIMO has developed a diode laser that generates photoluminescence and thermographic signals by asymmetric homogeneous illumination of the solar cell. Homogeneously illuminated fields create value in metrology applications in a variety of industries, including photovoltaics.

Problem: Illumination systems for analyzing surface properties are often located perpendicular to the inspected surface. Therefore, the solar cell has to be illuminated at a certain angle to improve the signal. As inline inspection becomes increasingly adopted for quality control in high-volume manufacturing, faster throughput with high precision is required.

Solution: Solar cell inspection tools based on the LIMO laser source operate with a single light source compared to other inspection tools using two light sources, rendering the tools more compact and reducing materials as well as assembly costs. In-line inspection of solar cells occurs at full production speed without interrupting the production, which leads to high productivity and low cost per tested unit.

Applications: Solar cell inspection tools.

Platform: The 120W fiber-coupled industrial laser system LIMO120-F400-SL808-103 is combined with the IOS00019x-series processing head. This device generates a homogeneously illuminated field under a 35° angle of incident that fits to solar cell sizes up to 210 x 210mm. The centre wavelength of 790–808nm is essential for the separation of excitation source and signal light. Small bandwidth versions (< 1nm) are also available.

Availability: Currently available.

ROFIN

ROFIN's PowerLine L Series lasers designed for large-scale solar cell manufacturing applications

Product Briefing Outline: ROFIN has introduced a new laser series for high-speed micro material processing, with a special focus on photovoltaic manufacturing. The new PowerLine L series are q-switched solid-state lasers specifically designed for micro material processing applications, which require high average power and high pulse energy.

Problem: Compared to ROFIN's DQ series, which offers 500 to 1000W, the PowerLine L 300 features more than 200W of laser power at 10kHz with smaller optical fibers and an optimized 400μm-square fiber. Compared to round fibers, square fibers provide greater efficiency by machining a larger area per pulse.

Solution: Selective opening of dielectric layers and direct laser doping are popular topics of interest in solar cell manufacturing. For both applications, the frequency-doubled PowerLine L 100 SHG has already proven its suitability as a result of various research projects. The laser source offers optimum beam characteristics and sufficient power for large-scale production. Green lasers with 532nm show the desired near-surface absorption in silicon and can be equipped with a wide range of long-life optical components and fibers.

Applications: Thin film removal on glass and flexible materials, ablation of dielectric layers, silicon processing together with drilling and cutting operations.

Platform: The Nd:YAG (neodymium-doped yttrium aluminium garnet) lasers are efficiently diode-pumped and designed to be reliable within an industrial environment and 24/7 operation. The PowerLine L 100 SHG uses a high performance SHG assembly with harmonic generator crystal for frequency conversion. The principle of q-switching yields peak pulse performances 1000 times higher than those created by CW laser power.

Availability: Currently available.

TRUMPF

TRUMPF's new laser markers offer shorter marking times

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

Problem: Faster processing times are required to meet high-volume manufacturing requirements. Process steps such as laser marking need to be performed quickly in otder to reduce bottlenecks.

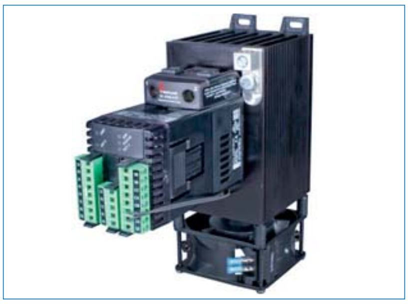
Solution: The lasers enable users to perform any marking process – including tempering, engraving, depositing, colour change, and foaming – quickly and with a high level of quality. The TruMark 6030 and 6140 lasers feature considerably shorter marking times when compared to other products in the TruMark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

Applications: Laser marking for surface processing.

Platform: The TruMark 6030 works in the infrared range of 1064nm. With its Nd:YAG (neodymium-doped yttrium aluminium garnet) laser crystal, the tool is designed for marking in the lower frequencies up to 60kHz. Users can achieve the best marking results with the TruMark 6140 and its Nd:YVO4 (neodymium-doped yttrium orthovanadate) laser crystal in the infrared range of 1064nm at frequencies starting at 40kHz.

Availability: Currently available.

Watlow



Watlow improve solar cell thermal processing with precise control of tungsten lamps

Product Briefing Outline: Watlow's upgraded EZ-ZONE ST features single-phase solid-state relay output up from 40 to 75A and phase angle power switching with soft start to prevent high in-rush currents, load failure or blown fuses during solar cell thermal processing.

Problem: Radiant quartz (tungsten) lamps are commonly used in the manufacturing of PV cells to deliver a variety of specific thermal profiles rapidly. To overcome inherent limitations (low resistance/high in-rush currents), these heating lamps require phase angle power to function properly. These lamps are also usually ganged into small banks for improved temperature uniformity, which require temperature control, power switching, current monitoring, over-temperature protection and field communications.

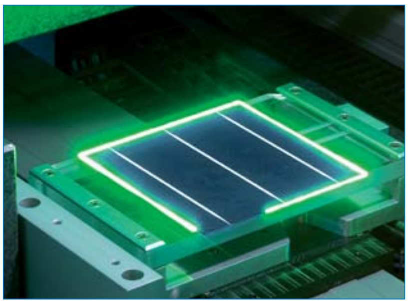
Solution: This upgraded controller is designed specifically for the production of PV cells where size and temperature uniformity are required to reliably produce a cell with high conversion yields. This expanded offering improves thermal uniformity, temperature repeatability and provides the functionality of multiple components and footprints collapsed into one. The design of the EZ-ZONE ST provides a complete thermal system kit to reduce project and engineering design time and is already tested and validated for the specified ampacity.

Applications: Solar cell thermal processing.

Platform: The EZ-ZONE ST comes complete with a free internal communications bus (standard bus) which provides a single entry point for configuration and monitoring or location to access multiple controllers on the bus. Option of 1/16 DIN RUI as a stand-alone device or combining the RUI with gateway functionality.

Availability: Currently available.

Manz



Manz Automation's OneStep selective emitter system boosts cell efficiencies 0.5%

Product Briefing Outline: Manz Automation has developed the OneStep selective emitter (SE) system for crystalline silicon solar cells. Among competing SE processes, the laser process consists of only one single process step, without any consumable usage. Investment payback is said to be less than one year, while the small footprint allows easy retrofit of existing production lines. The tool is claimed to enable cell efficiency gains of up to 0.5%.

Problem: One method of raising efficiencies is the incorporation of a selective emitter cell structure into industrial solar cell production, as it can increase solar cell efficiency due to enhanced blue light response, leading to higher short circuit current J_{sc}, and a reduced emitter saturation current density J_{oe}, boosting the open circuit voltage V_{oc}.

Solution: The OneStep system features one single additional process step, when compared with standard crystalline silicon solar cell production. This step is introduced between emitter diffusion and phosphorous glass (PSG) etch. Pulsed laser irradiation locally scans the wafer surface, forming highly-doped areas by local liquid-state diffusion of phosphorous from the PSG layer. After anti-reflection coating, the metallization grid is deposited on top of the highly doped areas. The local doping leads to a reduction of the specific contact resistance from silicon to metal, thus allowing for the use of lowly doped emitters with high sheet resistance.

Applications: c-Si production applying n-type emitters and front-side metallization as well as existing lines (retrofit).

Platform: Throughput: 1200 or 2400 wafers per hour (configurable); accuracy: ±10µm. Footprint (including automation): 4.7 x 2.7m^2. Fully automated and compatible with all established carriers. Efficiency gain up to 0.5% absolute.

Availability: Currently available.

Advanced process control – lessons learned from semiconductor manufacturing

M. Schellenberger, G. Roeder, R. Öchsner, U. Schöpka & I. Kasko, Fraunhofer Institute for Integrated Systems and Device Technology (IISB), Erlangen, Germany

ABSTRACT
Advanced Process Control (APC) has become an indispensable cornerstone of today's semiconductor manufacturing. With roots in chemical processing, APC has not only proven itself in semiconductor manufacturing, but has potential to enhance yield in adjacent industries, such as photovoltaics. This paper gives a short introduction to APC, including its key elements, and proceeds to illustrate examples and success stories from the application of APC in semiconductor manufacturing. Based on these application examples, the lessons learned are summarized and the potentials of APC for PV are derived.

Introduction

Semiconductor manufacturing consists of hundreds of process steps, with the entire device processing time, from blanket wafers to packaged chips, usually taking six to eight weeks. Fig. 1 shows a schematic of the general semiconductor fabrication process. In order to satisfy device quality requirements and to maintain high yield, a very tight control of every single process step is required and implemented in the production lines.

Photovoltaic devices, particularly thin-film cells but also mono- and polycrystalline cells, also have quite a demanding multilayer structure. The individual manufacturing processes, often bearing similarities to semiconductor production, are set to provide the desired layer thicknesses, homogeneity and composition, the crystal phases and the crystal structure defining the cell properties. Even the smallest process variations can affect the cell structure, and more importantly, the cell properties. Continuously increasing quality and cell efficiency requirements, combined with the enormous price pressure, require very high process stability and fast reaction concerning process variation and drift. Therefore, as was seen in the semiconductor manufacturing industry, tight process control will gradually become vital in the photovoltaic industry to establish and to maintain high quality and high efficient production with increased yield.

Introduction to advanced process control

The semiconductor industry has always taken measures to ensure high quality productivity by increasing process control, as is the case in other branches of manufacturing industries. Common approaches include statistical process control, the use of neural networks – especially in high-dimensional problems, and advanced process control (APC).

The fundamental goal of APC is twofold: to obtain measures for process control closer to the process and to automate control actions. Fig. 2 illustrates how the increasing value of a semiconductor wafer can increase the potential loss in case of error. To minimize loss, the early application of appropriate measurement and control methods is necessary.

> "The fundamental goal of APC is twofold: to obtain measures for process control closer to the process and to automate control actions."

APC comprises control methods that act directly on processes. The most important methods can be summarized as follows:

- *Methods for statistical process control (SPC)* SPC is a well-established technique of using statistical methods to analyze process or product metrics to take appropriate actions to achieve and maintain a state of statistical control and continuously improve the process capability. Many SPC tools are based on the so-called Western Electric Rules [1].
- *Methods for fault detection (FD), fault classification (FC) and fault prediction (FP)* FD is the technique of monitoring and analyzing variations in tool and/or process data to detect anomalies. FC builds on that and covers techniques of determining the cause of a fault once it has been detected. Both methods are often used together as 'fault detection and classification' (FDC). FP is the technique of monitoring and analyzing variations in process data to predict anomalies and faults before they actually occur.

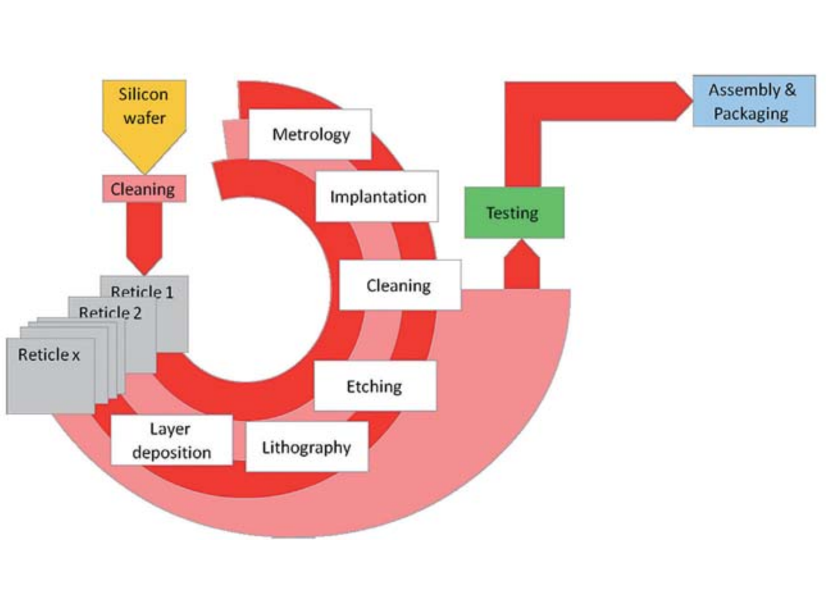


Figure 1. General fabrication flow of microelectronics devices.

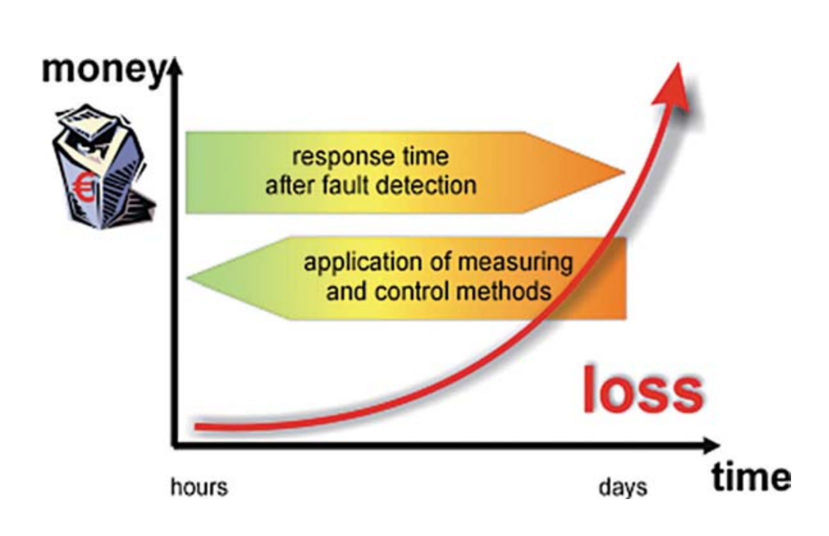


Figure 2. Correlation between the time of error detection and occurrence of loss.

- *Methods for run-to-run control (RtR)* RtR is the technique of modifying recipe parameters between production runs to improve processing performance. A 'run' can be a batch, lot, or an individual wafer. In serial processing this method can just be applied between two measurements.
- *Methods for virtual metrology (VM)* VM is the technique of deriving wafer parameters or product parameters from existing manufacturing parameters or from upstream metrology (e.g., process state, additional sensors, temperature, pressure, gas flow etc.) by using physical models.

It is obvious that the proper application of these methods relies heavily on the availability of data throughout the fab. Those data may come from the manufacturing equipment (e.g., equipment health indication, uptime data), from the process (e.g., temperature, pressure), or from the wafer (e.g., layer thickness, layer composition). In order to be able to apply control algorithms, 'quality parameters' have to be identified as well as 'tuneable parameters'. Quality parameters describe whether a production run was successful; tuneable parameters are parameters that can actually be adjusted to adapt a process.

In addition, wherever data are collected, specific emphasis must be put on data quality (e.g., accuracy, resolution, correct time-stamping, context information), because every control measure can only be as good as the data upon which it relies.

Fig. 3 depicts some of the aforementioned elements of APC in an abstract process flow. This is independent from an actual implementation in semiconductor or PV manufacturing, as data about processes and product properties are collected by sensors and dedicated metrology. The data from the sensors are used for a simple 'go/no go' decision at process *n*, based on the knowledge of whether or not a certain quality parameter is beyond a defined limit. Both process and metrology data are used to feed a run-to-run control algorithm to adjust tuneable parameters of process *n* to adapt to changes in quality parameters detected at the post-process metrology or previous metrology step. This is either called feed-forward or feedback control, based on the metrology step used for automated adjustment of recipe parameters. A combination of both feed-forward and feedback is possible.

Examples and success stories for the application of APC

Examples of successful application of APC in the semiconductor environment are manifold. However, not every single application is transferable to other production environments. The

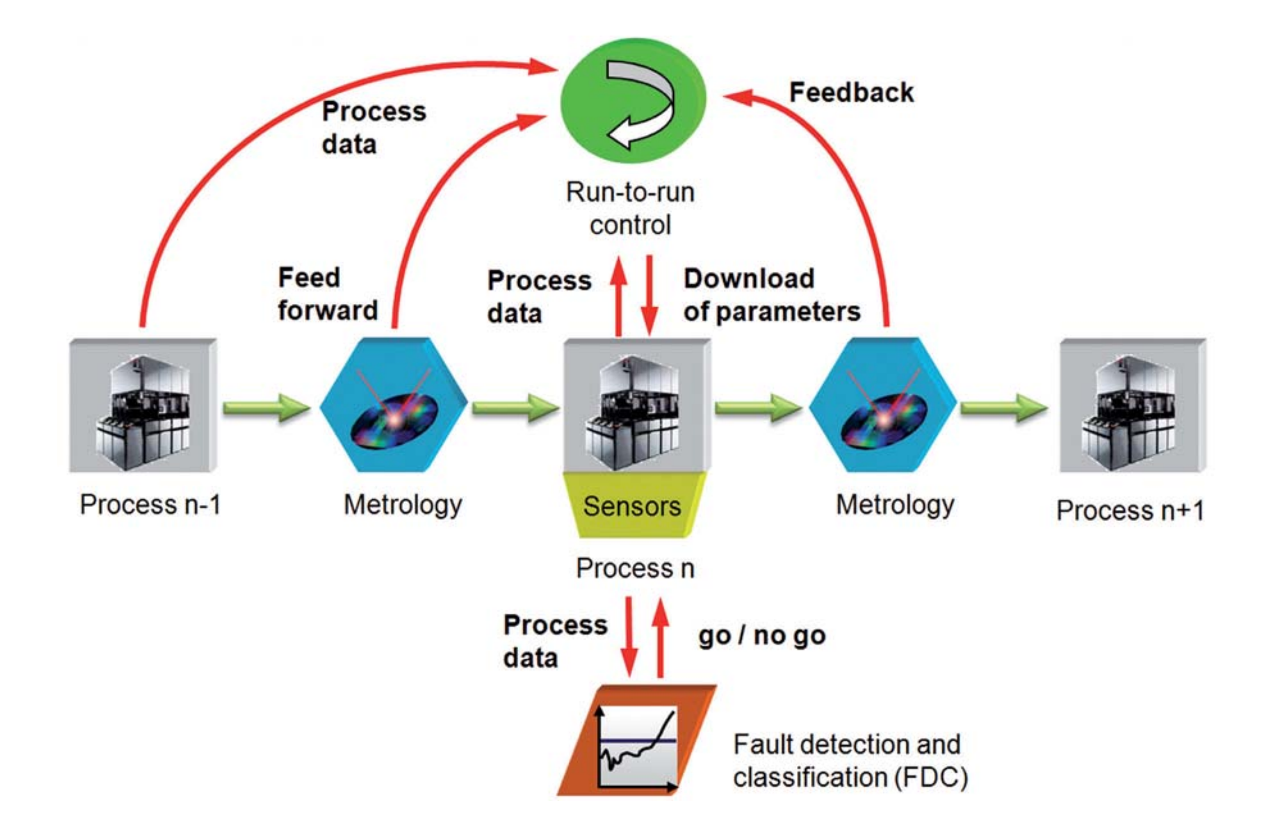


Figure 3. Interaction of APC elements.

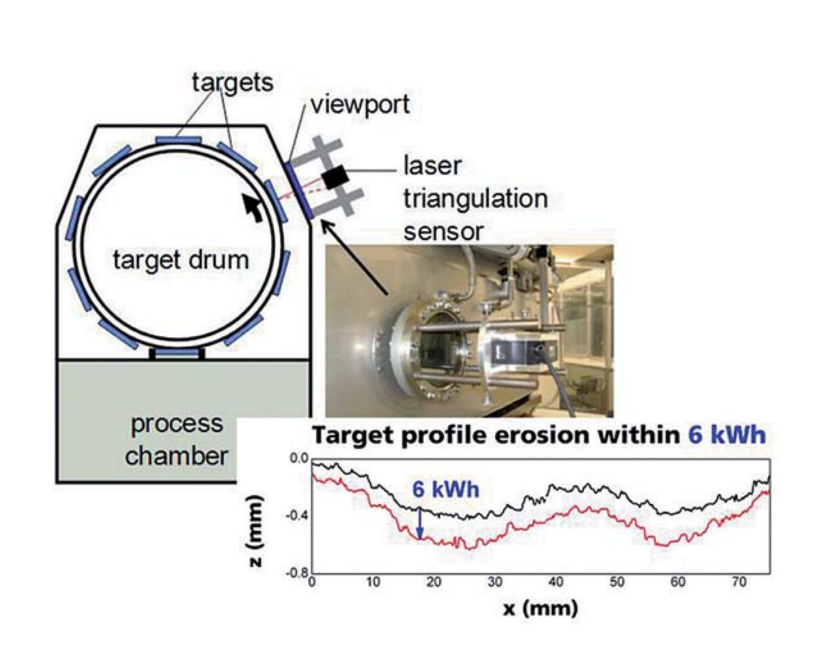


Figure 4. Laser-triangulation system for the target control in dynamic linear magnetron sputtering. The difference between the black and red curve represents an energy usage of 6kWh.

following sections focus on deposition and metallization processes, often based on plasma-enhanced methods, which are important techniques both in semiconductor manufacturing as well as in the photovoltaic industry. Common quality parameters for these processes may be identified in both industries, and features such as deposited thickness, homogeneity of layer thickness and layer composition can act as quality parameters to optimize anti-reflective coatings (ARC). In the semiconductor industry, the tight control of critical dimensions is also a very important issue.

Integrated metrology as enabler for APC

In a straightforward approach, these parameters may be measured by standalone metrology tools and the measured quality parameter of the substrate or device under investigation may serve as an input parameter to control a process and the respective equipment. Interestingly, for large substrate areas and high-throughput production processes in particular, it turned out to be more efficient to measure parameters that may serve as input for a control strategy more closely to the equipment (see Fig. 2).

In semiconductor processing, integrated metrology (IM) has proven to be an enabler for APC and to provide substantial benefits in process development as well as in volume production. Several prerequisites are necessary for the successful and effective implementation of IM. These include: the availability of solutions for mechanical integration and automation of sensors or measurement equipment; the availability of analysis methods to correctly measure inside an equipment or process environment; and the efficient connection to a data framework enabling fab-wide APC strategies. In the past, various IM solutions were developed for different process classes in the semiconductor industry, e.g. plasma processing, lithography, thermal deposition and oxidation processes, and implant. Retrofit solutions for IM integration may be applied for existing equipment, but the most efficient approach is development of IM and APC strategies at the early stage of the process equipment development.

Example 1: Control of sputter erosion

In sputtering processes, the cathode material (target) is removed by accelerated ions in the plasma, and the removed material is then deposited on the wafer. During that process, the target is eroded and, as a consequence, the envisaged process result on the wafer is influenced by this erosion. Additionally, the use of magnetic arrays (magnetrons) behind the target, used to enhance the deposition rate, causes inhomogeneous erosion resulting in the formation of deep grooves in the target surface and leading to unpredictable process results in homogeneity and

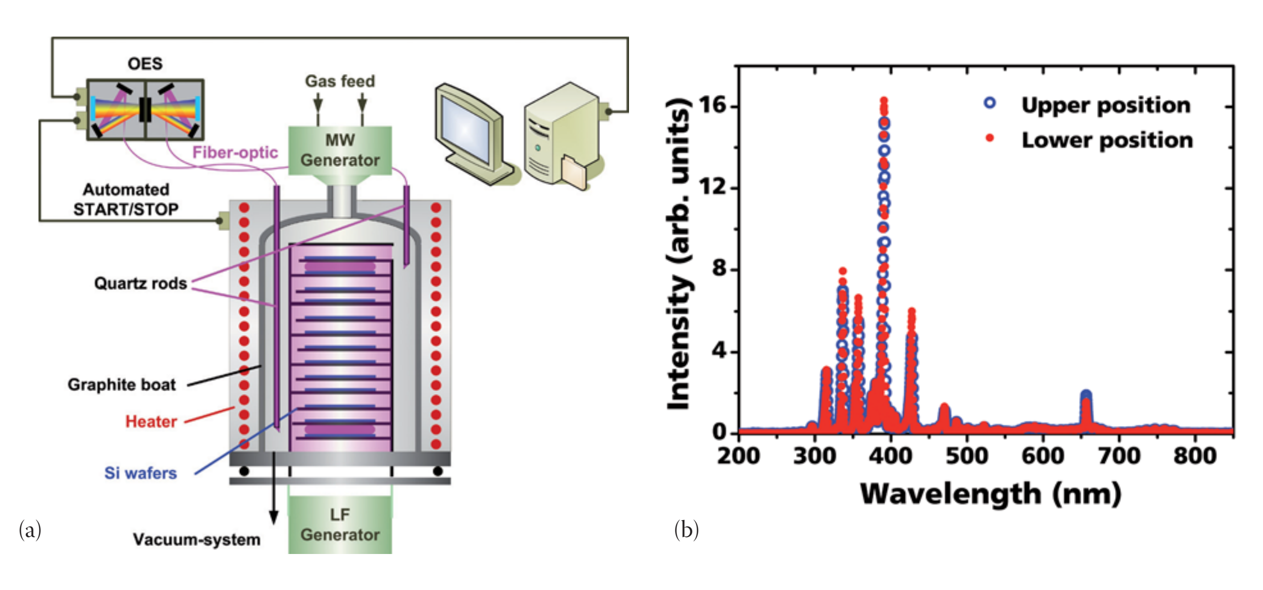
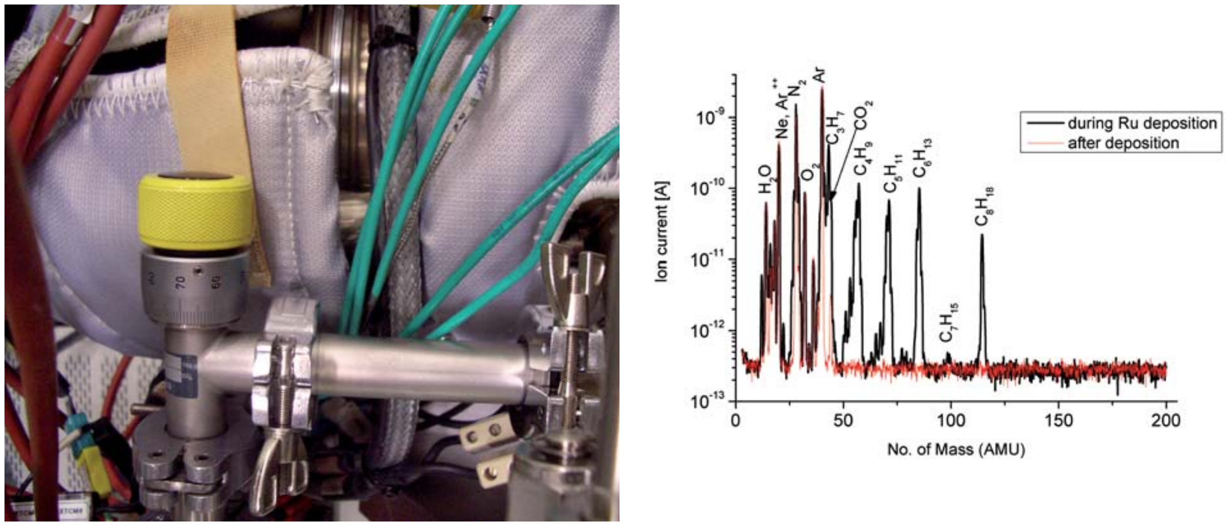


Figure 5. Image (a) shows integration of the optical emission spectrometer into a 300mm mini-batch plasma furnace for thin-film deposition. The graph in (b) shows the coincidence of the emission spectra measured at the upper and lower electrode position for optimized plasma homogeneity.


VarioLoad
InTex



(a) (b)

Figure 6. Adaptation of the mass spectrometer port to a flange of the MOCVD reactor (a). The graph in (b) depicts the mass spectrum of the precursor and carrier gases during ruthenium deposition and on completion of the process.

composition. Exceeding the target lifetime may also result in contamination of the deposited layer by sputtering the backing plate.

There are several options available to help monitor the target erosion state, including modelling the target erosion by using equipment data like operating hours and RF power. However, a direct measurement of the target erosion is advantageous and more accurate. To this end, a measurement system based on the principle of laser-triangulation was developed for the assessment of new equipment for linear dynamic magnetron sputtering. The measurement system was adapted to a viewport and enables the profile analysis of the sputter target surface and the determination of the surface erosion, which is not visible to the operator (see Fig. 4). By means of the measurement system, it is possible to control the process parameters based on the current target profile. The application of end-point control enables the optimum usage of expensive target material. With a resolution of 0.1µm, the measurement system is capable of reducing the safety margin in target thickness for the prevention of contamination to a third of its former value. Given the extremely thin targets used by the tool, this could result in savings of up to 5-10% of target material as well as a significant reduction in downtime and maintenance effort.

Example 2: Control of homogeneity and plasma composition

A frequent problem in plasma processing is the control of plasma composition and plasma homogeneity, especially in large-volume reactors. Multichannel optical emission spectroscopy (OES) is a powerful measurement method of controlling these parameters. In OES, the light spectrum emitted from the plasma is analyzed and the chemical species in the plasma are identified from the characteristic emission lines. By comparing the spectra at different locations in a reactor, the homogeneity of the plasma may be controlled.

A low-cost OES system was applied in a two-channel configuration to support process development for a new 300mm mini-batch plasma furnace for thin-film deposition, as shown in Fig. 5a. An innovative solution for spectrometer integration was developed to measure the spacing of a stacked electrode assembly. Light from the plasma was guided to the spectrometer through quartz rods, applying the principle of total internal reflection. The spectrometer controls were fully integrated into the furnace control software. By applying an advanced algorithm for spectrum analysis, the plasma generated by two different plasma excitation sources could be optimally adjusted and controlled in composition and homogeneity vs. the reactor volume using one key number. Fig. 5b shows the comparison of the spectra of an N_2/NH_3/He plasma recorded at the upper and lower electrode and with optimized homogeneity of the plasma composition.

The measuring plasma composition and uniformity approach can be easily transferred to other plasma equipment. The advantage for an established process is that the plasma composition that directly influences layer thickness and composition can be controlled in real time. Deviations in the plasma composition and uniformity may be easily detected, preventing misprocessing of subsequent wafers. Enormous cost savings can be achieved if the approach is applied during process development. Further processing of device structures is necessary to assess electrical layer properties and homogeneity of processing for the deposition processes described here. Using this OES solution over two days, a total of 400 process settings were investigated from which 10 processes were selected for further process assessment on device structures.

Example 3: Process stabilization and cost optimization in chemical vapour deposition (CVD)

An important issue during process development and actual processing is to achieve stable process conditions at optimized cost. An important factor in many processes is the avoidance of overhead process times and the reduction of precursor or gas consumption. In order to maintain the process results, while addressing these objectives, precise process knowledge is vital. The application of integrated metrology supports these objectives since important process parameters can be measured directly on the equipment. For example, a deposition module for pulsed MOCVD was optimized for deposition of thin ruthenium films applying mass spectroscopy which was integrated in the MOCVD module (see Fig. 6a). By integrating mass spectroscopy, the stabilization times and precursor injection parameters were optimized for the complex deposition processes, which consist of a sequence of single steps.

Fig. 6b shows the mass spectrum taken during a ruthenium deposition process with N_2, O_2, Ar, CO_2, H_2O and octane with its fragments, which serves as a measure for the precursor in comparison to the remaining gas composition that is present after completion of the deposition [2].

"An important factor in many processes is the avoidance of overhead process times and the reduction of precursor or gas consumption."

By simultaneously measuring the concentration of the reactive species in the reactor, important deposition mechanisms can be investigated and optimized gas and precursor flow settings can be derived. With optimized precursor and carrier gas adjustment and stabilization time, processes with optimized layer quality at optimized throughput can be achieved. For example, the process investigated here yielded a reduction of process duration up to 20% by optimized gas adjustment.

The role of standards in APC

To support the cost-effective application of metrology as both an enabler of APC and of actual APC systems, the semiconductor industry developed a host of standards covering different aspects of APC. SEMI (Semiconductor Equipment and Materials International, [3]) coordinates the elaboration, synchronization and distribution of standards both for semiconductor manufacturing and PV, some of which are mentioned here:

- Standards for APC:
  - SEMI E133 defines the capabilities of APC systems as well as their interaction between each other and the fab environment.
  - SEMI E126 defines commonly-used quality parameters related to the success of process runs, for individual equipment groups such as etch, CVD, deposition or diffusion.
- Standards for (integrated) metrology:
  - SEMI E127/E131 comprises specifications for communication and interface requirements for integrated metrology.
  - SEMI E141 acts as guide for the specification of ellipsometer equipment for use in integrated metrology.
- Standards for equipment automation, data acquisition and data quality:
  - A SEMI guideline defines quality of protocols, quality of data and test procedures for verification.
  - SEMI E5/E30 define the well-known 'SECS/GEM' interface for equipment communication; several standards (SEMI PR8/E121/E125/E132) specify the higher-performing 'Interface A' (often referred to as 'equipment data acquisition,' or EDA).

The so-called 'PV Group' at SEMI takes care of standards for the photovoltaics industry, particularly standards from the realm of equipment automation and process control systems that are already being (re-)used in or adapted for the photovoltaics industry. SEMI PV2, the Guide for PV Equipment Communication Interfaces, for example, builds on some of the aforementioned semiconductor standards.

Lessons learned and potentials of APC for PV

It is obvious that findings from the semiconductor industry cannot be reused like for like in the photovoltaic industry. Although both the processing schema and the cost schema are way too different to simply enable duplicate solutions, the principle techniques, methods and algorithms can be applied.

Thus some overall 'lessons learned' can be summarized that hint at the potential for APC in PV:

1. **Know your process**. A sound process understanding is required to identify the right quality parameters characterizing the quality of a product, to measure them and to build models and algorithms for sustainable APC control. As shown earlier, (integrated) metrology may help to deepen process knowledge.
2. **Use data you already have**. In each fab, a huge variety and number of data are available – from sensors and metrology to equipment and logistics. Before adding new data sources, it is better to link existing ones to allow full extraction of information.
3. **Keep things simple and inexpensive**. In the examples discussed, it was shown that the quick integration of a mass spectrometer fostered process understanding and allowed for an optimized process setting. 'Inexpensive' is certainly a different absolute figure in different processing environments, but one should be aware that a simple sensor can suffice in place of a full-featured set of metrology equipment for the measurement of one important quality parameter and setting up an APC capability.
4. **Go for low-hanging fruits**. As for most things in life, the 80:20 rule holds also for APC – experience shows that for the final 20% of solutions, 80% of the effort has to be spent. Thus, it is better to start with well-understood processes and problems, implement simple sensors, use linear algorithms, etc., and then build on the success achieved with those solutions.
5. **Make use of standards**. Smart people have invested a lot of time in thinking out scenarios and requirements. Using standards wherever possible helps to keep things complete and to keep implementation costs low due to the use of compliant and exchangeable IM/APC entities.
6. **Take care of data quality**. Every control action is only as good and as reliable as the data flowing into it.

Up to now, one could argue the necessity of implementing APC into photovoltaic production processes. Many claim it is semiconductor centred and too costly. But discussions on high-cost also plagued APC in semiconductor manufacturing from the very beginning – and today, every fab has APC applications implemented in its production flow. Indeed, the changing political and economical environment, paired with increasing technological demands and shrinking process windows (e.g., PVD or CVD thin multi-layer deposition, high temperature anneals, or patterning by laser scribing) also inherent in PV will see APC become a tool of ever-increasing importance to keep production cost low and yield high.

Specific, cost-efficient APC solutions for PV will be developed and applied, since many of the more expensive solutions from semiconductor manufacturing cannot simply be reused. But the transfer of APC from semiconductor manufacturing to PV production is not a one-way street: many of the smaller European semiconductor manufacturers have begun to ask for cheaper APC solutions than those applied by the big high-volume manufacturers. Thus, a huge field of joint development, networking and interlinking in APC with sharing efforts and sharing cost may yet evolve here.

Acknowledgment

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Silicon solar cell fabrication in a CMOS line

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ABSTRACT

Solar cells are generally built in a process facility, often a turnkey line, where high throughput, minimum handling, and lowest cost are dominant factors. There are many complementary metal oxide semiconductor (CMOS) lines in the semiconductor industry – probably more than the number of turnkey lines – where yield, reliability, and device size and complexity are major issues, where millions of chips are made with very close tolerance, and the cost of importance is that of the finished chip. The possibility of using or converting a CMOS line for building Si solar cells has been considered by many in the past [2]. These lines have advantages such as sophisticated and highly developed automated equipment, frequent in-process metrology and quality control, and a high degree of flexibility as well as highly advanced shop floor control systems. The major disadvantages are cost and low throughput. This paper will discuss the differences, advantages, and disadvantages of CMOS and turnkey lines and show preliminary results for Si cells made in the CMOS line.

There are major differences between CMOS processing and turnkey processing, beginning with the starting material and including junction formation, electrode deposition, dielectric coatings, furnace processing, and the use of metrology. At IBM, a CMOS line has been used within the Research Division to explore typical CMOS processes as applied to building solar cells, studying techniques for enhancing the performance, and extending these enhancements to multicrystalline starting material.

Line comparisons

While many similarities exist between CMOS and conventional solar cell fabrication lines, there are also significant differences. Fig. 1 shows a step-by-step comparison of CMOS and turnkey processing as used for CMOS fabrication (left) or solar cell fabrication (right).

"CMOS lots are generally processed in batches of 10–25 wafers, and the starting wafers all meet high specification standards."

CMOS processes start with polished wafers, usually 8- to 12-inch diameter round, as described in Fig. 2. Texturing is not used, and wafers are optimized for majority carrier properties. This sometimes includes a 'denuding' step in which annealing under specified conditions causes oxygen to precipitate in a zone 10–20 microns below the surface. This precipitated oxide acts as a gettering region to reduce unwanted impurities from the wafer surface. CMOS lots are generally processed in batches of 10–25 wafers, and the starting wafers all meet high specification standards. Impurity densities other than intended dopants are low, in total below $10^{12}cm^{-3}$, but oxygen is high (>$2x10^{17}$ cm^{-3}) to allow the denuding. There are no cracks or scratches and the surface roughness is less than 0.2nm.

Turnkey processing starts with smaller wafers, usually 125 to 156mm squares, that are rough cut, requiring saw damage etch as a first step. Texturing is carried out by acid solution for multicrystalline substrates or alkaline for mono-Si. Oxygen content is also high but there is no denuding step as the entire volume of the wafer is involved in cell operation, and creating a zone of high defect densities is detrimental to cell operation.

The minority carrier properties are key – lifetime and diffusion length in particular, while the majority carrier properties are only of interest for setting the wafer resistivity. There is a considerable variability in the starting wafer properties; impurity content, dislocation densities, and grain morphology vary across the wafer and along the ingot, and this variability contributes to the necessity of 'binning' of finished devices by efficiency categories. Impurity contents are several orders of magnitude higher than in CMOS wafers.

In CMOS lines, junctions are provided by ion implantation, generally phosphorus (but sometimes arsenic) for n-type layers and boron for p-type. Fig. 3 outlines features of ion implantation (I/I). Implantation is an expensive process but has significant advantages. Almost any desired element can be implanted and both the depth and dopant concentration can be independently controlled. A given element can be implanted using different species and ionizations such as B^+, BF_2^+, or BF_2^{++}, etc. The implant also causes 'damage'

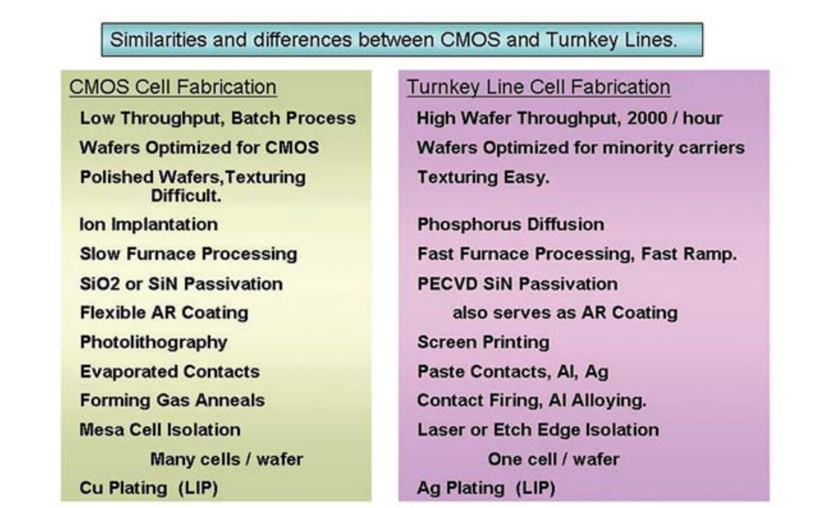

Figure 1. Comparison between CMOS and turnkey processing for fabricating Si solar cells.

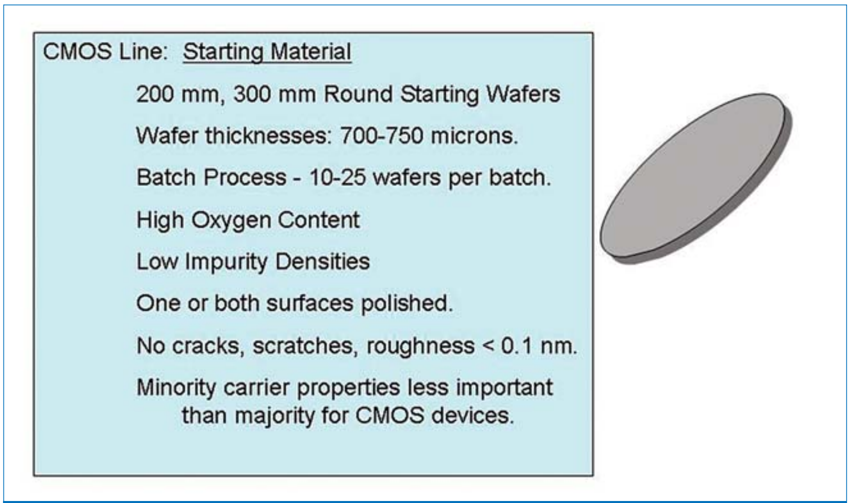

Figure 2. Properties of wafers used in CMOS processing.

in the form of displaced host atoms, and the implanted dopant does not 'sit' properly on substitutional sites, so a high temperature annealing is used to activate the dopant and minimize the damage. This can be furnace annealing or RTA (rapid thermal anneal), yielding a relatively low throughput. Selective emitter processing is straightforward using different doses and energies, but patterning is required to differentiate between the n^+ and n^{++} regions. Etch-back processes can also be used to create the selective emitter as is often carried out with diffused emitters.

> "Dielectric coating technologies are one of the advantages of CMOS facilities."

Ion implantation can be adopted directly for solar cell fabrication, but the high cost and lower throughput prevent its widespread use. By contrast, emitter diffusion is fast and relatively low in cost, using $POCl_3$ or H_3PO_4 as phosphorus sources. Throughputs of several thousand wafers per hour are standard in turnkey lines. Dopant concentrations and depths are controlled by the dopant source and the high temperature/time of the diffusion, but are not as easily controlled as in implantation. Low cost and throughput are the major advantages of diffusion for solar cell build.

Furnace annealing in CMOS lines is used in many process steps such as dopant activation, silicide formation, and oxidation. However, conventional CMOS furnace processes tend to be slow, with slow ramp-up and ramp-down rates and lengthy dwell times at peak temperature, although rapid thermal anneal can be used for some process steps. Annealing is done in batches of 10 to 50 wafers and process times can be several hours. In turnkey lines, only the emitter diffusion involves a furnace, along with high-temperature contact firing near the end. These steps are usually continuous as opposed to small batches, resulting in the aforementioned thousands of wafers per hour.

Dielectric coating technologies are one of the advantages of CMOS facilities. CMOS devices utilize a variety of coatings, from SiO_2 and SiN to HfO_2, TiO_2, TiN, and others. A variety of deposition processes are available: LPCVD (low-pressure chemical vapour deposition), HPCVD (high-pressure CVD), PECVD (plasma-enhanced CVD), spin coating, evaporation and sputtering. There is great flexibility in the use of coating materials, thicknesses, multi-layer stacks, and deposition methods. On the other hand, turnkey manufacturers might argue that only PECVD of SiN is required. Nevertheless, improvements in anti-reflection and passivation might be obtainable making use of the greater flexibility and alternate dielectrics.

Contacts for CMOS processing are applied by e-beam and thermal evaporation or sputtering. These are relatively expensive and slow methods for applying metal coatings and a great deal of waste is encountered, since the metal layer is deposited over a wide area and not simply the desired contact areas. Photolithography is used to define the contact areas, requiring expensive optical equipment and multiple photoresist layer depositions and removals. The deposited metal layers are thin, generally less than 1 micron, and build-up of layer thicknesses to minimize sheet resistances is required. One advantage of contact processing with photolithography is that contact dimensions can be varied over a wide range, as wide as desired down to several microns in finger width.

An alternative being investigated is direct metal plating onto the device structures, and modern CMOS chips may utilize a mixture of deposition techniques and plating. These plating techniques are directly applicable for solar cell build.

Contacts in turnkey lines are made with screen-printing of Al and Ag pastes fired in RTA-like thermal processes. The Ag is fired through the SiN coating, while the Al is alloyed into the rear surface to form both a contact and a back-surface field (BSF). The grid pattern is formed by the screen. In CMOS manufacturing, there is no electrically active back contact, except in some cases for mounting purposes. However, ion implantation is easily adapted for rear surface processing, for example, implanting boron for the BSF in $n^+/p/p^+$ cells with a wide choice of doses and depths. Al or another metal would then be applied on top of the implanted BSF: Al is a common metal in CMOS processing, and alloyed Al to form the BSF would be easy to implement in CMOS lines.

Metal plating is common in both turnkey and CMOS lines. The plating, often light-induced plating (LIP), is used to build up the thickness of the screen-printed contacts for turnkeys and to increase the thickness or provide connections between contact

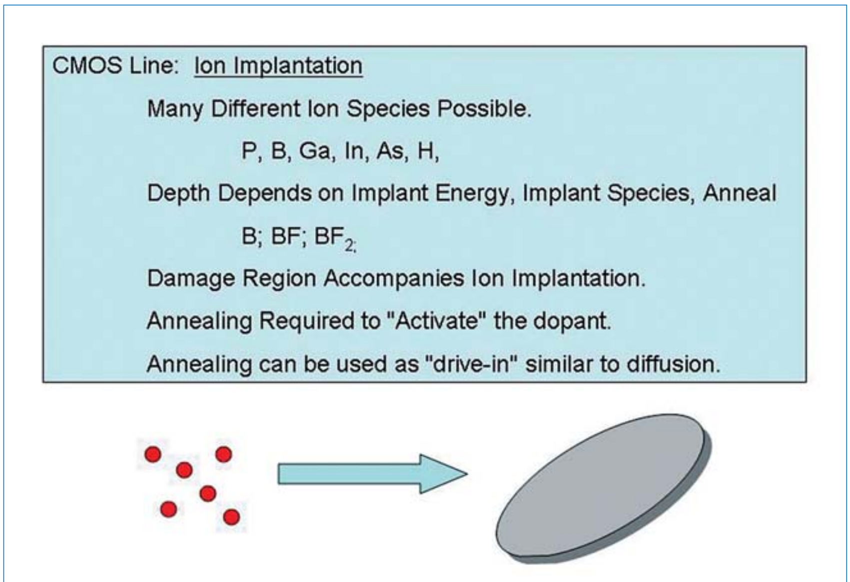

Figure 3. Ion implantation processing for CMOS and solar cells.

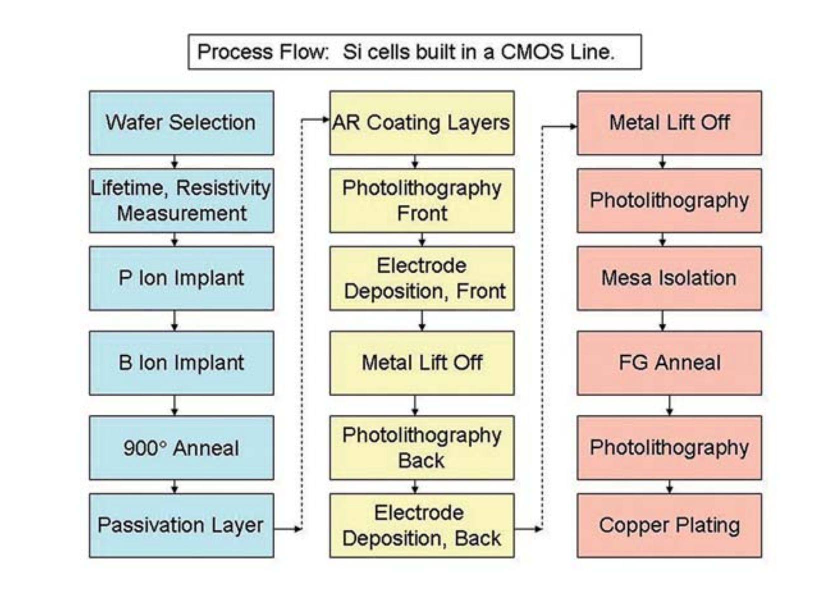

Figure 4. Process flow for fabricating Si cells in a CMOS line.

levels (M1, M2, M3, etc.) in CMOS devices. The success of metal plating in CMOS fabrication, particularly Ni, Ag, and Cu, can easily be extended to solar cell processing.

Another major difference between CMOS and turnkey lines is the use of metrology and statistical process control. CMOS manufacture makes use of extensive metrology at almost every step along the process. Starting material meets stringent resistivity, flatness, slip, surface roughness, and particle control, much of which is done at the wafer manufacturer. Single film thicknesses are measured by single wavelength ellipsometry or reflectometry and more complex layer stacks with spectroscopic ellipsometry. Sheet resistances are measured by scanning four-point probe or Eddy current mapping, surface roughness by AFM, and particle counts by optical scattering. Optical inspection is used at every critical process step, especially to inspect surface cleanliness after opening patterns in photoresist and dielectrics with RIE or plasma etch, which can leave polymer residues. Records are kept of thousands of key parameters of wafers and statistics are used to ensure process repeatability and integrity. Each wafer is identified by a unique code and traceability is of high importance.

“Sheet resistances are measured by scanning four-point probe or Eddy current mapping, surface roughness by AFM, and particle counts by optical scattering.”

Solar cell fabrication in turnkey lines generally uses less metrology in the interest of cost and throughput, and wafers presently have no traceability. Process control is addressed by the final cell results and their analysis, while wafer and process variability are manifested in the efficiency binning. The value and importance of wafer quality control and metrology techniques to assess quality is beginning to receive wider recognition [1].

Examples of process flows for fabricating solar cells in CMOS lines and turnkey lines are shown in Figs. 4 and 5. The major differences, as has been mentioned, are in the emitter junction formation, BSF formation, use of photolithography instead of screen-printing, evaporated or sputtered electrode material, and plating. Mesa isolation in CMOS processing is equivalent to edge isolation in turnkey processing. Differences also arise between different turnkey processes; some make use of $POCL_3$ diffusion sources and belt furnaces, while others utilize H_3PO_4 mists and batch furnaces, and edge isolation is carried out in different ways and at different stages. The phosphorus diffusion capability enables the use of gettering as an added process step in turnkey lines to improve starting material quality. Diffusion can be easily implemented in CMOS lines.

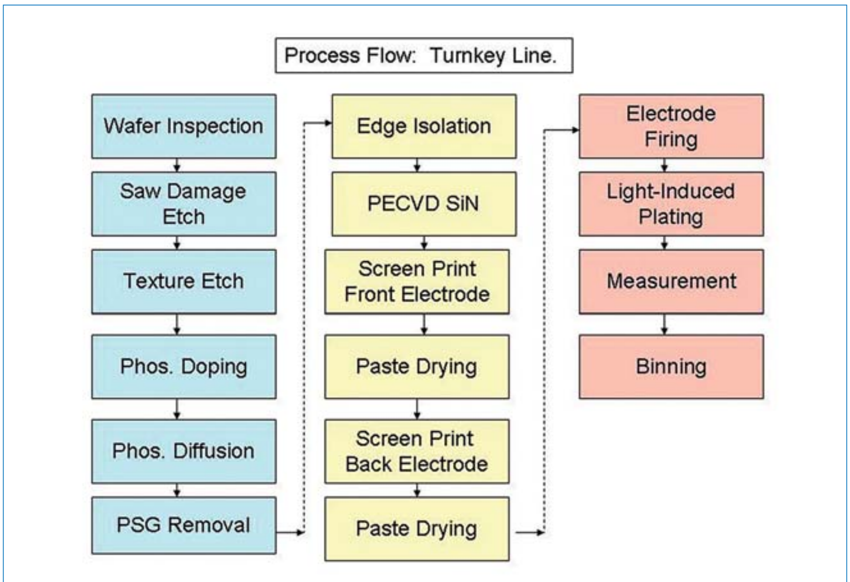

Figure 5. Process flow for fabricating Si cells in a turnkey line.

Wafer sources and process lines: a cost comparison

For assessing the costs of Si cells manufactured using a CMOS manufacturing line, a number of factors need to be considered. The first is what type of starting material will be used. Options include solar-grade square wafers, mono- or multicrystalline, UMG, or 'scrap' semiconductor-grade CMOS wafers. If scrap CMOS wafers are used, the wafers are nearly without cost as they would otherwise be thrown away or used as raw Si feedstock for new ingot build; in any case they are no longer usable for CMOS production. The second factor is tool usage according to manufacturing priorities in the CMOS line.

“The CMOS line may be converted to only solar cell build and the equipment may be fully depreciated by prior CMOS manufacture.”

If the line is to be used for both CMOS and solar cell fabrication, the solar production might bear some of the depreciation cost. However, the solar wafers can be loaded in front of the manufacturing tools, according to the process step to be applied, and wait until the tool is idle. Therefore, equipment depreciation is less of an issue, because this method helps maximize the utilization of the production machines which might otherwise lay idle.


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Alternatively, the CMOS line may be converted to only solar cell build and the equipment may be fully depreciated by prior CMOS manufacture. This is the most cost-effective scenario for using such a line for solar cell fabrication.

Cost estimates for solar cell manufacture have been carried out for scrap CMOS wafers where multiple cells are made on a wafer and used in CPV approaches, and for mc-Si and UMG square wafers with one device per wafer as standard in the industry. The process yield had been assumed to be 95%.

The wafer manufacturing cost for such a setup is shown in Fig. 6, making use of scrap CMOS wafers and converting into power output for 15% efficient devices. One wafer contains several hundred cells, each 1 x 1cm^2, adding up to around 8W per wafer at one sun. The volume build concerns numbers of wafers manufactured per year (125k wafers in the case of 1MW), with around 8W per wafer.

For round wafers with a 200mm form factor and fabricating 1 x 1cm^2 dies can yield around 500 dies per wafer; the cost per Wp for various efficiencies is shown in Fig. 7. The cost improves with increasing efficiency as well as increasing volume.

The cost per Wp is within the range of US$0.15 up to US$0.6 which is fairly low, especially at high volume build. The chart in Fig. 7 reflects the same assumptions as outlined earlier. The wafers have several hundred cells and the efficiency range used for cost calculation is from 15% up to 18%. These cells are used in single sun application for the purposes of calculation; as expected, the cost figures improve with increasing efficiency. The die and chip cost are shown in Fig. 8, where the dies are the individual cells cut from the wafer and the chips are the finished solar cells made from the dies.

Both the die and the finished chip (1 x 1cm^2 solar cells) boast attractively low costs. The power per die or chip ranges from 15.1mW up to 18.2mW for the 15% to 18% efficiency range. The chips can be used in CPV applications with proper device design to obtain much higher power output per cell, depending on the concentration ratio.

The approach as discussed is capable of providing solar cell devices from semiconductor scrap at very low cost ratios. The cells can be used directly in CPV applications or mini module designs. Mini modules, with a larger number of cells, would be assemblies created using the 1 x 1cm^2 cells. Module assembly must be performed using high automation and technologies such as pick & place and PCB (Printed Circuit Board) in terms of connections, etc. A typical flow from scrap wafer to solar wafer and finished die/cell is shown in Fig. 9.

The use of UMG material or regular solar-grade material such as multicrystalline wafers will cause the cost curves to move up due to the higher wafer material cost. Using UMG or solar-grade material estimates indicate that cost per Wp figures fall to US$1 and below; however, this does not take into account equipment depreciation. All facility and operational as well as material costs must be included in order to achieve a realistic calculation.

There are certain requirements that must be realised in order to be able to manufacture these wafers in a regular CMOS manufacturing line. Solar wafers, in this scenario, must be handled by the CMOS equipment and must be adapted for handling square wafers, possibly with different form factors. The related cost is considered in the calculations. Fig. 10 shows the cost estimate for solar-grade and UMG material at several efficiency levels, using a form factor of 156 x 156mm for the processing of the cells.

The highlighted area in Fig. 10 shows that processing solar wafers in a depreciated CMOS line using adapted handling can be profitable, especially in the case of high volume production.

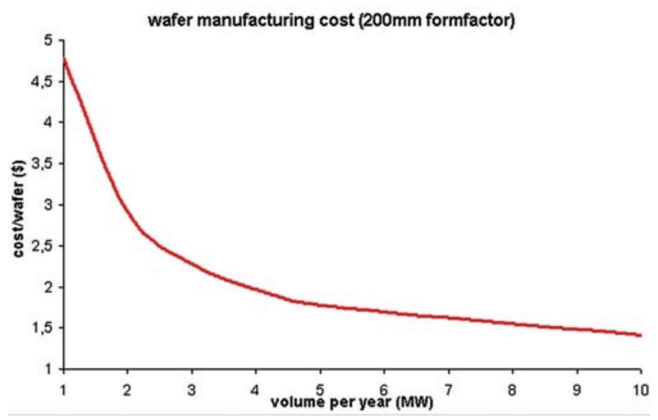


Figure 6. Wafer manufacturing cost curve vs. volume build.

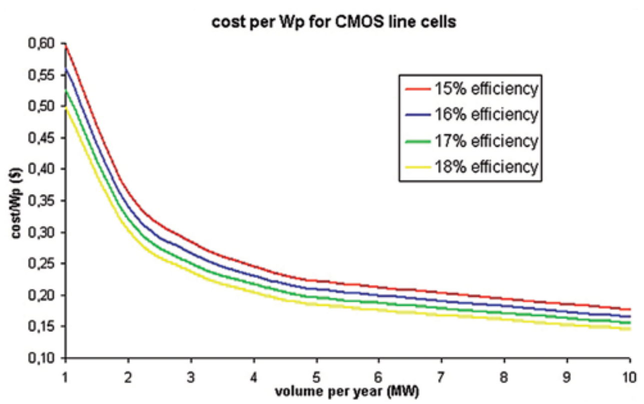


Figure 7. Cost per Wp vs. volume build.

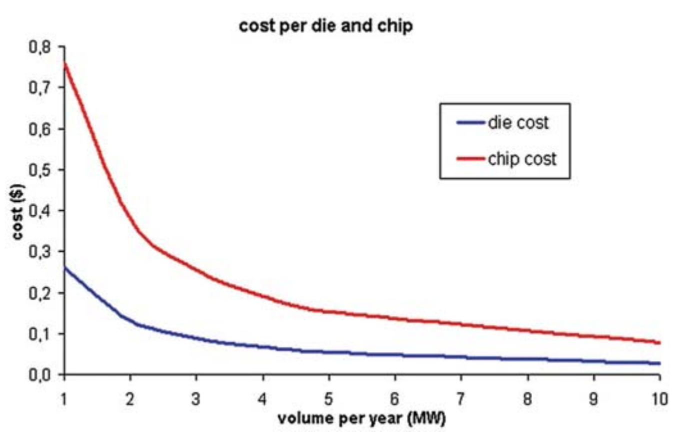


Figure 8. Die and chip cost curves vs. volume build.

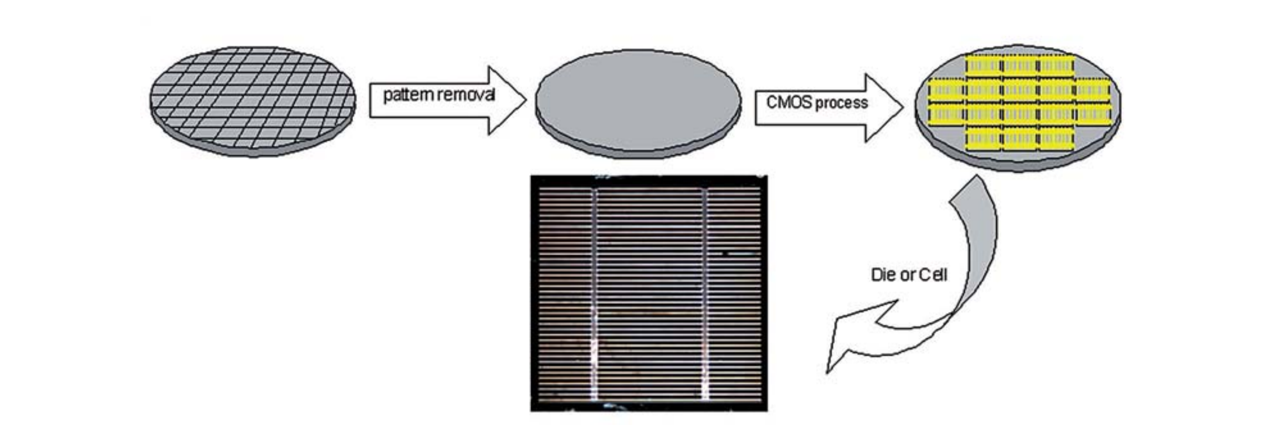


Figure 9. Typical flow in CMOS line from scrap to solar wafer.

Extension to thin solar cell processing and alternate cell structures

Thin solar cells take many forms, from thinner 'bulk' wafers to thin films of Si grown on glass, to amorphous Si and alternate materials such as CdTe, CIGS, and the new 'earth abundant material' cells known as CZTS (copper zinc tin sulphide).

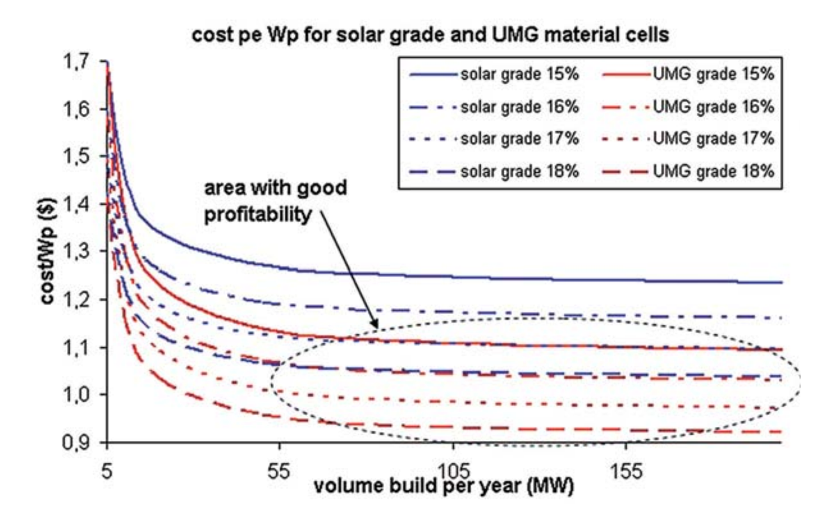
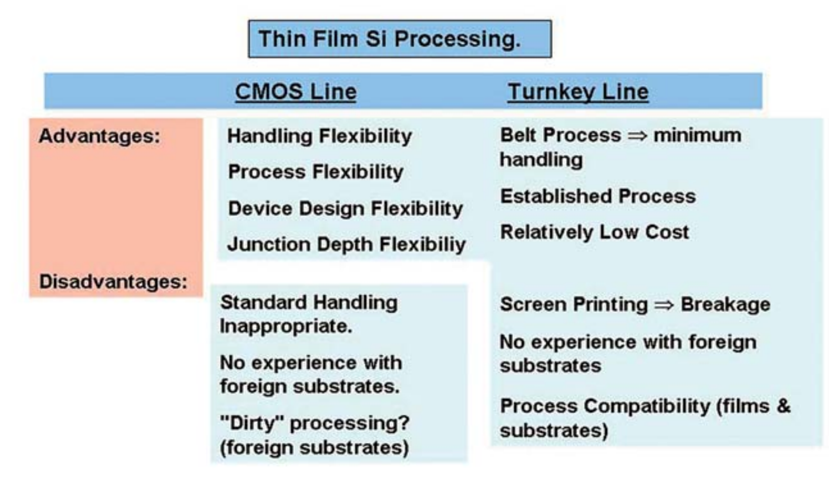


Figure 10. Cost per Wp vs. volume build for solar-grade and UMG material.



Thin Film Si Processing.

	CMOS Line	Turnkey Line
Advantages:	Handling Flexibility Process Flexibility Device Design Flexibility Junction Depth Flexibiliy	Belt Process ⇒ minimum handling Established Process Relatively Low Cost
Disadvantages:	Standard Handling Inappropriate. No experience with foreign substrates. "Dirty" processing? (foreign substrates)	Screen Printing ⇒ Breakage No experience with foreign substrates Process Compatibility (films & substrates)

Figure 11. Advantages and disadvantages of CMOS and turnkey lines for thin wafer processing.

Process differences also become more divergent, involving roll-to-roll fabrication, nanoparticles, electroplating, evaporating, or spin-coating the absorber material and other layers in the cells.

The closest use of CMOS lines to thin cell fabrication would be in thin bulk Si where wafers of 50 to 100 microns in thickness are of interest. Processing of thinner Si layers mounted on foreign substrates is also possible. Fig. 11 shows some of the advantages and disadvantages of thin wafer processing in CMOS versus turnkey lines; wafer handling becomes a major issue in this regard. Although CMOS processing wins points due to process flexibility, it brings with it the disadvantage that the industry has little experience with processing of Si films on foreign substrates where tool modification and/or redesign might be necessary.

Alternative substrates such as metal, glass or graphite would be inappropriate were the line to be used for both the fabrication of CMOS structures and solar cells. This situation would be acceptable if the CMOS line were being converted into solar cell fabrication exclusively. Turnkey lines are already established with a minimum of handling and tools have been optimized to be applicable to solar cell processing.

"Laser doping, laser contact firing, and low temperature deposition of dielectrics for passivation and AR coatings are valuable for both CMOS and turnkey lines."

But despite the advances, some issues are problematic for both types of lines, such as those processes that have been designed for Si wafers and for which there has been little experience of dealing with cells on foreign substrates. Some alterations are necessary when using substrates such as glass, especially under allowable temperatures for junction formation and contact firing. Laser doping, laser contact firing, and low temperature deposition of dielectrics for passivation and AR coatings are valuable for both CMOS and turnkey lines.

CMOS lines are easily extendable to alternate Si cell structures such as HIT (heterojunction), IBC (interdigitated back contact) and amorphous Si or tandem cells. The processes and equipment used

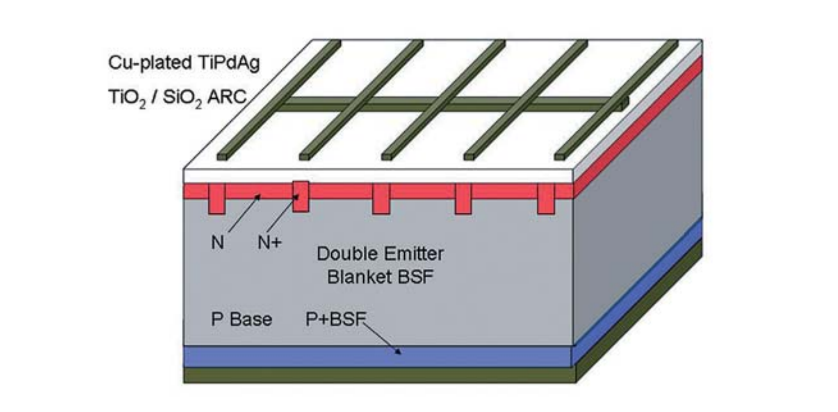


Figure 12. Device schematic, double emitter, blanket BSF device with thermal SiO2 passivation and high performance ARC.

to fabricate these cells such as PECVD and patterned junction formation are already available, while laser processing for monolithic integration can be readily implemented. The one missing piece for some structures in CMOS lines is TCO (transparent conducting oxide) deposition, but equipment such as CVD, sputtering, and spin or spray coating for the TCO is either straightforward to add or is already available.

Silicon solar cells built in a CMOS line – an example

For several years, Si solar cell research has been ongoing at IBM using the process sequence shown in Fig. 4. The starting material was 10Ω/cm p-type Si of 200mm in diameter and 700 microns thick, polished on one side and lapped/etched on the other. Wafers were selected for high minority carrier lifetime, which ranged from 400µsec to 1 millisec. Cells were made with either single or selective emitter ('double emitter' – DE) by phosphorus implantation, $1x10^{15}cm^{-2}$ dose at 10keV followed by 900°C anneal for 240 minutes. The BSF was made by $1x10^{16}$cm-2 boron implantation at 80keV. The n^{++} dose for the double emitter contact area was also implanted at $1x10^{16}cm^{-2}$. Passivation was accomplished by a 10nm thermal SiO_2 and the AR coating was a double layer of either SiN/SiO_2 or TiO_2/SiO_2. The contacts were evaporated Ti/Pd/Ag with 10 to 20µm finger widths. Forming gas anneals at 450°C were used to activate the contacts. LIP Cu plating was used to build the fingers and busbars to 10-15µm thickness; busbars were 200 to 300 microns wide. Cells were isolated by RIE which created device mesas 3 to 5 microns deep. Cell areas ranged from $1cm^2$ to $4cm^2$ but some cells were made that were up to $20cm^2$ in area.

Fig. 12 shows a schematic of the cells made in this line. Most of these cells were double emitter with implanted emitter and BSF regions but for comparison reasons, single emitters and devices without BSFs were also made, while AR coating materials were varied and substrate materials down to 1Ω/cm resistivity were explored. Low resistivity semiconductor-grade substrates tend to have high oxygen content for denuding so that lifetimes in the lower resistivity material suffer from the boron-oxygen recombination centre.

Fig. 13 shows the internal quantum efficiency of cells made with and without the double emitter but without BSF in both cases. The single emitter doping level was 30Ω/⊗ with a peak doping of around $1x10^{20}cm^{-3}$. The band gap narrowing, low Auger lifetime, higher surface recombination velocity (SRV) and reduced diffusion coefficient combine to significantly degrade the short wavelength response and increase the J_O (junction leakage current), lowering the V_{OC} by 20–30mV. In contrast, the double emitter was 150–200Ω/⊗ with a peak doping around $1x10^{19}cm^{-3}$, resulting in a flat response into the UV wavelength region.

The spectral responses of double emitter cells with and without a BSF are shown in Fig. 14. The effect of the BSF is clear from both the long wavelength response and the higher V_{OC}. On average, the BSF cells exhibited a 40 to 60mV higher V_{OC} than the non-BSF cells. Although the wafers are 700µm thick, the minority carrier lifetimes of 500 to 700µsecs in the finished cells result in an expected diffusion length of 1.2–1.4mm, allowing the BSF to participate in the cell output. The cells that have both DE and BSF exhibit nearly flat quantum efficiency throughout the visible wavelength range.

Currents as high as $40mA/cm^2$ have been obtained on these cells despite their lack of texturing and their highly polished surfaces. These high currents are a result of the use of high-performance double-layer AR coatings. Fig. 15 shows the reflectance spectra for SiN/SiO_2 and TiO_2/SiO_2 coatings. Simulations were used to optimize the thicknesses of the various dielectric layers. The SiN-based coatings average around 8% reflection over the solar spectrum below 1.1 micron wavelength while the TiO_2-based coatings average 4.9% over that range. The TiO_2-based coating has particularly low reflectance in the near IR just below the Si bandgap and in the visible down to blue wavelengths. The absorption loss due to the TiO_2 increases below the 0.35 micron wavelength where there are few terrestrial solar photons.

As this paper's aim was to investigate the properties of Si cells made with 'standard' CMOS processing, many experiments were carried out with and without DE and BSF, using different passivation methods, different AR coatings, and different contact methods (evaporation, sputtering and plating). Fig. 16 shows the results of a few of these runs, with particular emphasis on the AR coating options. The effect of the DE and BSF are clearly seen in improved V_{OC} and J_{SC}, while some variability appears in FF due to series resistance differences. The benefit of the higher-index TiO_2 coating (index µ 2.5) is also clearly seen. The main factor limiting the efficiency is the low V_{OC} value, which may be a consequence of damage or impurity inclusion during the implant. V_{OC}s as high as 0.625 were obtained in some devices at 25°C, probably 50mV less than expected. The use of diffusion, thinner wafers, and damage-/contamination-free implantation would raise these values.

Simulations using PC1D modelling have proven a good match to the cell results. Fig. 17 shows tables, charts, and graphs for the modelled and experimental results and displays reasonably close correspondence between the two. The model predictions of the benefits due to the DE, BSF, and improved AR coating are demonstrated in the cell results.

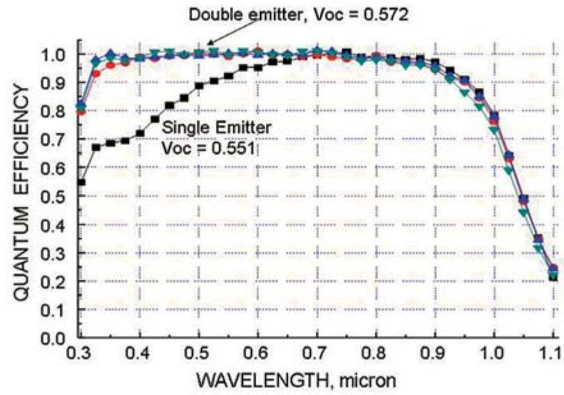


Figure 13. Internal quantum efficiency of single and double emitter (DE) Si cells with no BSF.

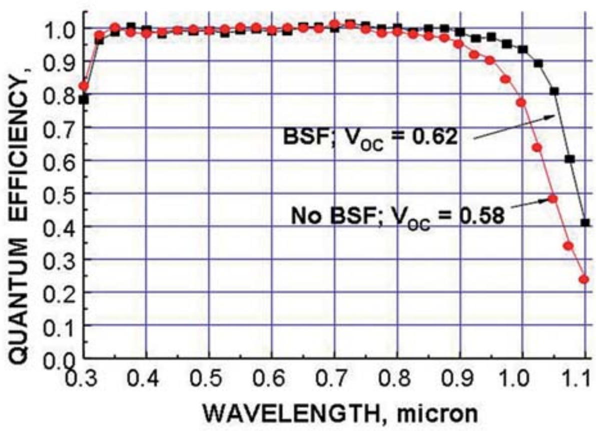


Figure 14. Internal quantum efficiency of double emitter Si cells with boron-implanted BSF.

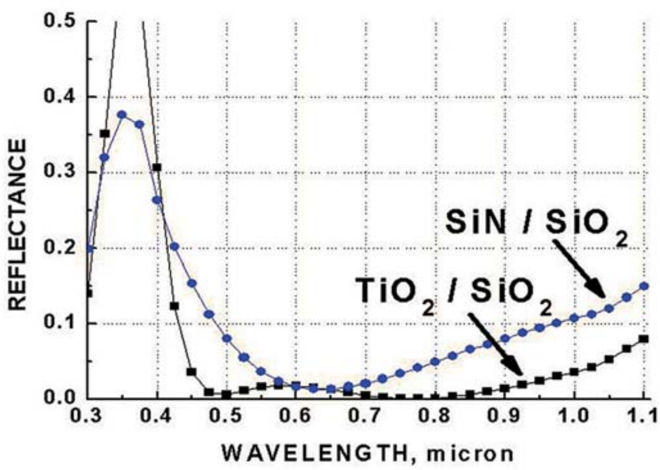


Figure 15. Reflection spectra of SiN- and TiO_2-based antireflective coatings.

The modelling can be used to predict the cell performance for devices manufactured in a regular semiconductor CMOS line, while advancements like the BSF, various passivation layers, selective emitter etc. can also be modelled, which helps the manufacturer to estimate future benefits and to determine if the advancement is beneficial in terms of cost and performance. A combination of the performance modelling with the regular cost estimation can yield a realistic cost analysis.

Evolution of CMOS lines to solar cell fabrication

CMOS lines have many advantages that make them suited to solar cell fabrication, including starting wafer quality control, precise and reproducible processing, a high degree of automation, extensive use of

Some Thick Film Si Solar Cell Results from a CMOS Line.

Device Lots with SiN/SiO_2 AR coating.

Device	Voc	Isc	FF	Effic.
SE, no BSF, SiN	.56	34.3	.78	15
SE, BSF, SiN	.605	35	.77	16.2
DE. BSF, SiN	.605	35.5	.78	16.8

Device Lots with TiO_2/SiO_2 AR coating.

Device	Voc	Isc	FF	Effic.
SE, no BSF, TiO2	.54	35.9	.74	14.3
SE, BSF, TiO2	.60	37.4	.77	17.5
DE. BSF, TiO2	.605	40	.75	18.1
DE. BSF, TiO2	.605	39.8	.775	18.7

Figure 16. Si solar cell parameters for cells with various processes and coatings.

PC1D modeling shows good match to device parameters measured

Device	Voc	Isc	FF	efficiency
SE, no BSF, SiN	0,56	34,3	0,78	15%
modelled	0,5582	36,2	0,742	14,99%
SE, BSF, SiN	0,605	35	0,77	16,20%
modelled	0,5909	37,8	0,7536	16,45%
DE, BSF, SiN	0,605	35,5	0,78	16,80%
modelled	0,6048	38	0,7454	17,13%
SE, no BSF, TiO2	0,54	35,9	0,74	14,30%
modelled	0,5554	38,1	0,7328	14,59%
SE, BSF, TiO2	0,6	37,4	0,77	17,50%
modelled	0,5927	39,5	0,7452	17,44%
DE, BSF, TiO2	0,605	40	0,75	18,10%
modelled	0,6068	40,1	0,7459	18,15%

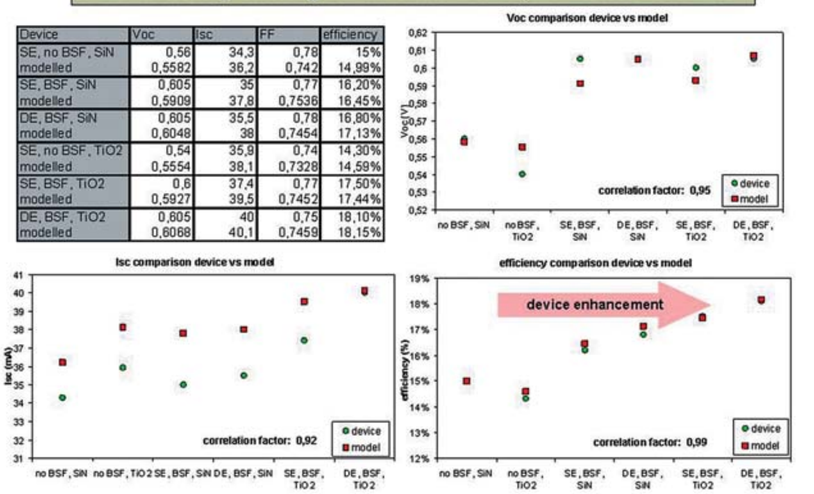


Figure 17. Comparison of experimental results and modelling with PC1D.

metrology, and highly developed process equipment. However, the adaptation of a CMOS line to cell fabrication requires a paradigm shift, as outlined in Fig. 18. Turnkey line cell manufacture could also benefit from several of these steps, but would require attention to such factors as acceptable cost per Wp, throughput, reduced binning distribution, and higher peak efficiency to ensure success.

The starting wafer variability is one of the key weaknesses in modern cell manufacturing, especially for cast multicrystalline wafers. Grain size, dislocation densities, resistivity, and impurity densities all vary from wafer to wafer and across the wafer, resulting in variability in minority carrier lifetimes, diffusion lengths, and shunting events such as conducting 'pipes'. Lifetime, diffusion length, and resistivity maps using photoconductivity decay, photoluminescence and eddy currents can show both the non-uniformities and the absolute values, allowing sorting of starting material and rejection of material which is sub-par [3].

> "The biggest paradigm shift would be in the furnace processing, where an in-line continuous wafer flow is considerably different from today's batch furnaces."

CMOS lines will have to adopt diffusion as the junction formation technology for the emitter and possibly for the BSF, though laser doping for LBSF (local back-surface field) could also be applied (as well as for the heavily-doped selective emitter regions). Adoption of phosphorus diffusion opens up the possibility of gettering for wafer improvement, which is useful for both line types. To maintain high throughput, gettering could be incorporated as a separate wafer preparation step prior to initiating the wafers into the line. Boron diffusion could be used for enhanced BSF compared to Al alloying; however, the low boron diffusion coefficient might require very high temperatures incompatible with the higher impurity levels in mc-Si wafers.

CMOS automation is presently set for round, thick wafers of 200 to 300mm in diameter. The line would have to be reconfigured for square wafers of 125 to 156mm on edge – these wafers are far thinner and more fragile, and wafer breakage of some fraction is inevitable. Any equipment would have to be able to withstand these broken pieces without incurring damage or reduced throughput.

CMOS lines are well equipped for dielectric layer deposition, notably PECVD SiN, and once equipment specifically designed for continuous wafer flow rather than batch fabrication is introduced, there would seem to be no barrier to entry for these dielectric deposition steps. The biggest paradigm shift would be in the furnace processing, where an in-line continuous wafer flow is considerably different from today's batch furnaces. Again, an equipment change would allow continuous flow, applicable also to etch and cleaning baths, which are now set for batch processing in CMOS lines.

Electrode deposition using plating would most likely be straightforward in CMOS, given that plating is already extensively used. Patterning that is now carried out with photolithography can be easily carried out by a variety of techniques including inkjet printing and stamping. Ni, Ag, and Cu plating are widespread in the semiconductor industry.

Laser processing is easily adopted into both CMOS and turnkey lines, with laser doping for both the selective emitter and the local BSF fast becoming well established. Benefits of laser applications include fast throughput, low wafer breakage, and self-patterning where the laser patterning is controlled by software and no physical patterning layer is required. The thermal budget is also reduced, lowering cost, improving the energy balance, and preventing temperature-induced changes in the wafer bulk.

It should come as no surprise that a CMOS line adapted for solar cell manufacture begins to look like a hybrid of a turnkey line. Many of the features of turnkey lines have to be utilized in CMOS cell manufacture in order to make it cost effective, especially those items which

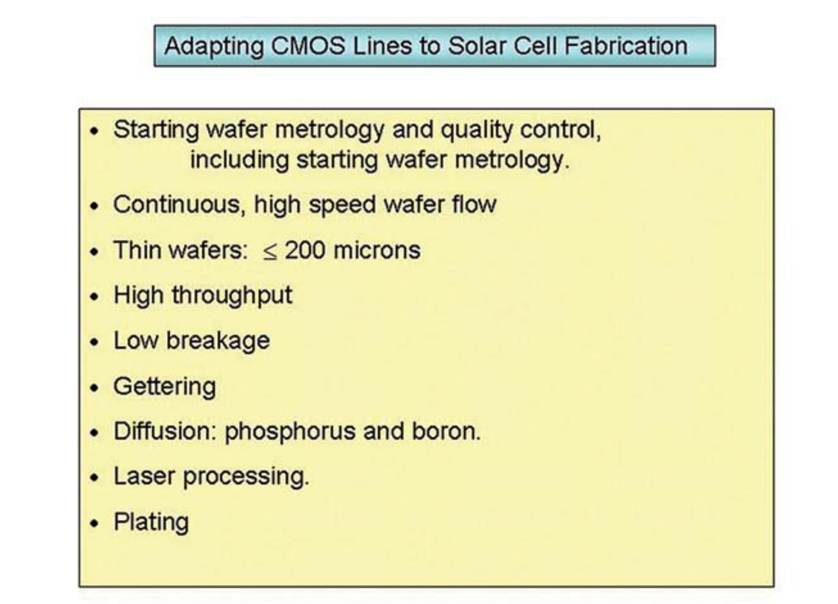


Figure 18. Conversion of CMOS lines for solar cell manufacture.

increase throughput and provide continuous wafer flow. However, features of CMOS manufacture such as starting wafer quality and selection, higher use of metrology, statistical process control and advances in automation would result in benefits to finished cell efficiency, binning distribution and average efficiency. A careful look at all the advantages and disadvantages of adapting a CMOS line to cell manufacture should be carried out with the goal of reaching an acceptable and hopefully reduced cost per Watt. A hybrid of CMOS and turnkey lines would incorporate the best features of both.

Conclusion

Similarities and differences between CMOS lines and turnkey lines as used for solar cell manufacture have been described in this paper. Both equipment and processing alternatives would need modification for large-scale Si cell fabrication in CMOS lines, with goals of greatly increasing throughput, accommodating the use of thin square wafers in place of thick round ones, and adapting processes and techniques that result in enhanced efficiency. CMOS lines and procedures such as starting wafer quality assessment and control and metrology for statistical process control could reduce binning distribution and increase average efficiency. Cost estimates suggest acceptable cost levels for Si cell technologies using scrap CMOS wafers for fabricating cells for low level CPV applications, or square form-factor solar and UMG-grade material using fully or nearly fully depreciated CMOS lines. The optimum process facility and set of procedures would make the best use of both CMOS and turnkey line features, adhering to the ultimate goal of high throughput and low cost per Watt.

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Mainstream c-Si metallization process developments and cost reduction strategies

Mark Osborne, Senior News Editor, *Photovoltaics International*

ABSTRACT

A recent spate of solar cell efficiency gains and record results underline the continued efforts to boost conversion efficiencies, which are at the core of reducing cost-per-watt goals. However, bringing such technology into the mainstream volume production world at little or no increase in manufacturing cost will prove more challenging. This paper takes a look at the current mainstream c-Si cell metallization efficiency developments that are starting to enter volume production with a promise of 20% cell efficiencies and low manufacturing costs.

Although many exciting and novel cell concepts are currently under development, volume cell manufacturers have to take a more cautious route to market, ensuring efficiency improvements are in line with cost reduction strategies. Key concerns also include yield, repeatability, and overall uniformity, amongst others. As many producers are now reaching 1GW+ in annual cell production volumes, being able to integrate new process steps to boost cell efficiencies with minimum disruption and increased cost are vital.

Only a handful of cell manufacturers that are in production have reported c-Si cell efficiencies above 18%. The market leader is SunPower with commercial-scale cell efficiencies now topping 22% with its Gen 2 offering. As recently as June 2010, SunPower announced a new world record – verified by NREL (U.S. Department of Energy's National Renewable Energy Lab) – with a conversion efficiency of 24.2%. The new record efficiencies highlighted that SunPower has been able to increase its cell efficiencies by a full four percentage points over the last five years.

While SunPower may claim the highest commercialized cell efficiencies, its relatively low production volumes (398MW in 2009) and high manufacturing costs – relative to its mainstream rivals – highlights the challenges many manufacturers could face should they pursue a similar technology route.

SunPower claimed that its goal was to see the cost per watt reduced by more than 35%, from approximately US$0.85/W to less than US$0.55/W in 2014, when the fab is fully ramped. These manufacturing lines are expected to be producing SunPower's Gen 3 cells by then, with industry analysts projecting US$1/W by 2014.

Concerns were also raised this year with Suntech's difficulties in ramping its proprietary 'Pluto' cell technology with 19% cell efficiencies, even though it was developed so that it could be retrofitted into existing manufacturing cell lines. The company had stated in the first quarter of 2010 that it was limited to a 4MW per month ramp rate, far below its own previous ramp projections. Suntech is said to be using copper rather than silver paste contacts.

Standard cell developments: front side

Significant effort is being focused on conventional or 'standard' cells via technologies that can be introduced into volume production at low cost and yet incrementally boost cell efficiencies. Not surprisingly, various 'low-hanging fruit' approaches are proving popular.

> "Migrating to ever-smaller line widths can boost cell efficiency, enabling a larger surface contact area."

As the front-side conductor is responsible for absorbing light and generating most of the electrical carriers, migrating to ever-smaller line widths can boost cell efficiency, enabling a larger surface contact area. A shallow emitter will also reduce shading on the front side, also improving absorption.

Work has been ongoing to provide low contact resistance while obtaining high conductivity, especially on larger substrate sizes. However, this requires improved paste characteristics to achieve improved cell efficiencies.

The Photovoltaic Business Unit of Heraeus has recently developed a new front-side silver paste (SOL9235H) that is cadmium-free and claimed to offer higher efficiencies along with superior contact quality and aspect ratios on both mono- and multicrystalline wafers.

Andy London, Heraeus's Global Business Unit Manager, noted: "Everyone wants to see higher efficiencies out of the silver paste regardless of the type of cell being produced. This doesn't matter even if it's a high ohmic emitter with a much narrower pressure window, requiring paste to have a wider process window. We develop little variations in the paste for required variations in aspects such as vapour deposition and diffusion for example. But better and better contact resistance is also wanted."

Not surprisingly, London also noted that customers wanted to find ways to reduce the consumption of silver paste and for less expensive derivatives to be developed. Collaborations across multiple areas were ongoing to meet the individual needs of customers that are being dictated by the different cell designs and process requirements. He also noted that matching R&D efforts with customer needs is a key ongoing endeavour, especially with five or six different cell approaches – and that's just in the mainstream.

London believes standard cell efficiencies could be at 20% by the middle of 2012, given the current paste and process developments. He was also quick to reiterate that developments in furnaces and screen printers had contributed considerably to these efficiency gains led by tight distribution characteristics.

"We have customers in production right now that have cell efficiencies of 18.8 and above with distribution above 19%. Looking back only 18 months, cell efficiencies were no more than 16%", added London. "We feel we have contributed in that movement to higher efficiencies."

Optimized for high-throughput processing, Heraeus introduced the SOL953, which provides fine line (80–150µm) resolution. It is designed to

easily penetrate the SiN_x:H anti-reflective coating during the firing process and provides low contact resistance. SOL953 can be co-fired with commercially available backside Al and Ag/Al pastes. Heraeus claims that customers who tested this new front-side paste during the development and scale-up phase reported increases of cell absolute output efficiencies in the 0.2 to 0.4% range.

Further developments in narrower line widths are ongoing. Heraeus is seeing lines of 20µm and below being printed in the lab, but a key challenge is repeatability and speed for high-volume applications. London explained that as the lines get narrower, the aspect ratio needs to get higher as conductivity of the line will control the efficiency.

"It would not be possible to obtain shallow emitters currently in use without the developments achieved with solar pastes, in particular our PV 159 offering", commented Patrick O'Callaghan, Global Technology Manager, DuPont Microcircuit Materials. "Now we see reducing contact resistance on the wafer is a very important issue for customers as narrower contacts are required. We have therefore continued to advance the technology on aspect ratio and contact resistance, particularly over the past five years."

> "The industry wants a 20% cell using conventional tools and processes before more 'exotic' steps and cell designs are really required."

O'Callaghan noted that with high aspect ratio printing, a thick print in one pass is now possible, which allows for lower grid line resistance due to additional metal deposited. The increased lay-down allowed for finer lines, leading to an equivalent usage and improved cell efficiency. He added that many customers are now printing 70µm finger lines.

DuPont's recently introduced Solamet PV16x series photovoltaic metallization pastes are claimed to provide up to 0.4% greater efficiency. The enhancements are achieved through advanced chemistry which provides lower contact resistance to the Si, as well as via reduced bulk resistivity of the paste, which yields higher gridline conductivity.

According to O'Callaghan, the industry wants a 20% cell using conventional tools and processes before more 'exotic' steps and cell designs are really required. DuPont has a roadmap employing an arsenal of developments that it hopes could meet this need for the mainstream sector of the industry. The most promising concepts for rapid adoption are selective emitter, N-base technology, rear-surface passivation and back-side metal contact technologies. Although these require new steps, they retain conventional tool technologies. The company's new front-side thick-film technologies include the following characteristics and applications: lower contact resistance pastes (0.3-0.5%); lower grid-line resistance; high aspect ratio printing (0.2-0.3%); double printing (0.3-0.4%) and improved fine line capability (0.3-0.5%).

Selective emitter double printing

There appears to be little rush to replace screen-printing, a much-proven technology with the ability to deliver high precision alignment, low breakage rates while operating at high wafer throughput levels. The move to selective emitter double printing is an attractive path that cell manufacturers want to tread.

A selective emitter addresses the blue light response of the cell. Changing the profile with lower surface doping concentration can generate meaningful efficiency gains.

In order to keep losses caused by series resistance low, fine-line printing is required to produce a denser grid of fingers if shading losses are to be avoided, a process that is carried out in two steps: thin seed layer printing and the subsequent light-induced silver plating step. Improvements in screen-printer alignment in recent years are key contributors to the adoption of this emitter design.

Another advantage of double printing is that it gives the silver metallization paste suppliers the opportunity to optimize for both steps, rather than making the necessary compromises required with a single printed thick paste.

"The first print needs to be as narrow as possible requiring excellent contact resistance. The advantage of double printing from a paste perspective is the ability to optimize the paste just for contact resistance characteristics. With the second contact print, as the paste is going onto a dry film, very little spreading results, delivering a very smooth print and a film that is optimized for conductivity", remarked Heraeus' London.

"With the bus bar and finger line processes separated, further optimization of the material can be achieved", added DuPont's O'Callaghan. "We will very soon be launching pastes specifically optimized for double printing. If done in the optimal way, double printing could give between 0.3-0.4% in efficiency gain."

However, companies such as Applied Materials with its Baccini-based Esatto platform have claimed as much as 0.46% absolute cell efficiency gain with double printing, data gathered directly from customers' evaluation work with the technology. Indeed, Applied claims that an extra benefit due to the optimization of metallization pastes is the potential to achieve a 14% reduction in material consumption. They have claimed that the combination of higher efficiency and reduced material expense is projected to lower manufacturing cost by over US$0.03/W and deliver a return on investment in as little as eight months.

In a production environment, their double-printing technology allowed the replacement of single 120µm-wide lines with two-layer, double-height lines less than 80µm wide on the finished cell with multiple layers of different materials overlaid and better than ±15µm repeatability. Of course, with the focus

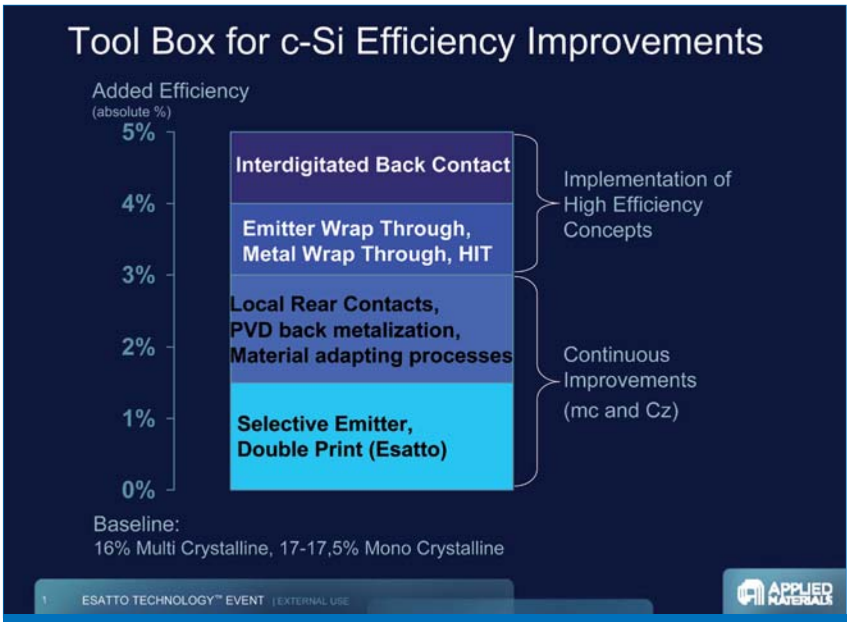

Figure 1. Applied Materials' tool box for c-Si efficiency improvements.

on narrower finger lines using double printing, print accuracy is now a key requirement for all equipment vendors.

As shown in Fig. 1, Applied Materials sees a 'tool box' of process improvements that could achieve up to 5% efficiency gains with continuous improvement strategies before the need for alternative technologies.

Dr. Christian Buchner, CEO of Schmid Technology, emphasised the rapid adoption rates, having launched its selective emitter processing technology at EU PVSEC in September 2009. The company has received confirmed orders for 1.5GW of equivalent solar cell production of its technology, which has, the company claims, bestowed the title of selective emitter market leader upon the company due to its simpler wet chemistry processes as part of an integrated line.

"Our research results show that the cell efficiency of multicrystalline wafers has been increased by 0.4% and that of monocrystalline wafers by 0.8%", noted Buchner.

Its cell technology, known as 'inSECT' (inline selective emitter cell technology), is claimed to be easy to integrate into existing manufacturing lines – perhaps another reason for the high interest levels. Throughput of the inSECT line is said to be 2,200/wph.

Only one further process step is necessary to reduce the surface between the subsequent contacts down to a depth of 50nm. The additional processing stage, including investments, consumed materials and amortization costs are claimed to be only €0.08.

However, as pointed out by Buchner, absolute cell efficiency gains using double printing need to be backed up carefully with low production costs to make the technology viable in the mainstream. An important point raised by Buchner about double printing revolved around screen-printer design and its impact on wafer breakage. Doubling the printing steps required taking a second look at wafer breakage as allowing doubling of the average percentage of breakages would raise production costs, negating some of the selective emitter double-printing gains.

"We genuinely believe from all of the manufacturing process data we have collected that screen printing contributes to wafer breakage due to the process touching the cell, either in the line or via the development of micro cracks that cause breakage later such as at the module assembly stage", commented Buchner. "This leads to around half to one percent of wafer breakage; with double printing this had to be addressed which led to the development of a 'touchless' process at Schmid."

"Absolute cell efficiency gains using double printing need to be backed up carefully with low production costs."

Buchner sees future benefits of this approach when the industry moves to thinner and thinner wafers, though he conceded that it was difficult to predict when this will happen.

Another equipment supplier focused on bringing double print selective emitter technology into the mainstream volume production arena is ASYS Solar. The newest printer in their offering is the XSR1 turntable printer, with a throughput of 1,600 cells an hour and a print accuracy of ±12.5µm @ 6 Sigma. It also incorporates a new vision system specifically designed for recognition of selective emitters, which is part of their ULTRAline metallization lines.

The company's XSR1 machine employs a turntable that can have four integrated processing stations, a combined optical breakage inspection and alignment station for alignment of the cell edge, as well as recognition of selective emitter structures. It also has a print station with automatic screen alignment, as well as an optional station for post-print inspection.

Dr Lars Wende, Vice President Solar & New Technologies at ASYS Group, was keen to highlight the print accuracy levels of their technology. Wende noted that they had incorporated a new vision system specifically designed for recognition of wafers employing the selective emitter, part of their ULTRAline metallization lines. More is to come from the company, with plans for further manufacturing cost reductions in paste and screen-print masks.

"We are working with partners on a range of efficiency and cost reduction strategies, including paste optimization with improved viscosities", noted Wende.

He also hinted at successful collaborations with Asian partners and the use of nanomaterials for metallization, all achievable with their technology offerings. It was interesting to note that Wende did not seem too concerned with wafer breakage issues, noting that even with double printing the company is achieving fewer losses than in conventional systems.

However, according to Darren Brown, Alternative Energy Business Manager at DEK, there are numerous challenges with the migration to selective emitter double printing.

DEK's PVP1200 screen printer, which is capable of 1,200 wafers per hour throughput, is proving popular, as is its PV3000 metallization line. Asian customers in particular tend to seek out high-throughput tools that offer high accuracy and repeatability, attributes Brown said were ideal for double printer applications.

"We are of course double printing at the moment, but excitingly the technology is really only in its infancy", commented Brown. "Bringing accuracy to the screen print process has been a key enabler for print-on-print processes but we are really only at chapter one...a challenge we're all facing in relation to print-on-print is screen manufacture. Producing high-quality precision screens is not a low-cost operation and with twice the number of screens required, consumable costs are an issue. These issues have been amplified with the need to closely match both screens needed for the process, causing issues with image stability."

With a focus on cost reduction of double printing, Brown pointed out that DEK has been working on various approaches to reduce the cost of precision screens. Some unique approaches that have yet to hit the shelves tackle lifetime issues, adding to the company's aim of further reducing manufacturing costs for the technology.

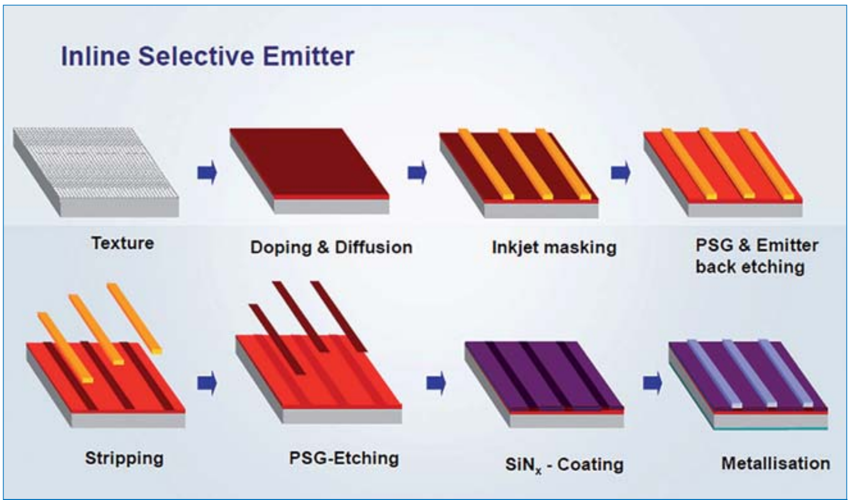

Figure 2. In-line selective emitter process steps (Schmid).

Firing

With such a broad range of primary changes being made to metallization geometries, there seems to be an increase in the risk of potential for physical damage through the contact. With over 90 customers in the industry, Despatch Industries' expertise in the sector led to its recent introduction of a transfer belt system for its 'Despatch UltraFlex' furnace, which it claims addresses this risk by contacting the cell only in the inactive area (the 1–1.5mm perimeter).

"The more specialized metallization geometries become, the more crucial the ability to tailor the thermal profile", noted Jeff Bell, Manager of Solar Product Management at Despatch Industries. "Even small temperature variations can affect aspect ratio and, as a result, current and shading. Our 'UltraFlex Microzone' technology enables very precise tailoring of the peak temperature and crucial 'time-above' profiles for new silver pastes."

The ability to change the thermal recipe along with the new materials and architectures is proving to be a necessity, and a feature that is fast attracting customer adoption of its technology, according to Bell.

> "The more specialized metallization geometries become, the more crucial the ability to tailor the thermal profile."
>
> -Jeff Bell, Despatch Industries

Another company that has been seeing increased activity for its next-generation metallization technology is BTU International, whose 'Tritan' metallization drying and firing system features a proprietary multi-speed drive system that enables aggressive temperature spikes without compromising the drying, burnout and cooling process steps.

Jan-Paul van Maaren, Ph.D., BTU International's Vice President of Marketing, noted: "The dual printing technology will still require the same firing technology as before but will probably require a more rapid spike... but we believe we are well ahead of customers' roadmaps, with the Titan capable of 200°C when temperatures of only 80 to 90°C are currently required."

BTU's Vice President of Sales, James Griffin, warned of some knock-on requirements related to the diffusion layer's becoming shallower and shallower.

"That dictates that the metallization step has less of a thermal budget to penetrate into the silicon. The contact has to be made, followed by a very quick 'freeze', because otherwise it will penetrate too deeply and create a short", noted Griffin.

He went on to say that some of BTU's customers were looking for totally alternative technologies to resolve the issue of printing and putting down narrow fingers. Evaluations using electroplating technologies are ongoing to achieve the next level of cell efficiencies. Griffin noted that BTU had technology available for that very application on the day we spoke.

Plating

Another company that is providing alternative technologies for metallization is Technic, Inc. According to Anthony Gallegos, Global Product Manager at the firm, many of the new entrants in cell manufacturing have shown great interest in moving to plating processes rather than following traditional metallization routes.

Technic offers 'Light-Induced Solar Plating' for front-side contacts. The company's light-induced electrodepostion is said to improve front-side conductivity while improving the overall uniformity. Utilizing its proprietary 'Technisol' chemistry, cell efficiency improvements of 0.4% are achievable.

However, Gallegos was quick to clarify that although some of the well-known cell efficiency leaders were known to be using electroplating methods with mixed results, these approaches used unconventional cell designs with the aim of achieving higher efficiencies. In contrast, the Technic ASL (alternative seed layer) process requires the use of conventional cell manufacturing methods in conjunction with Technic's process.

"The cell manufacturer can still utilize their existing manufacturing steps up to SiN_x", explained Gallegos. "Then they will laser grid lines into the SiN_x and use our ASL process to metallize the grid lines [chemical seed layer] followed by Light Induced Plating. Then the cells can be completed as normal."

Gallegos claimed that, as long as conventional cell designs are used, there are no problems with this plating technology, which is seen as offering a high-speed process ideal for volume production solar applications. Careful not to allude to customers' investigation of this plating alternative, Gallegos indicated that customer feedback and interest was increasing all the time. Perceived issues with contamination, bath life and waste treatment have all been dispensed with as the technology is widely used in other industries.

Conclusion

A path to 20% cell efficiencies using improvements focused on metallization processes while retaining low-cost manufacturing is well underway. Similarly, further enhancements to boost productivity and reduce material costs of selective emitter formation and double printing are ongoing. The ability to retain conventional processes with compatible in-line process step additions is providing the mainstream cell producers the ability to meet near-term manufacturing goals. How far such technologies can be pushed before more fundamental changes to cell designs, equipment and processes are required is not yet clear; however, the promise of 20% cell efficiencies with the lowest manufacturing costs will undoubtedly continue the growing adoption of photovoltaics technology.

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Thin Film

Applied Materials stops selling 'SunFab' thin-film lines: focus on c-Si solar and LED technology

Applied Materials' SunFab line.

In a significant change of direction, Applied Materials has revealed that it will stop selling its turnkey a-Si thin-film technology under the SunFab name to potential new customers, shifting emphasis away from thin-film altogether and focusing on crystalline silicon (c-Si) and LED manufacturing equipment and technology. The restructuring of Applied's Energy and Environmental Solutions (EES) division was said to cost the company between US$375 million and US$425 million.

Applied said it will continue to offer individual SunFab tools for sale to thin-film solar manufacturers, including CVD and PVD equipment. R&D efforts to improve thin-film efficiency levels and high-productivity deposition will continue for existing customers.

Many of Applied's SunFab customers have struggled to gain traction in the market due to the competitive strength of thin-film leader and CdTe technology user, First Solar, which has the lowest manufacturing cost-per-watt structure. The dramatic fall in polysilicon prices as significant new capacity comes on stream has also played its part in boosting the competitive position of c-Si technologies and recent resurgence in cell efficiency gains.

The restructuring will impact between 400 and 500 job positions globally, Applied said. A number of affected employees may transfer to other groups or functions within the company. Applied said it had more than 12 SunFab customers since launching the technology in 2007. Mike Splinter noted that there had been a lack of demand going forward for its SunFab technology and it was "impractical" to continue operations as they were. The R&D facilities in Germany will be closed and the only development work will be carried out at Applied's main R&D facility in Silicon Valley.

Manz Automation forms alliance with Würth Solar: sets sights on CIGS thin-film manufacturing

Manz Automation has signed a licensing and strategic alliance agreement with Würth Solar for the exclusive rights of use to Würth's CIGS production technology, for an initial period of 10 years. The company aims to use the alliance to become the market leader as a provider of fully integrated, cost-effective CIGS production lines (CIGSfab). The existing contractual relationship with Würth Solar and the ZSW centre for solar energy and hydrogen research also means that Manz has exclusive access to research results regarding CIGS modules on glass substrates.

Manz will pay a total of €50 million in installments through to commissioning of the first CIGSfab. Financing for the transaction has been secured through existing equity, additional borrowing, and from the cash flows that result from the expanded business model in future. The estimated sales potential for a CIGSfab with a capacity of 120MW per year is around €150 million.

Amonix to begin manufacturing CPV systems in North Las Vegas

Bringing approximately 300 new jobs to North Las Vegas, CPV designer and manufacturer, Amonix, has signed a lease for a 214,000 square foot facility. The company has revealed that the Pecos Road-based plant will employ local residents to fill the management, technical, and production vacancies.

Amonix, which already has three solar power systems installed at separate locations in Nevada, plans to use the plant to manufacture systems for additional installations within the state and for export to neighbouring states. A portion of the facility's power will come from an Amonix 7700 system. The manufacturing facility, which is expected to have an annual production capacity of 150MW at full capacity, will be up and running by the end of 2010.

Business News Focus

Solexant plans thin-film solar manufacturing plant in Gresham, Oregon

Solexant has selected Gresham, Oregon, as the site for its new manufacturing plant for next-generation nanocrystal CdTe thin-film solar cells. The plant, which is expected to cover approximately 100,000 square feet, will initially employ around 100 workers and is expected to produce 100MW of modules. At full production, Solexant hopes to increase the plant's workforce to 170. Long-term, the company aims to expand the facility to manufacture panels capable of generating 1,000MW.

Source: Sulfurcell

Close-up of Sulfurcell standard module.

Sharp signs agreement for 73MW of solar plants in Thailand

Sharp has signed an agreement with NED, the wholly-owned independent power producer of Mitsubishi, based in -Thailand, to establish 73MW of thin-film solar power generation plants. The construction of the project, which is expected to be one of the largest in the world, will begin by the end of July 2010 for completion in 2011.

The announced plant will contribute towards the government of Thailand's target to generate up to 20% renewable energy by 2022. The amorphous/micromorph-silicon thin-film solar cell modules to be used in the plant will be supplied partially by Sharp's PV factory in Green Front Sakai in Sakai City, Osaka Prefecture, Japan, which began operations in March 2010. Sharp will contribute a business model for the power plant but will collaborate with ITD/ITE for the design and construction.

German CIS thin-film manufacturer targets U.S. market

Five years after starting production of its copper-indium-sulphide (CIS) thin-film solar modules, Berlin-based Sulfurcell plans to set up a North American network of system integrators and installers. As with the perceived consumer concerns for more aesthetic-looking PV modules, Sulfurcell believes its 'black-tile aesthetics' will prove popular in that market. Sulfurcell will be offering framed, frameless, and roof-integrated modules.

Sulfurcell's North American operations will be run out of new offices in Los Angeles, California. The company has claimed that it has sold over 100,000 modules, which would make it one of the three largest manufacturers of CIS/CIGS-based thin-film producers in the world.

First Solar installs 1.3MW system on Oder facility roof

In a move toward power generation, First Solar has begun the operation of a 1.3MW solar power plant on the roof of its production site in Frankfurt (Oder). The company now represents the entire value

Source: First Solar

First Solar's manufacturing research and design campus in Frankfurt (Oder), Germany.

chain of photovoltaics, from manufacturing of the solar modules and power generation to recycling. The new plant will generate more than 1,000MWh of clean energy every year, using more than 17,070 FS-275 thin-film modules installed over the 12,400m^2 facility. More than 120 inverters transform the power into alternating current, which is then fed into the local network from the internal First Solar network.

News

First Solar CFO heads up utility systems business group initiative

Now that the end of the NextLight acquisition is drawing near, First Solar has turned its focus to the large-scale photovoltaic system solutions market with the formation of a utility systems business group. The company's chief financial officer of four years, Jens Meyerhoff, has been named president of the initiative.

When NextLight closes in the next quarter, First Solar will have a total of 2.2GW utility-scale solar project power purchase agreements in North America. To date, First Solar has built or has under construction 189MW of utility systems projects in North America. The company has begun an immediate search for a new CFO; Meyerhoff will remain in the position until a replacement is appointed.

EDF Energies to use Suntech and First Solar modules at new solar farms in Ontario

Construction has commenced on three solar photovoltaic projects totalling 36MW in Ontario, by EDF Energies Nouvelles. Two projects (12MW each) are to use Suntech c-Si modules while a third PV power plant will use CdTe thin-film modules from First Solar. All three plants are expected to be grid connected by the end of the year. White Construction Canada is the general contractor for EDF EN Canada, the subsidiary of EDF Energies Nouvelles.

Suntech modules will be used at the Elmsley Solar Projects, located near Lombardy in the Township of Rideau Lakes, while First Solar modules will be used for a project located near the town of St. Isidore in the Municipality of the Nation. All three sites are being developed under the Government of Ontario's Renewable Energy Standard Offer Program (RESOP).

Abound Solar and Key Equipment become financing partners

Abound Solar and Key Equipment Finance, part of KeyCorp, have joined forces for a new program that will fund commercial-scale solar PV systems for Abound's U.S. customers. Abound will be able to offer flexible financing for PV systems with the company's CdTe solar

Abound Solar's CdTe solar module.

Source: Abound Solar

modules. This will include the cost for balancing the systems components and installation services.

With this new financing option, Abound hopes to allow its customers the ability to match the expected cost savings from solar panels to the cost of payments, all while allowing the end-user to keep the tax benefits from being a system owner. The program allows for transaction sizes between US$100,000 to millions of dollars.

LayTec expands distribution network with new partners in Asia

In response to an increase in demand for its metrology systems for PV applications, LayTec has expanded its distribution network with two new partners in Asia: DKSH Korea and MOS Technology.

DKSH Korea, based in Seoul, Korea, will help LayTec with its market expansion in the country. DKSH is part of the Swiss DKSH group. In Taiwan, MOS Technology, located in Zhubei City, Hsinchu County, will offer its services for LayTec. In addition, LayTec announced that its headquarters in Berlin will be expanding this year, which will not only increase the size of the headquarters, but will add an additional 60 employees to its team.

Suntech stops thin-film production: 2Q revenue US$620 million plus

The increasingly cost competitiveness of crystalline silicon technology has seen another thin-film victim, this time in the form of Suntech. Although only a small part of the leading China-based c-Si module manufacturer's product armoury, its amorphous silicon thin-film solar module line has ceased production.

Suntech is currently restructuring its Shanghai facility to focus on the manufacture of crystalline silicon solar cells at a time when the company is at full capacity and sold-out in the first-half of the year. Suntech was a customer of Applied Materials' 'SunFab' turnkey technology and had installed a 50MW line in 2009. Applied Materials had recently announced it would be stop selling the SunFab technology to new customers and reallocated staff and resources to c-Si technology.

"While the thin-film and Shunda related charges will significantly impact our second quarter financial results, they have no bearing on our core manufacturing operations which are performing very well," said Dr. Zhengrong Shi, Suntech's chairman and CEO. "Going forward, we will continue to focus on our primary mission of supplying the most reliable and high performance solar panels in the industry."

Suntech said that it expected to incur a non-cash impairment charge of approximately US$50 million to US$55 million in the second quarter of 2010 in relation to the thin-film line closure. The company also said that due to debt obligations at solar wafer producer Shunda, which it has a stake in the company and a 7GW wafer supply deal is currently undergoing significant reorganization and that it would incur non-cash charges of US$106 million to US$126 million in the second quarter of 2010. This is related to its investment and prepayments to Shunda, the company said. Suntech expects total net revenues for the second quarter of 2010 to be in the range of US$620 million to US$630 million. Gross margin is expected to be in the range of 17.5% to 18.5%.

Emcore, San'an create Suncore joint venture to develop, manufacture, distribute CPV gear in China

Emcore and San'an Optoelectronics have signed a joint-venture deal for the development, manufacture, and distribution of concentration photovoltaic (CPV) receivers, modules, and systems for terrestrial solar power applications in China. The JV, called Suncore Photovoltaics, will be owned 40% by Emcore and 60% by San'an, which is San'an is the largest producer of LED chips and epitaxial wafers in China and is also a leader in CPV manufacturing and deployment in the country.

Under the terms of the agreement, all operational activities and business for CPV receivers, modules, and systems at both San'an and Emcore's Langfang, China, manufacturing facilities will

Thin-Film Order Focus

Oerlikon Solar receives follow-up order from Tianwei

Oerlikon Solar's customer, Baoding Tianwei Solar Films, has placed an upgrade order to increase its production capacity of thin-film silicon solar modules from 46MW amorphous technology to 75MW micromorph technology. The upgrade will start in January 2011 and is expected to be ready for mass production by March 2011.

Manz Automation's equipment backlog passes €100 million

Backend PV equipment orders at Manz Automation that total over 500MW in equivalent output are primarily responsible for the tool supplier's order backlog now exceeding €100 million. Manz said that a total of nine backend lines have been ordered.

Manz noted that its high-precision printer, HAP 2400, combined with the OneStep selective emitter technology, was proving to be a popular system within complete backend line orders, especially from customers in Germany, China, South Korea and India. The combination of these technologies in backend lines is claimed to increase the effectiveness of crystalline cells by up to 0.5%.

Interestingly, the company noted several new orders for thin-film equipment, a sector that was slow to recover compared to the crystalline manufacturing market. Manz said that it had also received new thin-film orders with a volume of around €8 million from customers in Germany and the U.S. In particular, second-generation laser scribing machines and equipment for factory automation had been ordered. A revival in orders for thin-film technology is expected to further improve in the second half of the year, the company said.

Bloo Solar selects developer and manufacturer for thin-film solar module

Bloo Solar's Solar Brush wafer development production has begun and with the hopes to bring the commercial modules to market in 2012, the company has chosen CVD Equipment to develop and manufacture the equipment for the solar module.

The Solar Brush is a third-generation, three-dimensional, single-junction architecture technology. The module is said to provide more surface area, better light trapping and less recombination, which produces higher efficiency and a total power output of 1.5 to 3 times higher than current technologies. Together, Bloo Solar and CVD will develop a key process for transparent conductive oxide (TCO) coating. CVD Equipment supplies offline and online CVDgCoat(TM) APCVD for fluorine-doped SnO_2 (SnO_2:F) coating and offline LPCVD for ZnO coating.

T-Solar selects BrightView's inline metrology solution

Amorphous silicon thin-film producer T-Solar has selected BrightView Systems' InSight M Series inline process control and optimization tool for thin-film PV production. The wide area metrology (WAM) system provides continuous monitoring and whole-panel mapping.

BrightView and T-Solar will also examine and analyze the relationship between process variations and long-term field performance of the modules, which T-Solar plans to install in diverse geographic areas, including projects in Peru, Italy, France and Spain. The InSight M metrology tool will used at T-Solar's thin-film factory in Ourence, Spain. T-Solar began production of its Applied Materials supplied a-Si thin-film 'SunFab' line a year ago and has an annual capacity of 45MW or 700,000m^2 of modules per year.

eventually be transferred to Suncore at its primary manufacturing operations to be located in Wuhu City, Anhui, China.

The Wuhu economic development organization has agreed to provide Suncore with significant economic incentives, including land, subsidies, grants, and other incentives, although the amount of the incentives was not announced. Suncore will become Emcore's primary low-cost, high-volume manufacturing base for CPV receivers incorporating the company's CPV solar cells, and also for CPV modules and systems to support both the JV partners' worldwide sales efforts.

Subsequent to the establishment of Suncore, the company will begin to produce 12MW of CPV systems for San'an's current customers and 2MW of CPV components for projects sourced by Emcore. The companies are also aggressively pursuing multiple CPV project opportunities, including the 280MW solar energy plan in six western regions of China recently announced by the Chinese government.

In conjunction with the formation of the JV, Emcore will grant Suncore an exclusive license to manufacture Emcore's current and future improved CPV receivers, modules, and systems in China for terrestrial solar power applications. San'an chairman Xiucheng Lin will serve as the new venture's chairman, while Emcore's senior VP Charlie Wang will become GM.

Testing and Certification News Focus

Ascent Solar receives Export Achievement Certificate

Ascent Solar Technologies has received a federal Export Achievement Certificate for the international market development and sales of its flexible and lightweight CIGS thin-film modules for building materials, portable power, and defense and transportation markets.

Soliant Energy receives UL Listing for SE-500X

Soliant Energy's concentrator photovoltaic (CPV) flagship product, SE-500X, has officially received Underwriters Laboratories (UL) listing and has also been certified under the SU 8703 UL draft standard, a new code defined specifically to test safety parameters of CPV products.

Concentrix introduces new U.S. subsidiary; achieves CEC listing

Concentrix Solar, the division of Soitec Group, has introduced its U.S.-based subsidiary, Concentrix Solar, Inc. The new division is based in San Diego where the company installed a CPV demonstration system in July 2009 to test its solar modules under California's climate conditions. The 6kW system has achieved 25% efficiency in generating electricity since its installation.

Clark Crawford will head the new office as general manager of business development. Previously, Crawford led sales and marketing efforts at CPV systems supplier Amonix. In addition to the announcement of its new subsidiary, Concentrix's multi-junction CPV module has received a listing with the California Energy Commission (CEC). The CX-75 module was tested at TÜV Rheinland's PV Testing Laboratory in Tempe, Arizona.

R&D News Focus

SoloPower launches flexible CIGS line, ships modules, ramps production capacity

SoloPower has launched the first module of its inaugural line of flexible, high-power, lightweight CIGS thin-film photovoltaic modules. Produced at the company's San Jose manufacturing facility, the 0.3m x 2.9m SFX1-i module weighs 2.2kg and has an 80Wp power rating and is targeted for large rooftop applications.

The initial module and a second, larger 260Wp-rated device – the 0.9m x 2.9m, 6kg SFX1-i3 – are shipping in sample quantities to several key customers in different geographical areas, with general availability of the new modules expected in the second half of 2010, according to SoloPower. A third module, the 170Wp SFX2 (0.3m x 5.8m, 3.6kg), is also being readied for deployment. To meet further market demand, the company is adding more than 75MW of CIGS cell and module production capacity at its plant.

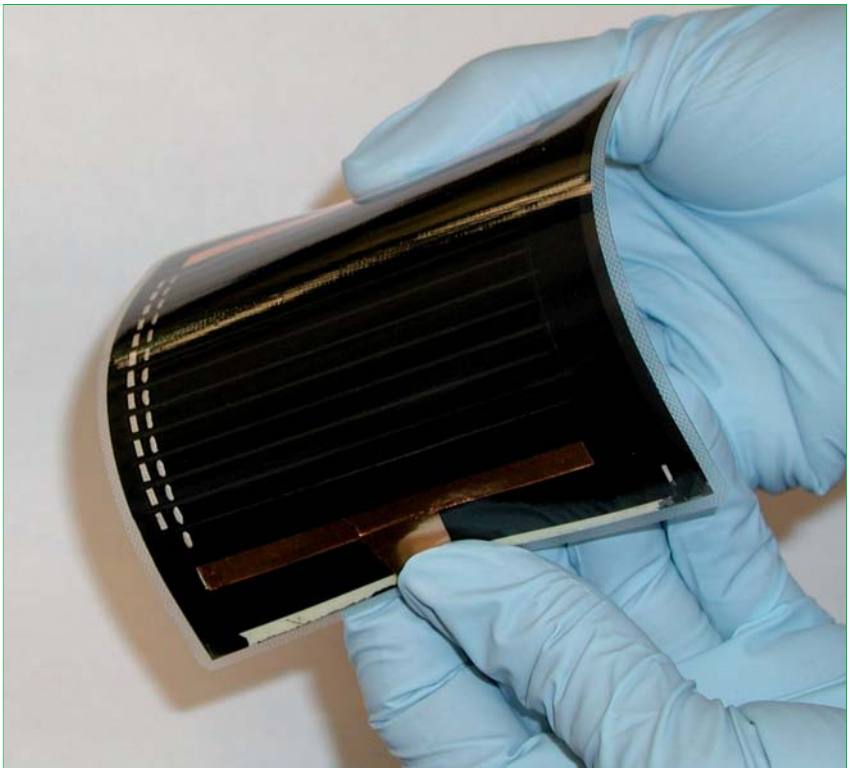
SoloPower CEO Tim Harris said the company has 13 different customers in 13 different locations in the U.S., Europe, and the rest of the world (and has signed three "uptake" supply deals recently), adding that the customers plan to have systems in place using SoloPower's flexible CIGS modules – ranging from 2KW to 100KW – within the next couple of months.

Ascent Solar chosen for DARPA PV project

Ascent Solar Technologies has joined the team for the Defense Advanced Research Projects Agency (DARPA) for their Low-Cost Lightweight Portable Photovoltaics (PoP) project. The "Flexible High-performance Tandem-junction PV Array" project will have three phases. The first phase, 18 months long, will have an approximate contract value of US$3.8 million. The PoP program will continue over the next 54 months to determine low-cost, lightweight photovoltaics that can withstand various environmental conditions while delivering a power conversion efficiency of 20% or greater.

OPV and DSC photovoltaic technologies need to be more flexible, says NanoMarkets

A key attraction of OPV and DSC is the flexibility and transparency of the technology; however, a new report from NanoMarkets sees the need for more



Source: Ascent Solar

Ascent Solar's flexible CIGS monolithically integrated 14-cell demonstration module on a plastic substrate.

flexibility should these technologies survive and prosper in niche markets. According to the market research firm, these technologies may offer low-cost, high-volume roll-to-roll production but the markets they could serve are little more than low-volume niche sectors.

Benchmarked against the likes of First Solar's CdTe thin-film modules, OPV and DSC would have to be priced at a considerable discount since their low conversion efficiencies and poor longevity almost rule out the technologies from mainstream PV markets. NanoMarkets believes that OPV and DSC will need to get creative by taking advantage of the features that these technologies still hold over other PV technologies, but that they are still destined for niche plays.

In 2015 NanoMarkets expects portable power OPV and DSC applications to generate US$580 million in revenues and transparent BIPV glass to produce US$280 million in revenues, two of the main markets available for the technologies, according to the market research firm. Creating better flex-cell materials than those now in production would also allow PV-coated fabrics and other solutions that are much more pliable than what is currently considered 'flexible PV.'

Plextronics announces developments in organic photovoltaics

Plextronics has announced its Plexcore PV 2000, an organic solar ink, which the company hails as being able to deliver higher performance in fluorescent lighting conditions in comparison to a-Si solar cells. The Plexcore PV 2000 is said to have a 30% to 40% increase in indoor power density in comparison with the standard organic solar technology.

Plextronics stated that Plexcore will contain safe, non-toxic material and have a lower cost due to the application of high-throughput, roll-to-roll printing processes for manufacturing. In addition to its Plexcore technology, Plextronics has announced a new manufacturing method that allows for low-temperature processing of OPV. Conventional industry techniques use a glass substrate annealed at temperatures at or above 110°C. The company has developed a process which allows for the annealing process at less than 65°C. Plextronics sees this breakthrough reducing manufacturing costs by using less expensive substrates.

Source: Plextronics

Plextronics' OPV technology installed at the NREL testing facility.

Source: Sunfilm

Sunfilm's silicon-based thin-film module.

Dyesol to develop performing dyes with CSIRO in US$1.17 million investment

Dyesol and CSIRO have completed their contract for collaboration toward the development of higher-performing dyes. The two-year project will be funded by an investment of up to US$1.17 million from CSIRO's Australian Growth Partnership (AGP) program. The collaboration involved the purchase of a Dyesol Laboratory solution by CSIRO.

Dyesol will project manage a team of scientists from CSIRO for an agreed development program, which targets the development of new intellectual property that Dyesol hopes to use in its DSC PV market position. Under the terms of the agreement, Dyesol can exclusively access the project IP.

Solarmer taps NREL to boost organic thin-film cell lifetimes

Improving the performance and operating lifetime of organic photovoltaic (OPV) devices is a key to its future commercialization and potential to offer significantly low cost - per - watt. To this end, thin-film OPV developer Solarmer Energy will collaborate with NREL to improve plastic solar cell performance, especially in the areas of encapsulation and packaging approaches.

The joint research covered by the cooperative research and development agreement (CRADA) will see NREL use its combinatorial degradation system, which compares the performance of up to 360 OPV devices in parallel under simulated solar conditions to accelerate the test results. The partners also seek to improve the cell design architecture for longer life. Solarmer's VP of engineering, Gang Li, said he expected the project to be a success.

Dainippon and Gifu University debut new analytic technology for thin-film solar cells

Dainippon Screen Manufacturing and Gifu University have produced a new technology that analyzes the characteristics of a-Si films for thin-film silicon solar cell panels. The result from the research of the new technology is being used in spectroscopic ellipsometric film thickness measurement systems by Screen. Product creation is expected to be completed by the third quater of 2010.

The thin-film silicon solar cells are said to be able to allow for large-size cell panels to be manufactured with only a small amount of silicon used. Dainippon and Gifu look for the cells to be used in ground-mounted solar systems. Screen and Gifu have been working together since November 2008 researching the analysis of thin-film silicon solar cells. To date, the research has produced the ability to demonstrate an analysis method for a-Si films to be used in the production of stable cell panels with minimal generation loss. This also allows for the digitization of information that is useful for a precise control of light-induced degradation. Work is still being conducted to commercialize the new technology into an accurate analysis of film properties and non-contact and non-destructive measurement of film thickness.

Sunfilm achieves record total area efficiency for largest thin-film module

Sunfilm has set a world record of 9.6% total-area efficiency for a module of 2.6m x 2.2m. Sunfilm's Model F achieved a maximum stabilized output power of 546Wp, achieved during a recent process optimization run on the company's production line. The thin-film deposition rate was the same as that used for Sunfilm's normal high-volume production. At 5.7m^2, Sunfilm's Model F is the largest thin-film tandem-junction module on the market. The module is designed for larger commercial roofs and utility-scale projects.

Product Briefings

CRAIC Technologies

CRAIC Technologies' 20/20 PV microspectrometer measures thickness of thin-film optical properties

Product Briefing Outline: CRAIC Technologies has launched the 20/20 PV Microspectrometer, which is designed to measure UV-visible NIR-range transmission, absorbance, reflectance, and emission and fluorescence spectra of sample areas smaller than a micron in width. The thickness of thin films and colour spaces can also be determined.

Problem: Engineers need to test the quality of the cell from a number of different aspects, which can be challenging due to the lack of range of some microspectrometers on the market.

Solution: The 20/20 PV Microspectrometer can take spectra and images of microscopic samples from the deep ultraviolet to near infrared with one seamless operation. It can acquire microspectra and images in absorbance, reflectance and fluorescence, and is available with both the DirecVu function to view samples by eye as well as with a high resolution UV-visible NIR digital imaging system. While microspectra are being acquired, the sample may be viewed with high-resolution digital imaging in the deep UV.

Applications: The tool can measure UV-visible NIR-range transmission, absorbance, reflectance, and emission and fluorescence spectra of sample areas smaller than a micron in width with one seamless operation. Sampling areas can range from over 100 microns across to less than a micron.

Platform: Available with both the DirecVu to view samples by eye as well as a high-resolution UV-visible-NIR digital imaging system.

Availability: Currently available.

Solar Metrology

SMX-ILH metrology system from Solar Metrology provides process control for active, contact and TCO layers

Product Briefing Outline: Solar Metrology has introduced the SMX-ILH (In-Line X-ray Head) tool, which is designed for in-line composition and thickness control of CIGS and CdTe photovoltaic thin-film deposition.

Problem: The special optical properties of TFPV films are notoriously difficult to measure. This is compounded by the high-volume production requirements of thin-film substrates and the impact the wrong composition can have on decreasing efficiency and manufacturing yield.

Solution: SMX-ILH provides process control for active, contact and TCO layers in PV thin-film stacks, and is capable of analyzing rigid glass, flexible stainless steel and polyimide roll-to-roll substrates. An optional proprietary thermal shield allows for film control at panel temperatures of up to 300°C. The tool is said to offer yield improvements and conversion efficiency gains in production for CIGS and CdTe PV panel manufacturers.

Applications: Inline composition and thickness control of CIGS and CdTe PV thin-film deposition. Typical measurement applications include Mo thickness, all CIGS combinations as well as CdS and related buffer layers.

Platform: The SMX-ILH platform comprises two primary configurations, Integrated and Remote. Integrated SMX-ILH models house all X-ray assemblies, motion control and user interface systems in a free-standing unit; rigid or flexible substrates pass directly through the SMX-ILH tool. Remote SMX-ILH configurations incorporate the X-ray head assembly, head motion systems and X-ray shielding directly into the tool or line; the X-ray head is mounted above the process line, and is operated from a remote system control station.

Availability: Currently available.

InnoLas

InnoLas's IMPALA laser processing systems offers multiple laser beams and parallel processing heads

Product Briefing Outline: InnoLas has developed the IMPALA series of large-scale laser processing systems, which features multiple laser beam techniques and parallel processing heads for increased throughput. Innovative handling concepts minimize defects and contamination, while the systems can be used in all high-accuracy steps (P1 through P3) of thin-film processing.

Problem: Precise laser scribing is key to successful production of thin-film solar modules. An accurate scribing process using an appropriate laser source according to the substrate can directly influence the quality and efficiency of the finished solar panels.

Solution: To optimize results, the 'Multiple Laser Beam Option' enables the processing of substrates with multiple laser beams in parallel. With the integration of laser sources of different wavelengths, the system can also be customized to specific application requirements. Substrates are manipulated on the machine platform with minimum mechanical contact to avoid damage and contamination. Machine precision minimizes distances between scribes in monolithic interconnections. The systems also offer the IMPALA TTG for 'Through-The-Glass' structuring.

Applications: IMPALA/IMPALA TTG are designed as work stations for precise processing over a large area for processing thin-film panels up to 1200 x 1600mm in size.

Platform: Modular in construction, they can be tailored to customer requirements. Both laser processing and mechanical scribing are available. A variety of laser sources (Nd:YAG-, Nd:Vanadate-, Pico-Second laser at 355nm/532nm/1064nm wave length) is available for different thin-film technologies.

Availability: Currently available.

TRUMPF

TRUMPF offers short and ultra-short pulsed lasers for high-precision thin-film applications

Product Briefing Outline: TRUMPF is offering user-orientated micro-processing lasers from the TruMicro Series 3000, 5000 and 7000 for an increasing number of applications for thin-film processes including CIGS patterning steps.

Problem: Conventional thin-film cell and module construction procedures are increasingly being displaced by lasers as they offer higher precision and repeatability while enabling higher throughput. Although lasers have had vast success in production facilities of the PV industry, only a fraction of the potential offered by lasers has been utilized so far.

Solution: Infrared lasers are generally used for the ablation of TCO films. For this application, the TruMicro Series 3000 offers a range of small, compact units with wavelengths of 1064nm and 532nm, ideal for P1, P2 and P3 patterning. With high pulse-to-pulse stability, the diode-pumped solid-state lasers can also be easily integrated into existing systems because of their advanced cooling design. Patterning of thin-film cells made of Cu(In,Ga)$(S,Se)_2$ presents a particularly high challenge for the laser process – and structuring of molybdenum in particular. For this application, nanosecond lasers are still used. However, picosecond lasers' ultrashort pulses can ablate material without significant heating of the marginal zone of the process, thus preventing cracking, melting or exfoliation of the layers. The Series 5000 offers a range of appropriate picosecond lasers for this purpose. Microprocessing lasers produce pulses with a length of 30 nanoseconds with 80 millijoule pulse energy. The Series 7050 with its short pulses and high pulse energy enables users to ablate the layer system neatly and highly efficiently without damaging the glass.

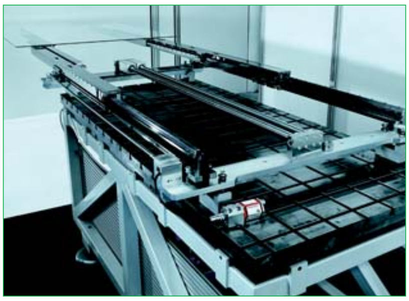
Applications: Wide range of thin-film processing steps.

Platform: TruMicro series 3000, 5000 and 7000 lasers have average outputs between 8 and 750W with pulse durations from the pico- to the microsecond range.

Availability: Currently available.

Product Briefings

Festo



Festo launches servo-pneumatic handling system for vacuum applications

Product Briefing Outline: Festo has developed the Sliding Fork, an innovative way of transporting glass. This unique servo-pneumatic handling system is particularly suitable for vacuum applications and is totally leak-proof, dynamic, with extreme torsional rigidity.

Problem: During the production of thin-film cells, the glass is introduced in the front-end area in different process chambers and is coated. This process area is under high vacuum at temperatures of approx. 200°C. The challenge in this process is keeping costs low while ensuring the highest standards for the process. The ambient temperature of around 70–90°C places high demands on the handling system.

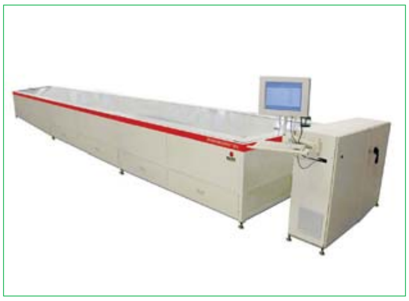
Solution: The stepless telescope-handling Sliding Fork system can operate in high-vacuum and high-temperature environments but is self cooling. The Sliding Fork is up to 50% cheaper than alternative robot solutions, according to the company. The stepless positioning with the servo-pneumatics feature grants the system a full stroke operation on both sides of up to 2m. It has a selectable drive depending on the application. A rodless cylinder with magnetic power transmission reduces the installation space and prevents leakage. It has an extremely high torsional rigidity in its extended position, with a max deflection of 7mm with a 15 kg load.

Applications: Loading and unloading of glass for thin-film cell manufacturing.

Platform: The Sliding Fork consists of a moveplate, a measuring system, three arms (steel and Al) and two DGO-25-SA. The difference between standard DGO and DGO-SA are the special O-Rings used to seal the rod with the adapter.

Availability: Currently available on request.

Spire Corporation



Spire's new solar simulator handles longer length modules

Product Briefing Outline: Spire Corporation has introduced a 6m x 1.3m solar simulator with a Class A solar spectrum and intensity uniformity of ±2%. The SPI-Sun Simulator 6013SLP (6013) is based on Spire's Single Long Pulse (SLP) series, which is designed to handle a wide variety of module shapes and sizes.

Problem: Some thin-film module designs are becoming very long compared to their width, for incorporation into roofing materials. Flexible modules have many unique form factors and can be very long – up to 6 metres in length. This makes for challenging handling issues.

Solution: Spi-Sun Simulator PV module testing systems feature light sources that closely match the solar spectrum while avoiding the excessive solar cell heating caused by continuous sources. The 6013 is designed for modules up to 6m in length and 1.3m wide, with a Class A solar spectrum and intensity uniformity of ±2%. It has an adjustable pulse length from 20 to 80 milliseconds and also has an adjustable intensity range from 200-1100W/m^2.

Applications: The SLP series is capable of testing crystalline and thin-film, single- and tandem-junction modules.

Platform: The SPI-Sun Simulator 6013SLP (6013) is based on Spire's Single Long Pulse (SLP) series and is available with the Module QA Tester. This integrated automation system allows for efficient module alignment, transport, probing and testing. The Module QA option enables high voltage isolation and ground continuity testing, automatic labelling of modules, and automated load and unload.

Availability: Currently available.

Umicore

Umicore's CIGS production scrap recycling closes the materials loop

Product Briefing Outline: Umicore Precious Metals Refining has introduced a CIGS production scrap recycling service with an initial capacity of 50Mt per annum. This new service allows the recycling of production waste (e.g. chamber residues) generated by CIGS solar cell producers, and valorizes copper, indium, gallium and selenium.

Problem: During the production of CIGS cell absorber layers, up to 60% of the metal is not deposited onto the substrate. Up to now, these metal fractions were not recovered, despite the fact that indium, gallium and selenium are valuable and relatively scarce metals that should not be sent to landfill.

Solution: Umicore has developed a new process for the recycling of CIGS production residues, on an industrial scale, in its Hoboken facility in Antwerp, Belgium. The four metals can now be recovered in an eco-efficient manner, enabling a closed-loop materials solution including minor metal sales, risk management and the recycling of the production residues. This CIGS production scrap recycling service will not only significantly contribute to cost per Wp reduction, but also helps to mitigate potential minor metal scarcity. Umicore's recycling service reduces the customer's need for new metals and complies with the 'green' aims of the PV industry.

Applications: All CIGS manufacturing operations. Recycling solution of full CIGS glass panels (rejects or end-of-life) is under development.

Platform: Umicore provides full local customer support, including metal accounting, pick up and assistance with logistic formalities. All Umicore production sites are ISO certified.

Availability: Currently available, 50 Mt per annum capacity.

Atmospheric deposition techniques for photovoltaics

Heather A. S. Platt & **Maikel F. A. M. van Hest**, National Renewable Energy Laboratory, Golden, Colorado, USA

ABSTRACT
With the never-ending need to reduce production costs, interest in atmospheric deposition techniques is steadily increasing. Even though atmospheric deposition is not new to photovoltaics, and in some cases is actually required to get the best cell performance, many of the fabrication processes for photovoltaic cells are vacuum-based. Due to the diversity in atmospheric deposition techniques available, there are opportunities for applications in thin film and patterned deposition. This paper discusses some of the deposition techniques and their applications, benefits and drawbacks.

Introduction

Solar cell manufacturing involves a myriad of simple and complex thin-film deposition techniques that include sputtering, evaporation, printing and chemical bath. Solid sources such as targets or powders provide the required elements and compounds to form films via the vacuum-based techniques, and there is a broad base of knowledge available for processing materials like ZnO or Mo into the appropriate precursor shapes. Vacuum-based techniques utilizing such precursors have traditionally dominated thin-film production, and steady improvements in material handling and processing conditions have led to dramatic decreases in the cost of photovoltaic-generated electricity to the current lowest prices of US$1.74/Wp for multicrystalline modules and US$1.07/Wp for thin-film modules [1].

> "Vacuum-based techniques utilizing such precursors have traditionally dominated thin-film production."

Also key to the vitally important decrease in the price of solar modules has been the more recent integration of solution-based thin-film deposition techniques like screen-printing and electro-deposition. While appropriate chemistries for the inks and baths are not fully established and often take time to develop, many of these liquid precursors are composed of low-cost materials such as water and abundant metal salts. Developing processes like aerosol jet-printing can produce patterns directly, so the inks are used efficiently and little waste is produced. Many of these techniques can also be used to deposit inks at atmospheric pressure – often simply in air, so there is no need for a vacuum chamber and the accompanying infrastructure. There are clearly some attractive aspects of solution-based thin-film deposition techniques.

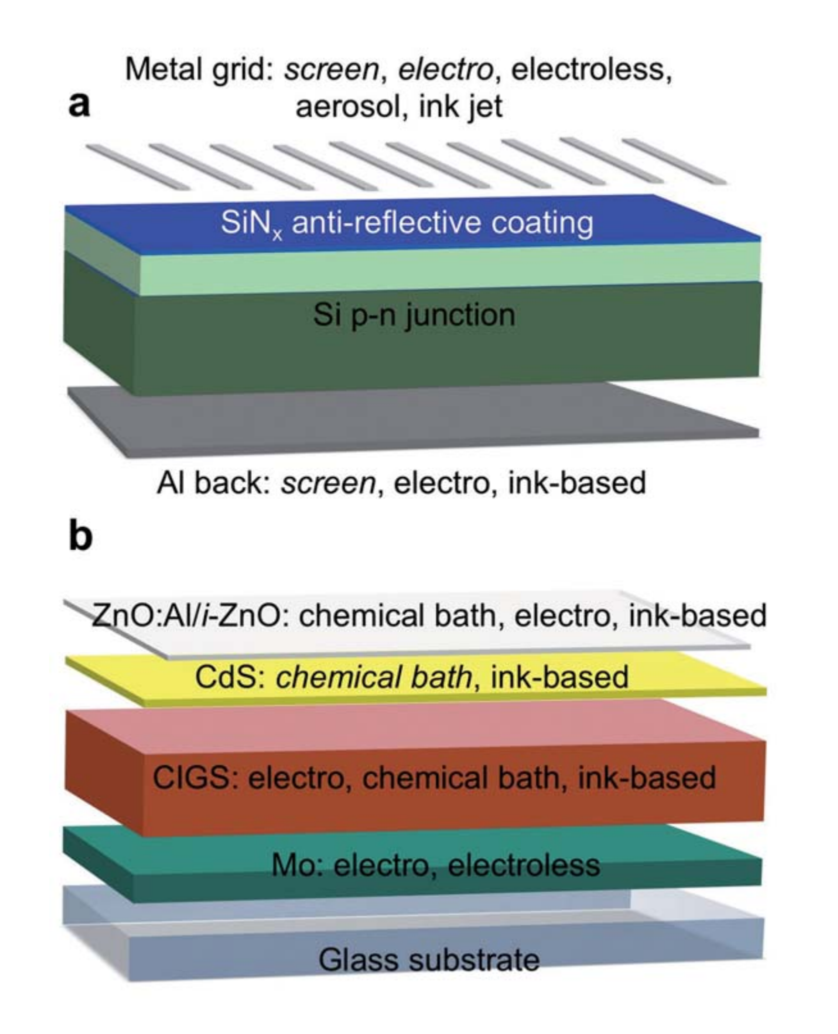


Figure 1. Atmospheric deposition processes that have the potential to contribute to a) a standard Si solar cell, and b) a standard CIGS solar cell. The techniques already utilized in production are indicated by italicized text.

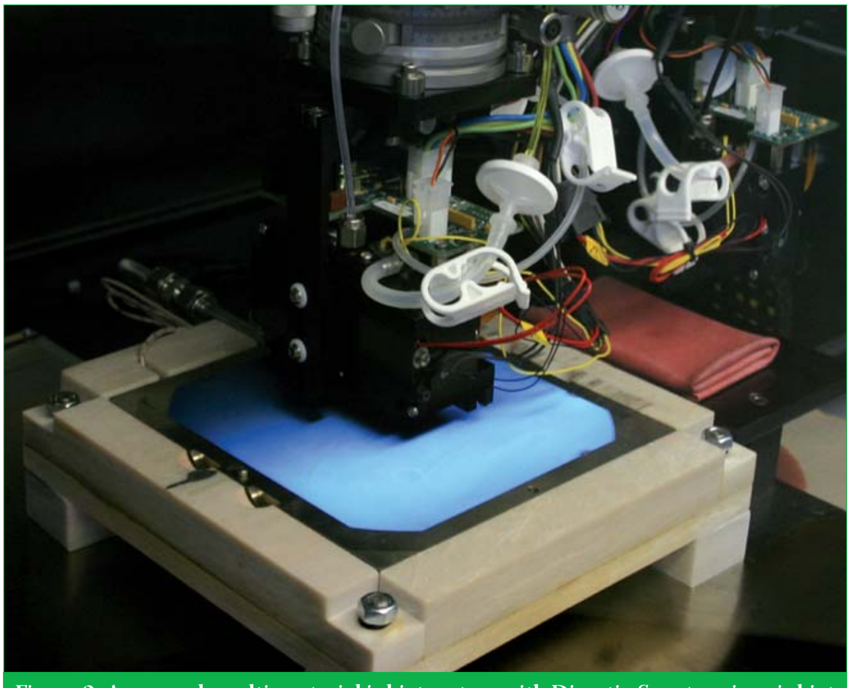


Figure 2. A research multi-material inkjet system with Dimatix Spectra piezo inkjet heads mounted on a universal X-Y platform. This research system is part of the Atmospheric Processing Platform in the Process Development and Integration Laboratory at NREL [5].

We will review the atmospheric processing techniques that are already contributing to photovoltaic module production, along with other promising methods that are under development. These techniques are summarized for wafer Si and thin-film $CuIn_{1-x}Ga_xSe_2$ (CIGS)-based cells in Fig. 1. The basic mechanics of each deposition methodology are described and further illustrated with specific examples and references for those interested in more details.

Direct patterning techniques

Screen-printing

For conventional wafer silicon photovoltaics, the most commonly-used technique to deposit contacts is screen-printing, which utilizes a woven mesh to support a mask with the desired pattern to deposit both of the contacts on the front and the back. The screen is placed in direct contact with the substrate, and paste is extruded through the screen onto the substrate. This process directly exposes the substrate to a force, which can result in breakage of the silicon wafer. Typical line widths that can be obtained are in the 100 to 125μm range; however, recent developments in screens and pastes have enabled line widths as low as 50μm [2]. Overall, screen-printing is a well-established deposition method in the photovoltaics industry. Silver pastes containing glass frit for high-temperature contact formation to silicon have been around since the 1970s. A close alternative to screen-printing is gravure printing in which the paste is transferred using a printing plate.

Screen-printing can also be used for alternatives to the normal front grid contact structures, i.e. interdigitated contacts, although the highest efficiency has been obtained using vacuum-based deposition approaches. Screen-printing is also used to deposit contacts on other types of photovoltaics, where the problem of breakage is limited since the substrate is either rigid, i.e. glass, or flexible, i.e. metal or plastic foil. Alternatively, screen-printing can be used to deposit films with thicknesses of several microns, i.e. CIGS or CdTe absorber layers.

Inkjet and aerosol jet printing

In an effort to reduce the contact grid line width, and therefore the shadow losses, inkjet printing (Fig. 2) and aerosol jetting (Fig. 3) are being developed as non-contact replacement methods for screen-printing. In the case of inkjet printing, small droplets (1-30pL) are created in a controlled fashion within the inkjet nozzle. These droplets can be deposited onto a substrate with great precision and reproducibility. In the case of aerosol jetting, a cloud of small droplets (~1pL) is

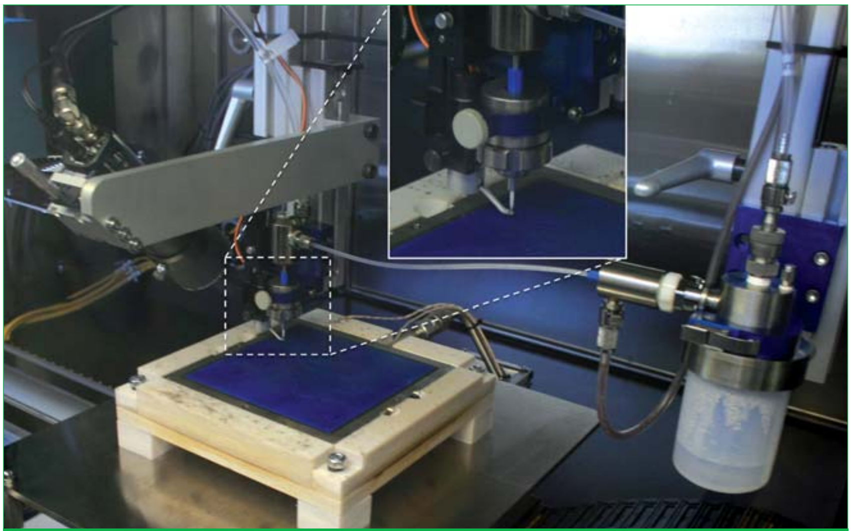


Figure 3. An Optomec research aerosol jet deposition system mounted on a universal X-Y platform. This research system is part of the Atmospheric Processing Platform in the Process Development and Integration Laboratory at NREL [5].

created and then transported to a nozzle via a gas stream. In the nozzle the aerosol is surrounded by a second gas stream, which confines the aerosol so that it can be deposited in a narrow area. Droplet position is random within the deposition area. Inkjet printing can produce metal grid lines with widths of less than 25µm [3], and aerosol jetting can even push below 10µm line widths [4].

Besides the reduced shadow losses of a front metallization grid, benefits of using non-contact printing methods include thinner wafers (in the case of wafer silicon), therefore reducing the material usage. It also enables the development of alternative contact structures, i.e. doped contacts and multi-layer contacts. The printing technologies permit changes to the printed pattern on the fly, which is ideal for prototyping. Multi-material printing systems enable deposition of interdigitated back contacts without the use of lithography. An example of a cell with aerosol-jetted contacts is shown in Fig. 4.

The key to the success of non-contact printing methods in photovoltaics is the development of deposition tools with sufficient throughput and inks that work well with these systems and produce the desired material properties, i.e. conductivity, adhesion, line width, line thickness, contact resistance, etc. Both methods are under development and in their initial production testing phases. Several companies are developing non-contact printing tools for the photovoltaic industry that work at production throughput [6], while smaller tabletop printing systems for initial rapid solar cell application development are also available. Most of the screen-printing paste suppliers and some chemical companies are actively developing non-contact printable inks.

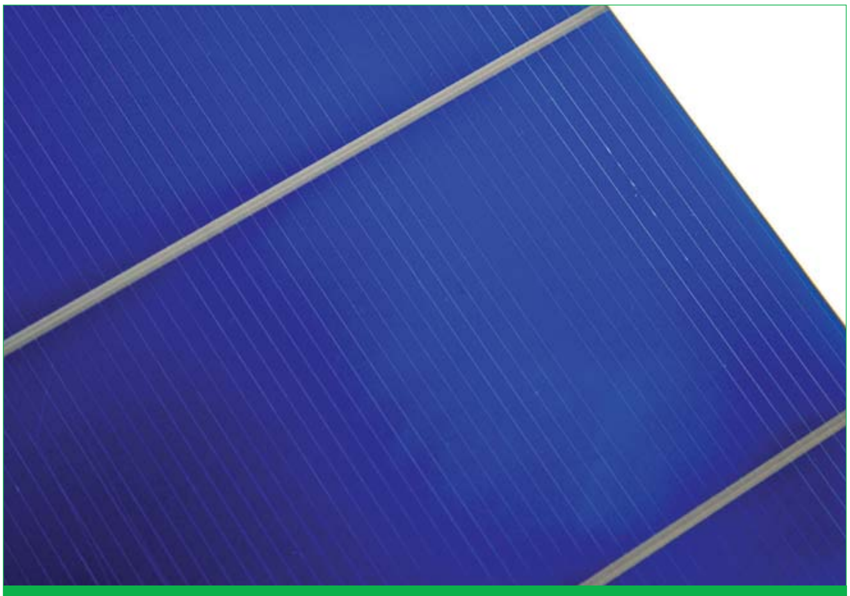


Figure 4. A single crystal silicon wafer with silicon nitride anti-reflection coating and a metallization grid deposited by aerosol jet.

The majority of metallization inks use nanoparticles as a precursor component; however, alternative inks exist that use metal organic decomposition precursors [3]. Non-contact printing methods can also be used for thin-film deposition, but their real strength is in the field of patterned deposits.

Bath-based thin-film deposition techniques

Bath-based deposition techniques require little up-front equipment investment in that they can be carried out in almost any container that will hold liquid. In addition, many useful films and patterns can be deposited from baths that are composed of abundant and low-cost reactants in aqueous solution. Bath-based deposition techniques have broad application, and as a result a dizzying number of variations exist. Here the focus will be on electro-, electroless, and chemical bath deposition to provide an overview of how such techniques are already contributing to photovoltaic cell production and where they may be utilized in the future.

Electro-deposition

In addition to the bath itself, the electro-deposition process requires an external current source [7]. This current is applied to the bath via two electrodes: the negative cathode, where positive cations migrate, and the positive anode, where negative anions collect. The most common use of this technique is to reduce metal cations to metal atoms at the cathode and thus form a coating. This cathode can be anything from a metal film or TCO-coated substrate to printed metal lines. For

Figure 5. A Sono-Tek spray deposition nozzle. This nozzle is part of a research deposition system at NREL.

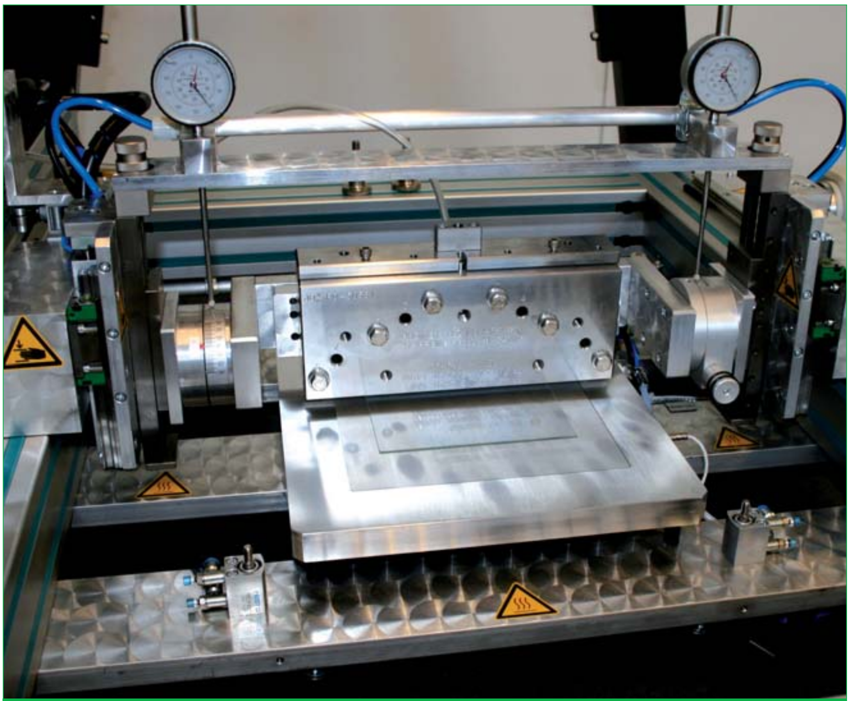


Figure 6. A Coatema easycoater with a 6” slot-die coating blade.

contact formation, electro-deposition can be used in a seed and plate approach to thicken seed lines deposited by a printing technique on a solar cell. While deposition of metals by means of this process is well established, a more recent and innovative application is the deposition of CIGS thin-film absorbers [8].

Electroless deposition

The very name of this approach provides a clear indication of the difference between this technique and its electro-deposition cousin. Instead of electrodes providing external current, chemical reducing agents are added to the bath to provide the driving force to produce individual metal or alloy coatings [7,9]. Not every metal or alloy can be deposited in an electroless fashion because a catalytic surface is required to drive the reduction process, so both the initial surface and the growing film must be able to fill this role. This technique can also be used to thicken previously deposited metal seed lines.

Chemical bath deposition

The compound films produced by chemical bath deposition proceed via a different mechanism than the electron-based electro- and electroless techniques. The final compound should be rather insoluble and also very stable in the typically aqueous bath, and the necessary ions must be generated slowly or the compound will simply precipitate from solution as large-grained powder [10]. The chemistry required to accomplish these stringent goals varies with the desired film, but once it is established the compound may be deposited on metals, plastics or ceramics. CdS is a widely-studied material that can be deposited via chemical bath, a technique that still produces the best quality films for buffers in CIGS solar cells [11]. CIGS layers have also been produced from chemical baths [8], and the deposition of metal oxide insulators and conductors have been widely explored [12].

Ink-based thin-film deposition techniques

Deposition techniques such as screen-printing and non-contact printing can be used for the deposition of thin films, but might not be the most cost-effective approach when a uniform coating is required on a large-area substrate. Alternative techniques that also have high material utilization used in production of photovoltaic devices are based on spray deposition and blade coating. Obviously, the main use for these techniques is in the deposition of thin film.

Spray coating

Spray coating is a technique that can be used to deposit homogeneous films on large substrates. During spray deposition, precursor ink is pumped toward the tip of a spray nozzle, where the liquid is agitated (ultrasonically or otherwise), creating a mist of small droplets. A gas flow can be used to carry this mist toward a substrate (Fig. 5). Many different spray nozzle configurations, shapes and sizes are available. Spray deposition is extensively used to deposit fluorine-doped tin oxide (FTO), a TCO commonly used in CdTe photovoltaics. In order to spray deposit FTO, a precursor solution is sprayed onto a hot substrate, and the desired material is acquired by means of pyrolysis on the surface. Due to the high temperature, this method can only be used to deposit a thin film on top of materials that can sustain such aggressive heating, such as glass.

> "During spray deposition, precursor ink is pumped toward the tip of a spray nozzle, where the liquid is agitated."

An alternative and less aggressive method using a spray-coating technique is to deposit the inks at a lower substrate temperature, and subsequently use moderate heating to drive off solvent. When using this method, in most cases, a post-deposition processing step will be required to obtain the desired material. If this processing step includes high temperatures, rapid thermal processing (RTP) can be used to keep the exposure time of underlying layers to a minimum. Spray deposition of films other than TCOs for photovoltaics is currently predominantly used on a research level, although it can be readily scaled to production-size substrates and throughput.

Blade coating

Blade-coating techniques come in numerous variations, and slot die coating is one of the most widely used in photovoltaic production. In slot die coating, two metal or plastic plates with controlled spacing are used to create a small bead of liquid at the open end. The slot die is positioned in such a way that the bead touches the substrate surface but the applicator itself does not. The substrate is moved perpendicular to the opening in the slot die. Ink must be pumped through the slot die at a rate equal to the consumption at the substrate in order to get a homogeneous coating (Fig. 6). Slot die coating is extensively used in the field of organic photovoltaics as it allows for the deposition of extremely thin films (~100nm). Slot die coating is very versatile as it can also be used to deposit film with thicknesses of several μm, which makes it suitable for deposition of inorganic thin-film photovoltaics such as CIGS and CdTe. The thickness of the deposited films is controlled by the properties of the ink, i.e., viscosity and wetability, as well as the slot die deposition parameters, i.e., substrate draw speed, slot width, slot-to-substrate distance and angle. As an alternative to slot die coating, knife coating can be used. Knife coating is less suitable for some applications since it is a contact deposition method, whereas slot die coating is a non-contact method.

Spin coating

Like the other ink-based thin-film deposition techniques, spin coating starts with liquid ink containing carefully chosen components. This ink is applied to the substrate, and the substrate is rotated rapidly. Solvent is lost as the ink flows radially outward and thins, which increases the concentration of the remaining solids and the overall viscosity of the ink [13]. Ultimately, the ink viscosity reaches a critical point and the final solid film forms, although in many cases post-deposition heat treatment is required to decompose undesirable components. Spin coating was developed to deposit organic photoresists for patterning electronic components, and it is a favourite technique of the organic photovoltaics research community for depositing conducting or semiconducting polymers. Inorganic material scientists have also developed inks that can be spin coated to deposit high-quality films of materials such as ZnO [14] and CIGS [15]. While this technique is quite versatile and useful for small-scale precursor ink development, it may not be the best choice for the large-scale manufacturing regime where fast processing and high throughput are required.

Conclusions

We have reviewed atmospheric thin-film deposition techniques that are already used in solar cell production, such as screen-printing, electro-deposition, and chemical bath deposition, as well as other techniques that are under development for future use. Many of these methods are simple enough that they can be implemented rapidly with low capital investment, although development of precursor inks is not always as straightforward. An excellent overview of chemical strategies for preparing such solutions for inorganic materials is available in a recent publication [16].

The ultimate goal of any efforts made toward precursor development and thin-film or pattern deposition is to decrease cost, and based on this criterion the atmospheric processing techniques described here are not equivalent. While low up-front equipment costs are attractive, materials utilization over the lifetime of a manufacturing plant will have a more significant impact on the final module cost. Spray and slot die coaters are able to deposit the majority of their inks as blanket-coated films, and the various printing techniques discussed utilize an even greater percentage of the precursor solution to create thin-film patterns. By contrast, bath-based techniques convert a small fraction of the initial solution into thin films or lines.

The photovoltaics community will undoubtedly continue to develop innovative approaches to reducing the cost of solar cells, and atmospheric techniques will play their part along with more traditional vacuum-based thin-film deposition methods. While it cannot be predicted which atmospheric processing techniques will gain wide acceptance within the industry, we are confident that at least some of them will provide stepping-stones toward the goal of grid parity.

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About the Authors

Dr. Heather Platt studied the solution deposition of metal oxide thin films during her Ph.D. work with Prof. Douglas Keszler at Oregon State University. She is now developing inks to deposit metal films and lines on silicon wafers for photovoltaic cells at the National Renewable Energy Laboratory (NREL). She is extensively using direct-write deposition, spray deposition and RTP.

Dr. Maikel van Hest is currently a senior scientist in the process technology and advanced concepts group in the National Center for Photovoltaics at NREL. His principal areas of research and expertise include: solution-processing for silicon and thin-film solar cell application, vacuum deposition and transparent conductive oxides. His current work focuses on the development and basic science of solution-deposited materials (metals, CIGS, CdTe and TCOs) and the development of next-generation process technology for materials and device development (direct write deposition, spray deposition and RTP).

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Ramping a novel cadmium telluride thin-film solar photovoltaic module production process

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ABSTRACT
Thin-film solar photovoltaic technology offers the benefits of low-cost and high-volume production. Yet numerous thin-film PV startups have struggled in their efforts to commercialize complex, expensive production technologies, as production ramps have taken longer than expected, and venture capital and other sources of funding have run dry. This article describes a proprietary cadmium telluride (CdTe) thin-film module production process commercialized by Abound Solar: heated-pocket deposition (HPD) of the semiconductor layer, and the replacement of a traditional lamination process with a novel edge seal. The simple production process has resulted in a fast ramp of module efficiency and throughput. The paper also describes how the process can result in fast throughput, high yields, and low manufacturing and capital equipment costs.

Abound Solar manufactures photovoltaic modules utilizing thin films of cadmium telluride (CdTe) as the main semiconductor layer. The company began in 2007 as AVA Solar with the goal of significantly reducing the cost of solar-generated electricity. The core technologies were developed during 15 years of research and development at Colorado State University (CSU). The efforts focused specifically on developing high-volume production processes with low manufacturing costs.

Automated manufacturing

Abound's advanced production facility is fully automated with production lines laid out in a linear manner to optimize workflow. In order to balance production cycles of all the different tools, equipment within the line 'pull' materials and work-in-progress from the preceding tool. Strategically placed queues help facilitate materials replenishment and minor maintenance, minimizing production disruption. Based on comments from program managers at the U.S. National Renewable Energy Laboratory (NREL), the plant may be one of the most highly automated PV manufacturing facilities in the world.

Figure 2. Automated back-end module assembly tools at the Longmont, Colorado manufacturing facility. These fully-automated systems have a throughput of approximately 65MW per annum.

In order to create a balanced production line, multiple pieces of equipment are used, in parallel, to perform processes with slower cycle times. This balanced production line forms what is referred to as a manufacturing 'cell', which has a nameplate capacity of 65MW, equivalent to a throughput of approximately 900,000 modules per year. Fig. 1 is a block diagram schematic of the manufacturing processes in each cell, while Fig. 2 shows a picture of the back portion of the manufacturing cell from bus car to back-box application tools. Module fabrication time, covering the time it takes to convert the incoming glass sheet to a packaged product ready to ship, is approximately 2.5 hours. The manufacturing cell will be the building block used for the company's upcoming expansion plans.

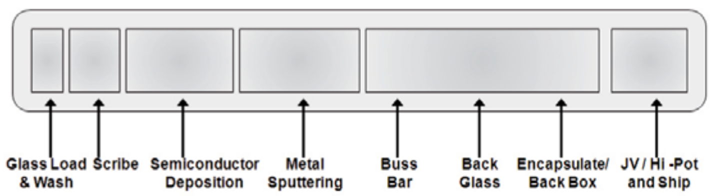

Figure 1. Overview of complete Abound Solar PV module manufacturing process, with glass entering on left and modules crated for shipment on right. The entire line forms one manufacturing cell with approximately 65MW annual capacity. Total product cycle time, end to end, is 2.5 hours.

Technology foundation

Semiconductor processing is the most critical aspect of thin-film PV

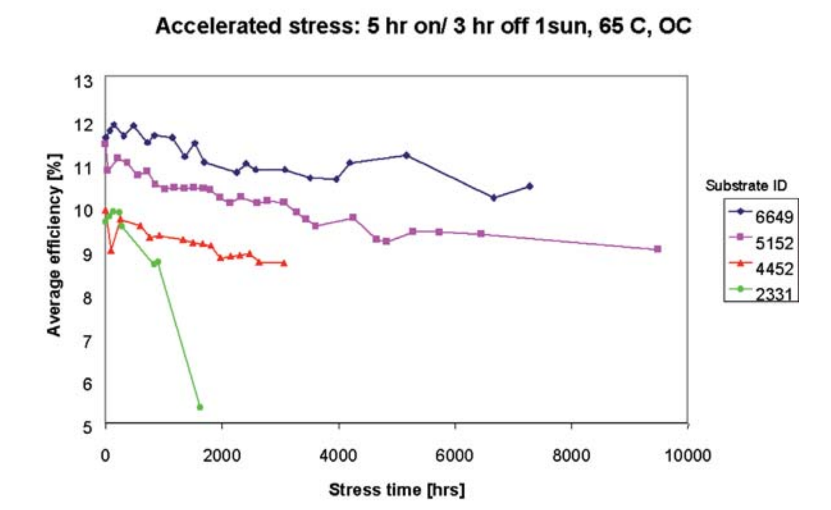

Figure 3. Effect of $CdCl_2$ treatment on stability, with each line an average of at least eight cells all with the same back contact; stress condition: 1000W/m^2 (five hours on out of an eight-hour cycle) illumination; open circuit bias; temperature 65°C [4].

manufacturing. Before the incorporation of the company, a 15-year process development program was conducted at CSU [1, 2] where a pilot-scale semiconductor manufacturing process was demonstrated for 8 × 9cm size substrates. PV device efficiencies of 11 to 12% [1] were routinely obtained while developing an understanding of how process conditions have an impact on device performance and stability (resistance to performance degradation under stress) [2,3]. Optimization of process conditions, particularly the cadmium-chloride ($CdCl_2$) treatment [1,4], was required to achieve good initial performance with excellent stability [3].

Fig. 3 shows the variation in stability with intentional changes in the $CdCl_2$ process. Copper doping at the back of the device was found to increase performance by reducing the device series resistance. When processed with optimal quantities and annealing temperatures, no significant variation in the copper depth profile was seen after stress when devices were analyzed by secondary ion mass spectrometry (SIMS), as shown in Fig. 4. Process repeatability over multiple runs and controlled operation over relatively long duration operation were also demonstrated [4]. The pilot-scale effort successfully proved the feasibility and capability of the inline semiconductor deposition process and enabled the formation of the company [5,6].

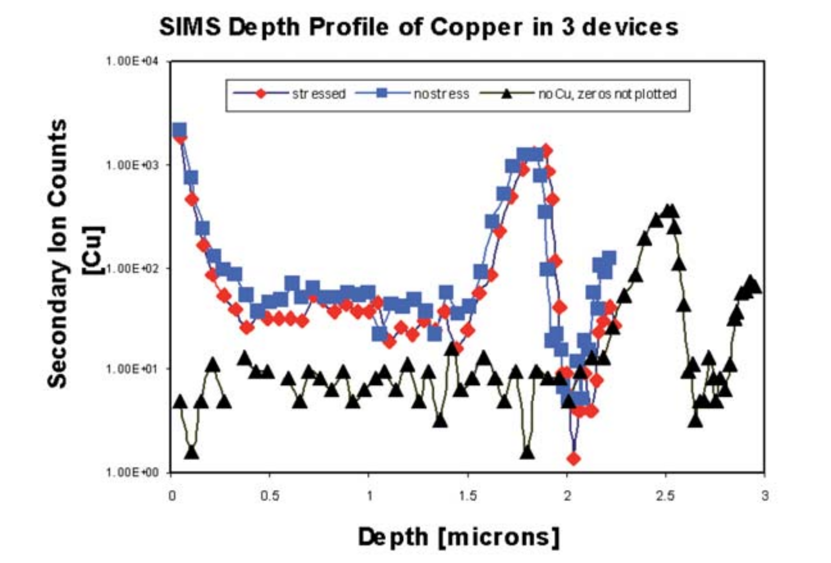

Figure 4. SIMS depth profile of nearly identical devices with and without stress. Stress condition: 3300 hours at 1000W/m^2 illumination (five hours on out of an eight-hour cycle); open circuit bias; 65°C temperature.

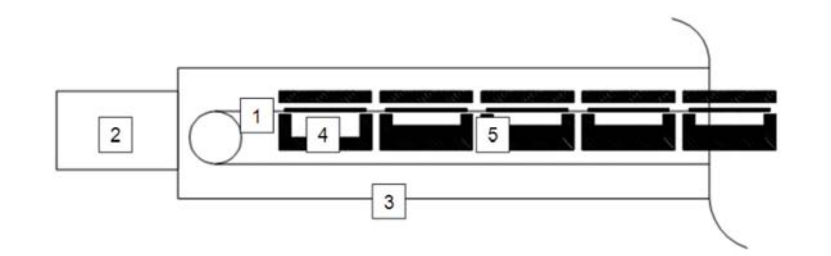

Figure 5. Schematic cutaway detail view of a portion of the semiconductor deposition system showing: (1) the substrate transport belt; (2) the entry loadlock; (3) the vacuum chamber; (4) the substrate heater; and (5) the series of HPD sources for sequential processing. The substrate is positioned between the upper and lower sections of the HPD sources on the belt conveyor.

Semiconductor processing

The heart of Abound's semiconductor processing toolset is the heated-pocket deposition (HPD) technology developed by the founding team at CSU [7]. The HPD technology can be configured to perform substrate heating, thin-film deposition, or chemical heat treating (such as the $CdCl_2$ treatment) and can operate in modest vacuum (~10^{-2} Torr) conditions. The HPD process head is comprised of a thermally conducive crucible with recesses or 'pockets' positioned under the substrate. A thermally active element that provides either heating or cooling is aligned over the substrate to further control temperature. When the crucible is heated above the sublimation point of the materials in the pocket, a vapour flux is generated. There is a separation distance between the substrate and the surface of the subliming material. Collisions between the sublimed species and the background gas (predominantly nitrogen) result in scattering, which facilitates vapour-flux uniformity. The pockets can be left empty for substrate heating processes. Substrates are transferred into the HPD unit on a conveyor belt.

A number of these HPD process heads are laid out in series to perform all semiconductor processes needed to fabricate the CdTe device. In this manner, a manufacturing system has been developed in which cleaned glass substrates enter on one side, and devices with all semiconductor processes completed emerge from the other end of the system. Fig. 5 shows a schematic illustrating some of the major components of the process tool.

The design for this semiconductor tool, including the HPD process heads, has been

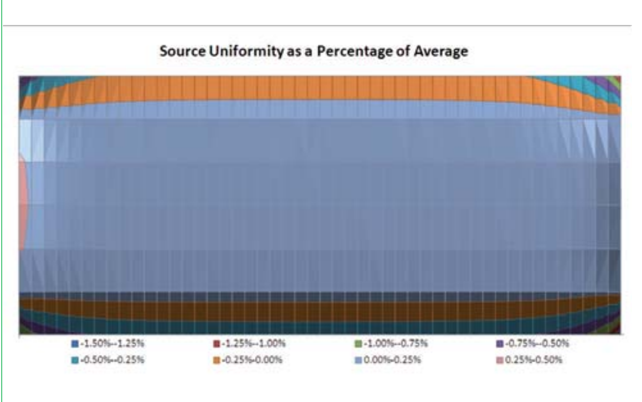

Figure 6. Finite element heat transfer computer model showing relative thermal uniformity of the HPD vapour source at operating temperatures.

optimized using finite element heat transfer and computational fluid dynamics modelling methods. Fig. 6 shows the numeric modelling results of thermal uniformity for a sample HPD vapour source; the pocket region of the process head is modelled here. Relative temperature variation would impact the vapour-flux emission uniformity in the HPD source, which ultimately affects module performance. Models such as this are used to optimize heater location and radiation shielding to minimize thermal gradients.

One design criterion for the HPD process head involved the maximization of the interval of operation before replenishment, since the maintenance frequency is different for different process heads, depending on the process and materials being vaporized. In the current-generation semiconductor tool, copper and cadmium-sulphide (CdS) process heads are run about four weeks and six months respectively, before replenishment. The latest production plan calls for the weekly replenishment of the CdTe and $CdCl_2$ process heads, after continuous operation and prior to chemical depletion.

The production tools are completely automated, with manual intervention needed only for servicing. Substrate loading, loadlock operation, belt indexing, HPD operation, and completed semiconductor plate unloading are also fully automated. Multiple tools operate simultaneously, with both upstream and downstream automated glass-handling systems in the factory. Tools are serviced sequentially, with all equipment operational or only one tool offline for replenishment at any given time.

Development speed

On a number of levels, Abound has developed at a rapid clip. The company has progressed from its initial formation to large-scale commercial shipment of Underwriters Laboratories- and IEC-certified products in less than 36 months. The semiconductor processing technology was taken from a pilot-scale demonstration for 8 × 9cm substrates to encapsulated prototype 120 × 60cm modules in under 24 months. The Longmont manufacturing line development took 17 months to progress from the signing of a lease on an empty building to automated fabrication of commercial modules.

Yields have increased through a consistent effort to identify, understand, and address root cause issues. Three processes – patterned laser scribing, perimeter deletion of semiconductor films, and encapsulation edge-seal application – were key targets of yield improvement efforts.

Patterned laser scribing of the semiconductor films is used for module series interconnection. Incomplete scribe lines can reduce the module power through a decrease in the shunt resistance or an increase in the series resistance. Process tuning and revisions to the laser optics cleaning have led to yield enhancements. The perimeter deletion of the semiconductor films removes any coatings around the edge of the module. High pot yield losses were significantly diminished through revisions to the edge-delete process,

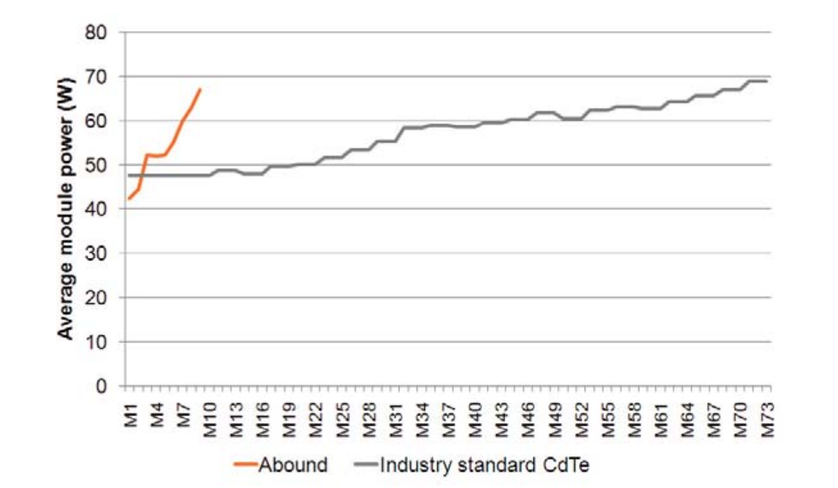

Figure 7. Module power output compared to a leading CdTe vendor.

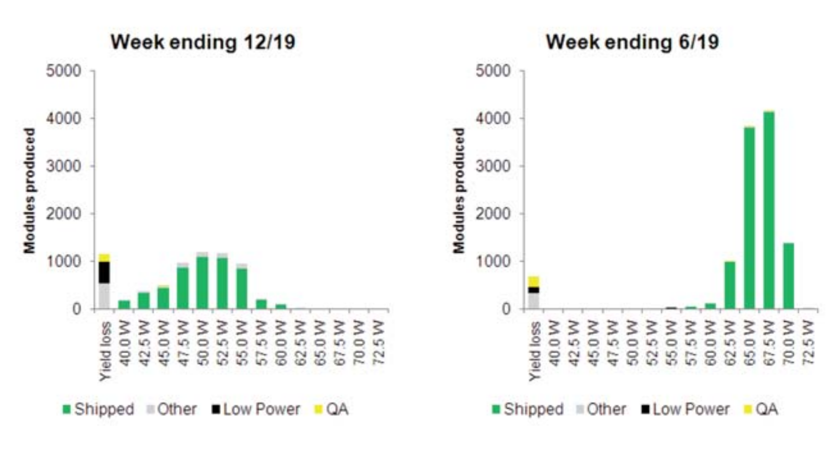

Figure 8. Representative production yield and efficiency improvements for the first half of 2010.

specifically the motion control software. Yield losses from the encapsulation edge-seal application processes were significantly reduced with the design and implementation of a new injector nozzle to apply silicone compounds without gaps.

At time of writing, the company produces approximately 9.5% (total-area) efficient modules. The initial production efficiencies were approximately 6% but were improved to the current levels in approximately nine months. A leading CdTe module manufacturer required approximately 65 months to achieve 9.5% modules (Fig. 7). It is believed that this relatively rapid improvement has been facilitated by the well-developed, automated HPD semiconductor process.

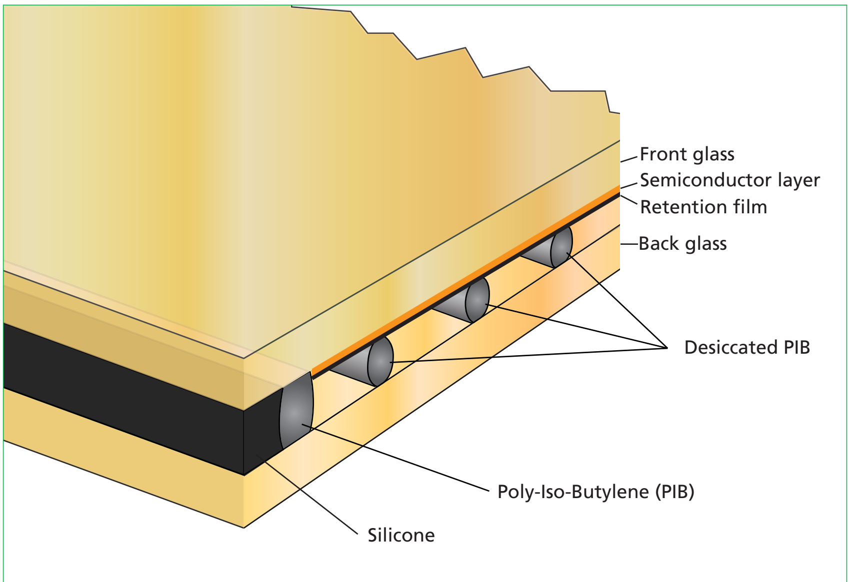

Figure 9. Diagram of module encapsulation design.

Average module efficiency has also improved rapidly through the optimization of semiconductor deposition. The CdS deposition and $CdCl_2$ heat treatment process were investigated for performance gains. Thinning the CdS layer is a well-known path to improved module current, as the increased current results from the improved blue light response with less absorption by the CdS window layer [8]. However, insufficient CdS leads to decreased device voltage, and it is difficult to directly measure the relatively thin CdS thickness (~60–120nm) once the CdTe film (~2 micron) is deposited over the previous layer.

> "Process tuning and revisions to the laser optics cleaning have led to yield enhancements."

A design of experiments approach was used to understand the effects of intentional process variation on module performance. Successful reductions in CdS thickness were accomplished by optimizing the substrate temperature both immediately preceding and during deposition of the film layer, while enhancements in HPD thermal uniformity, aided by the finite element modelling methods, improved CdS uniformity. These upgrades enabled reductions in the overall film thickness, while minimizing thin, low-voltage regions.

Optimal substrate processing temperatures were also developed for the $CdCl_2$ treatment. Treatment temperatures were generally increased, which resulted in higher device voltages while providing excellent device stability under accelerated stress. As with CdS, relatively minor enhancements in the $CdCl_2$ process station's thermal uniformity fostered more uniform properties across the module.

With the improvements in the overall module performance, the distribution of product performance has also narrowed (see Fig. 8). In addition to being a metric for manufacturing process capability, a narrow performance distribution benefits customers by reducing performance variation and facilitating PV system design.

Module encapsulation

The company has developed a proprietary module encapsulation design (shown in Fig. 9) that is optimized for the specific characteristics of the CdTe thin-film semiconductor deployed in

Figure 10. Desiccated PIB dispense station on a manufacturing line.

production. The objective of this design innovation was to improve reliability and manufacturability compared to existing module packaging methods.

The frameless module is constructed with two glass pieces. The heat-strengthened front glass contains the semiconductor films and faces the sun when the module is installed. A tempered back glass provides mechanical strength and is affixed to the front glass with a silicon edge seal. The silicone materials impede liquid water penetration and a poly-isobutylene (PIB) seal inboard of the silicone resists moisture-vapour ingress. Additional desiccant containing PIB bridges between the two glass plates, further improving mechanical strength (see Fig. 10). The desiccant captures any moisture that may penetrate the edge seal and will maintain low moisture-vapour levels suitable for the 30+ years of field exposure. The semiconductor material on the front glass is coated with a 'retention film,' which provides an additional level of encapsulation and retains glass pieces in the unlikely event of module breakage.

The addition of the desiccated PIB inside the module structure has improved reliability and enabled the moisture level near the film to be maintained at a consistently low level during the module lifetime. Alternate encapsulation systems without internal desiccation schemes will likely see moisture levels increase as the encapsulate materials saturate with water over time. The IEC and UL certification standards require that modules pass 1,000 hours of damp-heat testing at 85°C and 85% relative humidity, widely considered a very rigorous test for thin-film modules. Modules with the novel encapsulation method and the internal desiccant have been damp-heat stressed for about 4,500 hours (Fig. 11) with no evidence of moisture ingress or significant performance degradation.

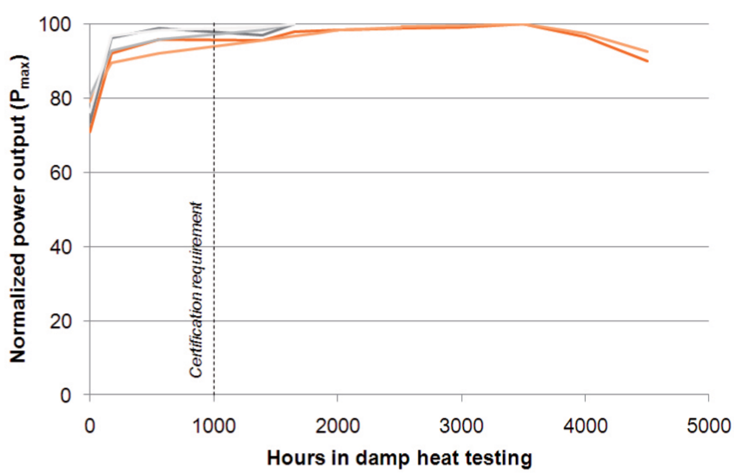

Figure 11. Performance of multiple modules in damp heat.

> "The addition of the desiccated PIB inside the module structure has improved reliability."

This module design has enabled the development of a streamlined synchronous manufacturing process, partially shown in Fig. 12. In a similar manner to the semiconductor processing tools, all module encapsulation, busbar, back-box application and potting processes are performed on automated inline equipment. The silicone/PIB edge-seal applications processes can each be performed in approximately 20 seconds per panel, in contrast to the traditional EVA lamination process cycle time of 10–15 minutes.

Capital expenditures and manufacturing costs

The company presented a detailed review of the factory construction, manufacturing equipment layout and production capacity to NREL managers to verify capital equipment costs. The review included categories such as hardware, equipment installation, building costs, and facility improvements/upgrades. When appropriate, purchase orders or quotes were used to ensure accuracy for the vendor-supplied hardware. Capital equipment costs significantly below US$1.50 per watt were demonstrated for the full build-out of the existing Longmont manufacturing facility to 200MW/year [9]. These results are among the lowest capital equipment costs reported for any PV manufacturing technology.

Module manufacturing costs are calculated to be less than US$1 per watt in the existing Longmont manufacturing facility, figures that were reviewed by NREL managers. Module manufacturing costs were demonstrated as the total manufacturing cost of sales of the modules produced in a given period divided by the total cumulative wattage output of the module produced in that same period. Direct material, variable costs including direct labour, yield losses, glass recycling, and freight costs, overhead and manufacturing equipment depreciation, were categories included

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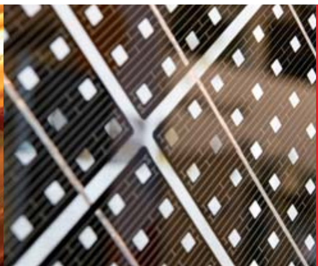

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in the analysis. Manufacturing costs below US$1 per watt for the initial manufacturing facility were calculated [9], also among the lowest reported in the PV industry, particularly for an initial factory.

Summary and future challenges

A manufacturing-centric approach was taken to design the production process and product at Abound Solar. The focus on minimizing capital expense while optimizing throughput has enabled the development of a robust CdTe production platform that has demonstrated low capital and operating costs and a fast ramp of throughput and efficiency. Future developments will be focused on continuing the pace of improvements in production volumes and product conversion efficiencies to meet customer demand and to be more competitive with crystalline-silicon PV products. Once key milestones have been achieved on throughput and efficiency, the company will begin the replication of the production line to expand capacity at its existing Colorado facility as well as at the Indiana manufacturing site to be developed. The addition of numerous lines across multiple sites will test the company's ability to maintain consistency across deployment teams and equipment fabricators. Ongoing R&D activities continue to refine semiconductor deposition parameters. The company believes that the original manufacturing platform will continue to be significantly robust to accommodate such refinement and widespread deployment, but only time will tell if the strong progress of performance will continue under such conditions.

Figure 12. Module fabrication back end and binned product.

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About the Authors

Kurt Barth is a founder of Abound Solar and an inventor of the company's proprietary thin-film solar manufacturing technology. He is Abound's senior technologist and has also been VP of product development, on the board of directors, and corporate secretary. Barth directed the company's Solar America Initiative project with NREL and has served as project director on many federally sponsored programs. He has over 17 years' experience in photovoltaics research and manufacturing process development. In addition to eight patents in the solar field, Barth has published more than 70 refereed papers and presentations focussed on thin-film solar. He holds a B.S. and M.S. in mechanical engineering from Colorado State University.

Mark Chen is director of marketing at Abound Solar, where he is responsible for strategic development, external communications and government relations. Before joining the company, he was a project leader at the Boston Consulting Group, where he focused on strategic and operational issues for semiconductor and telecommunications clients. Chen holds a B.S. and M.S. in electrical engineering from MIT and an M.B.A. from Harvard Business School.

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High productivity combinatorial study of wet chemical texture etch of sputter deposited Al-doped ZnO thin films for thin-film Si solar cells

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ABSTRACT

This paper presents a high-productivity combinatorial (HPC) parallel processing method based on multiple site-isolated cells on a single substrate. This method has been applied to the acidic wet chemical texture etch of sputter-deposited Al-doped ZnO (AZO) film on glass substrates for light-trapping enhancement for thin-film Si solar cells. Taking a fraction of the time and resources that would usually be required for such a project, the HPC method allows fast chemical screening of various inorganic and organic acids as potential replacements for the standard hydrochloric acid (HCl) texture etch process currently used in R&D and pilot production. Several candidate acids have shown either similar texture performance at much reduced AZO film etch or superior texture performance at the same etch depth as compared to the standard HCl texture etch. The large amount of data collected using the HPC approach also enabled us to ascertain the crystal orientation-dependent anisotropic etch as the dominant texture etch mechanism for AZO films using a wide selection of acids.

Background

Surface texturing of aluminium-doped zinc oxide films (AZO) is an efficient way of increasing the efficiency of amorphous silicon-based solar cells by trapping light more effectively. Dilute HCl solutions have routinely been used to etch the sputter-deposited (or physical vapour-deposited, PVD) AZO films to generate the necessary surface texture. Up to now, relatively few chemicals have been tested to improve the surface texturing process, and there appears to be a very limited understanding of the relationship between chemical structure, surface topography and light trapping efficacy.

"Up to now, relatively few chemicals have been tested to improve the surface texturing process."

The combinatorial methodology is demonstrated as a fast, efficient, and accurate mode of improving research and development of solar applications. Using Intermolecular's HPC technology, a large number of potential formulations were tested in a fraction of the time and resources normally required. A new methodology is presented for screening thousands of samples in far less time and with fewer substrates than previously possible. The large amount of experimental data enables the identification of different classes of chemicals that can be used to control the resulting topography, and to formulate an empirical understanding of the relationship between surface topography and light scattering. These empirical and phenomenological models will be further used to find the best texturing formulation to obtain maximum solar cell efficiency.

Experimental

Deposition of AZO films

AZO films were deposited on circular glass substrates with 8" diameter on an Applied Materials Endura PVD tool at Intermolecular's lab in San Jose, California. Process conditions were optimized to obtain good quality AZO films with resistivity in the range of 550-650μΩ/cm and good transparency. As a nominal baseline, films with thickness from 1200 to 1300nm were deposited from a composite ZnO target with 2 weight % Al doping. Substrate temperature during deposition was 300°C; deposition time was 600 seconds. The root-mean-square (RMS) roughness as measured by atomic force microscopy (AFM) was in the range of 4-6nm.

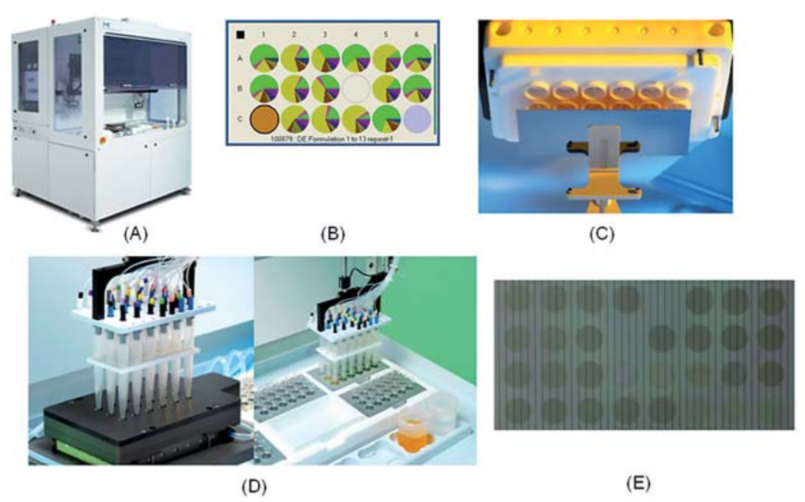

Figure 1. Intermolecular Tempus-F20 tool set. A: Tempus-F20 photo; B: chemical formation library schematics; C: reaction cells; D: chemical solution dispense system; E: example of the 32 reactor cells after texture etch.

Thin Film

Texturing and characterization

The circular substrates with AZO films were cut into rectangular pieces of ~120mm x 60mm in size for performing multiple experiments in parallel on the Intermolecular Tempus F-20 platform as described in the following sections (see Fig. 1). Rectangular substrates with 32 unique experiments were placed in various characterization tools and mapped in an automated manner. Intermolecular's Informatics system automatically acquires process and characterization data from various tools and organizes them in the database by correlating the process and characterization results of each experiment. This structured data is then made available for analysis on the Informatics platform. Automated mapping on characterization tools, data acquisition and data organization are important aspects of the HPC approach, and are made all the more necessary when dealing with hundreds of experiments and characterizations in one day (see Fig. 2).

Film thicknesses of untextured AZO films were measured using spectroscopic ellipsometer (Woollam M2000) and x-ray fluorescence (XRF) techniques (Panalytical PW2830). Sheet resistance and resistivity were measured using a four-point probe (CDE ResMap 273). Thickness loss after texturing was measured by change in sheet resistance and confirmed by XRF measurements, and AFM measurements were obtained using Veeco's Dimension 3000. Diffused light scattering and total transmission measurements were carried out on Shimadzu 3700 tool using a 60mm integrating sphere. X-ray diffraction (XRD) measurements were performed on a Panalytical X'Pert Pro MRD XL DY-2709. Fig. 3 shows the XRD spectra of a representative film.

Intermolecular Tempus F-20 platform for HPC research

The Tempus F-20 platform was used to make chemical formulations and multiple texturing experiments on a single substrate. The reactor of the Tempus F-20 is shown in Fig. 1. Up to 32 different formulations can be processed in isolated reaction sites on a single wafer coupon. The formulations to be tested can be mixed automatically on the tool or on a Tempus F-10, both of which eliminate human error from the mixing process to yield better repeatability without any loss of precision. After the solutions are prepared, the robotic arm shown in Fig. 1D picks up the solutions and dispenses them into the isolated reactor sites. Process steps and process parameters such as temperature, solution agitation and reaction cell rinse procedures, etc. are all automated while still giving the user full flexibility. All process and formulation information is captured by the Informatics platform and organized along with characterization data to help data analysis.

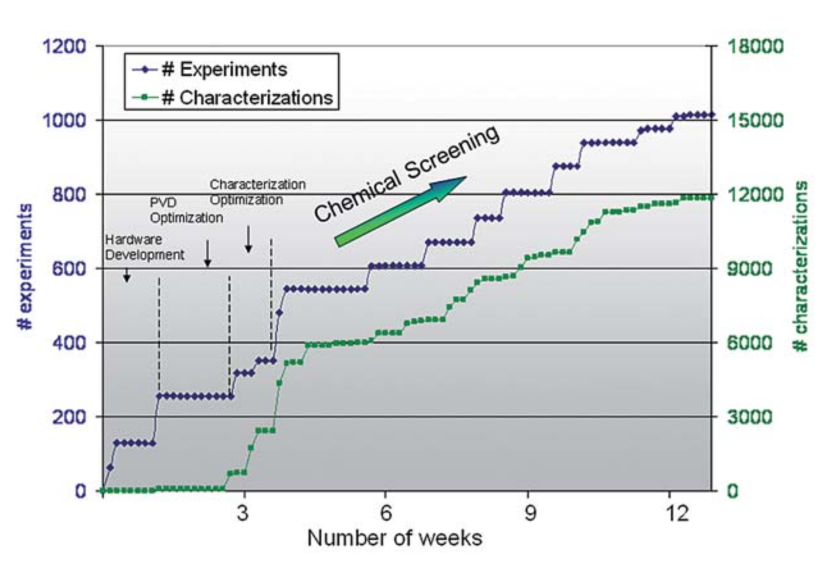

Figure 2. AZO texture etch process progress over three months using the Intermolecular HPC approach including the Tempus-F20 process tool, the Informatics system, and the automated film characterization methods.

Results and discussion

Employing the HPC approach enabled the performance of a large number of experiments with varying etching chemicals, compositions and etch rate in a very short time (see Fig. 2). After few days of hardware improvements and development of AZO films, we were able to do a large number of experiments and test four inorganic acids, 11 organic acids and their mixtures in a very short time. In a few weeks, nearly 700 unique experiments were conducted. The massive amount of experimental data generated during these experiments helped the development of formulations that appear to offer performance advantages compared to the standard HCl-based formulation. In addition, this massive data set also enabled us to better understand the fundamental etching mechanism at work in this process.

Properties of AZO films

The same AZO films and deposition conditions were used for all experiments. The crystal orientation of AZO film relative to the substrate is important to obtain the correct texture. The modified structure zone diagram [3] indicates that compact crystallites with c-axes perpendicular to the substrate surface are needed to produce a suitable texture for thin-film solar cells. Fig. 3 shows typical XRD spectrum of AZO films used in this study. The existence of only two major XRD peaks for (0002) and (0004) faces confirmed that the c-axis of the crystallites is indeed perpendicular to the substrate surface. The size of the crystallites calculated using Scherrer equation [1] from XRD analysis is in the range of 20-30nm, consistent with most previous reports [2].

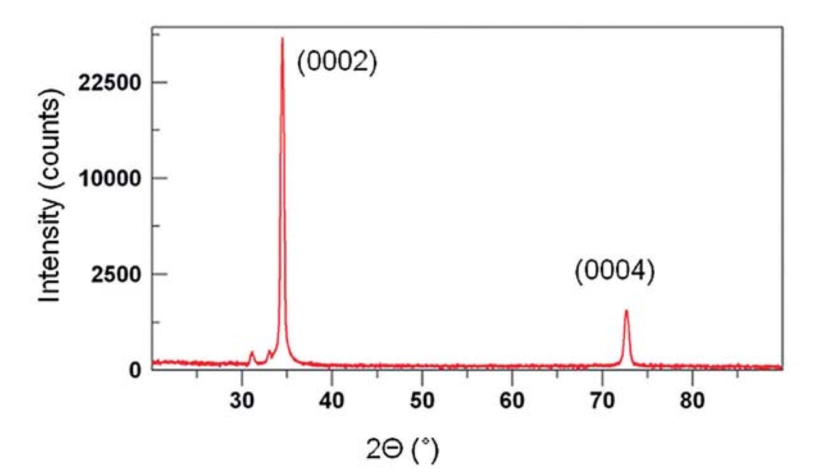

Figure 3. XRD spectrum of typical AZO films used.

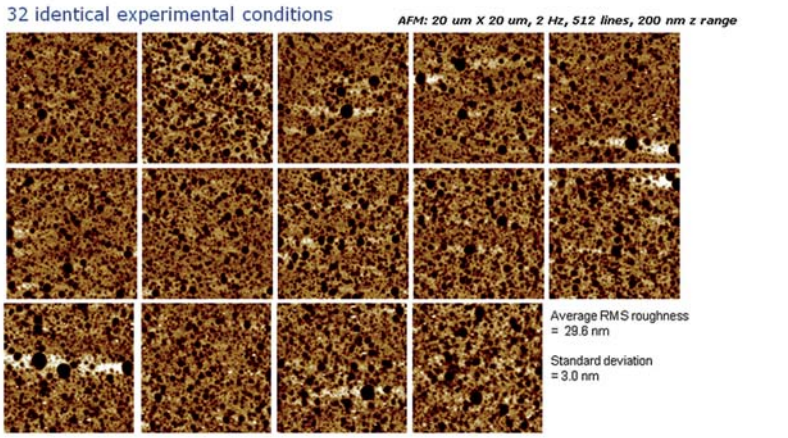

Figure 4. 2D AFM morphology for 14 selected cells from 32 cells on a single AZO substrate processed under identical conditions.

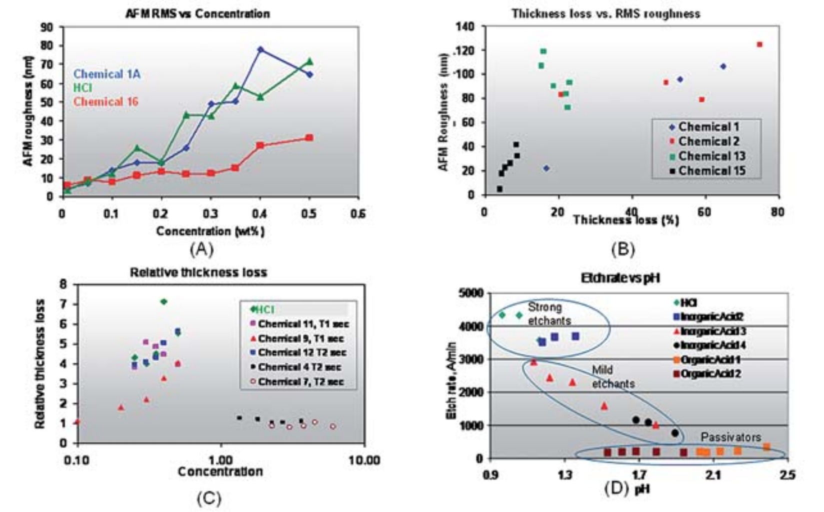

Figure 5. Primary screening results for wet texture etch of AZO films. A: AFM roughness as a function of acid concentration; B: AFM roughness as a function of AZO film thickness loss with different acid etch; C: relative AZO film thickness loss as a function of acid concentration; D: AZO film etch rate as a function of acid solution pH.

Reproducibility for site-isolated parallel processing of wet chemical texture

Fig. 4 shows the AFM morphology of 14 selected cells obtained under the same process condition as an example of the process reproducibility for site-isolated parallel processing. Cell-to-cell variation was confirmed to be small enough to allow for the comparison of various experimental results.

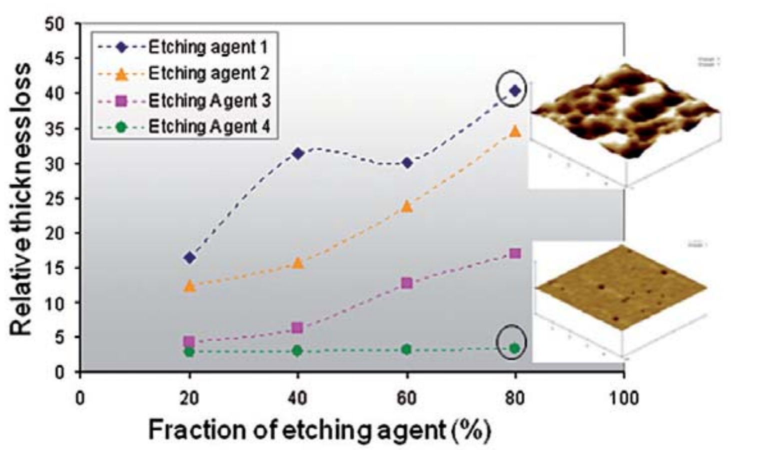

Figure 6. Relative AZO film thickness loss as a function of passivator concentration for mixed acid formulations containing various active etchants and passivator chemicals.

Primary screening

Experiments were performed in screening phases known as primary screening and secondary screening. In primary screening, various chemicals were tested to determine whether or not they produced sufficiently textured surfaces with reasonable loss in thickness at varying concentrations. The texturing performance was characterized by thickness loss and RMS roughness as shown in Fig. 5. The graph in image A shows that almost all chemicals displayed increasing texture with increasing concentration. However, some chemicals were more efficient at producing texture at lower concentrations. Image C in Fig. 5 shows thickness loss by various chemicals at different concentrations, which enables the identification of what chemicals can etch AZO and determine etch rates. The graph in B compares the texturing performance of various chemicals, and through the use of the primary screening process, those chemicals that produce higher RMS roughness with less thickness loss can be identified. The chemicals were also classified into strong etchant, mild etchant and passivators based on the etch rate and pH plots (image D, Fig. 5).

Mixed formulations were also tested for their texturing performance. Fig. 6 shows a plot of few combinations of etchants with one passivator, clearly showing that varying the relative concentration of passivator has different effects with different etchants. For example, the passivator is very effective in reducing the etch rate of etchant 4; however, when combined with etchant 1, its effectiveness in lowering the etch rates is reduced.

Secondary screening

After selecting various potential chemicals and mixtures of chemicals based on etch rate and RMS roughness, secondary screening was performed by measuring the optical spectrum in diffused transmission mode. Illustrative optical spectra of some textured surfaces are shown in Fig. 7A. The optical performance was evaluated by the peak value of percentage transmission in the optical spectrum. Fig. 7B shows the optical performance of various formulations at varying etch times plotted with respect to the thickness loss (only data from some selected formulations are shown here). It is clear from this plot that many chemical formulations perform better than the industry standard HCl formulations. Similar optical performance is obtained at smaller thickness loss, while better optical performance is obtained at the same thickness loss. In this manner, by using a phased screening approach and HPC tools, we were able to obtain many formulations that show better optical performance compared to HCl while also classifying different chemicals based on their texturing performance.

Topography of textured surfaces and optical performance

During the primary and secondary screening, we used RMS roughness as a preliminary quantitative measure of surface topography. RMS roughness is a very rudimentary method of characterizing surface roughness. Fig. 8 shows optical performance of various textured surfaces plotted against the respective RMS roughness. In general, the optical performance increases with the RMS roughness as a first order effect, but it is also evident that the samples with almost the same RMS roughness have very different optical performances. AFM images of respective samples are also shown in Fig. 8, which also illustrates the significant differences in surface topology.

These results show that RMS roughness is not a sufficient parameter to characterize surface topography and the resulting light scattering and optical performance of the textured surface. Optical modelling to predict light scattering from the surface of known topology using fundamental Maxwell equations is very difficult, and to date, such models have only been able to predict the effect of surface roughness on light scattering texture feature sizes << λ [4,5]. Optical models based on the fundamental Maxwell Theory that can predict the effect of higher order surface topographical parameters are not currently available.

Recently, Krasnov [4] presented a semi-empirical model that can correlate light scattering with multiple surface topographical parameters obtained from AFM images. Surface topographical parameters, such as RMS roughness, Skewness, Kurtosis, and 3D FFT spectra were used to precisely predict angle-resolved scattering (ARS) and spectrum-resolved scattering (SRS) from textured surfaces of AZO films. The model was able to explain the difference in peak positions and width of ARS with various surface topographical parameters.

Currently, we are applying Karsnov's model with the vast amount of data obtained using the HPC approach to further refine the model and develop a phenomenological model and library to correlate the chemical structure of texturing molecules and formulation parameters with light scattering performance of the resulting textured surfaces. Furthermore, we are using this data to find the formulation that can be used to generate textured surfaces that produce highest efficiency solar cells.

Mechanism of chemical texturing and relationship with molecular structures

Anisotropic etching on single crystal ZnO by HCl and other acids to produce hexagonal craters is well understood and is described in literature [2]. The differential etch rates of various crystal planes at the sites of surface defects causes the formation of very uniform hexagonal structures. However, formation of such regular hexagonal craters has not been reported in literature for PVD-deposited AZO films. The hexagonal crater geometry is observed on most of our samples etched with many different inorganic and organic acids, and therefore is independent of the type of acids used for texture etch. Fig. 9 shows 3D and 2D AFM images of such samples.

The graph and images in Fig. 10 show RMS roughness and indicates the bottom angle of the crater for some formulations.

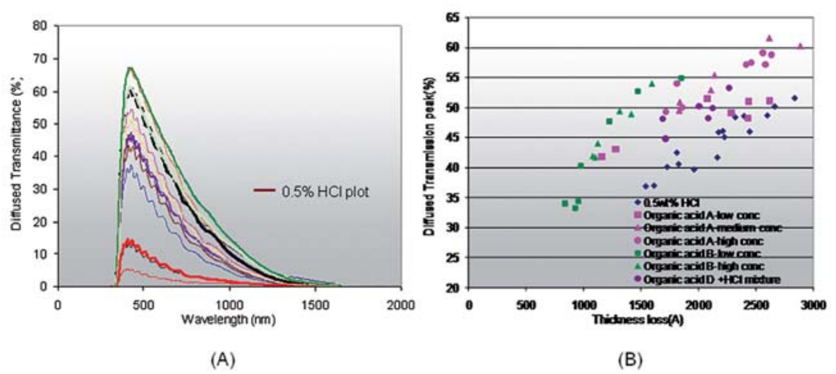

Figure 7. Diffused transmission of textured AZO films from UV-Vis-NIR measurements using a 60mm integrating sphere. A: diffused transmission spectra from AZO films etched in various acid solutions; B: diffused transmission of textured AZO films as function of film thickness loss.

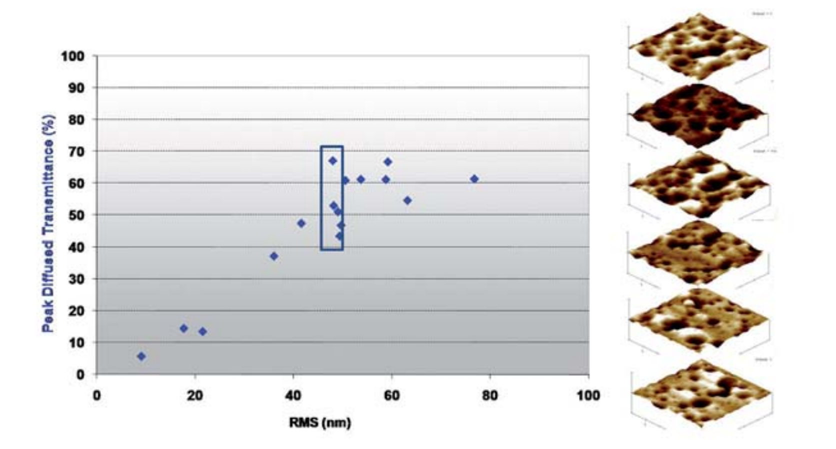

Figure 8. Correlation and lack of correlation between diffused transmission and AFM film roughness for textured AZO films.

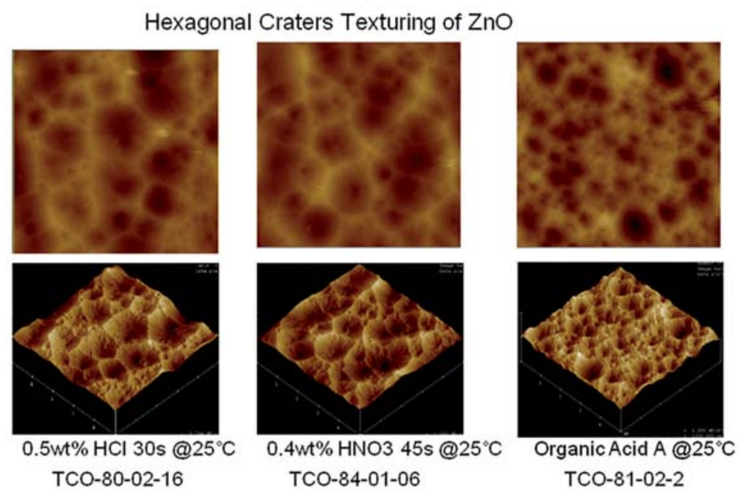

Figure 9. 2D (top row) and 3D (bottom row) AFM morphology of selected textured AZO films showing hexagonal geometry of the craters giving rise to AZO film texture.

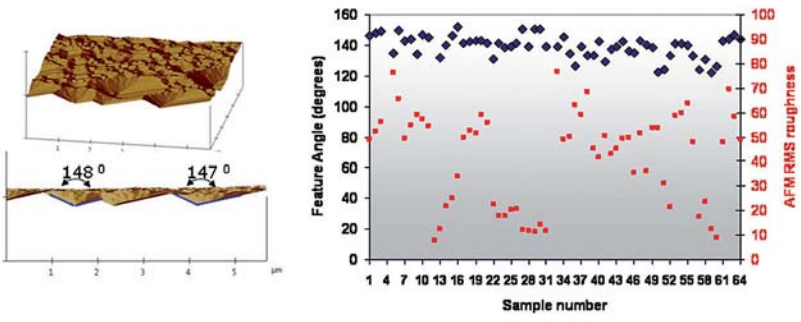

Figure 10. Crater bottom angles measured from AFM for textured AZO films.

Figure 11. Pathway from chemical structure of acid molecules used for texturing AZO film to the resulting solar cell efficiency.

It is clear from this plot that even though the surface roughness varies by an order of magnitude from sample to sample, the crater angle remains relatively invariant between 110° and 150°. The crater angle for a single crystal ZnO surface is ~123° to 130° [2]. We also observed correlation of the bottom angle with molecular structure and composition of various acidic formulations. It has been observed that some classes of acids result in lower angles than others. Furthermore, for some formulations, the crater angle increased or decreased with increasing extent of etching, thereby changing the shape of the craters. This also suggests that relative etch rates of different crystal planes changes with the extent of etching.

> "It has been observed that some classes of acids result in lower angles than others."

For other formulations, the crater angle remained the same with increased etching and the crater shape also remained the same while the crater size increased. For these formulations, relative etch rates of different crystal planes did not change with the extent of etching. We have been able to identify various classes of acid etchants that result in different crater shapes, and are currently using this information along with Krasnov's model to find the optimum formulations.

Conclusion: from molecular structure of acids to solar cell efficiency

In most cases, there is no sufficient theoretical, empirical, and phenomenological understanding of each of the steps in the pathway from the chemical structure of AZO-texturing acid molecules to cell efficiency (Fig. 11), and so each step must be investigated separately. As a result, a reasonably good understanding of how the chemical structure of molecules affects solar cell efficiency is not available and the best solution is often never found. The use of Intermolecular's HPC platform enables parallel experiments on a single substrate and allows scientists to perform a great number of experiments to test the many chemicals, process and formulation parameters in a short time. Parallel and automated characterization combined with a phased screening approach allowed us to quickly identify the chemical classes and chemical formulations that result in the best possible surface texture with minimum loss of AZO thickness. Light-scattering measurements enabled us to develop empirical correlations between surface texture, topography and optical performance, the data from which are being used to further test and validate Krasnov's mathematical model. We are in the process of developing technology for making and testing multiple solar cells on a single substrate in a HPC approach, which will allow us to quickly find the best formulations to produce the highest efficiency solar cells. In parallel, selected formulations will be tested using conventional approaches.

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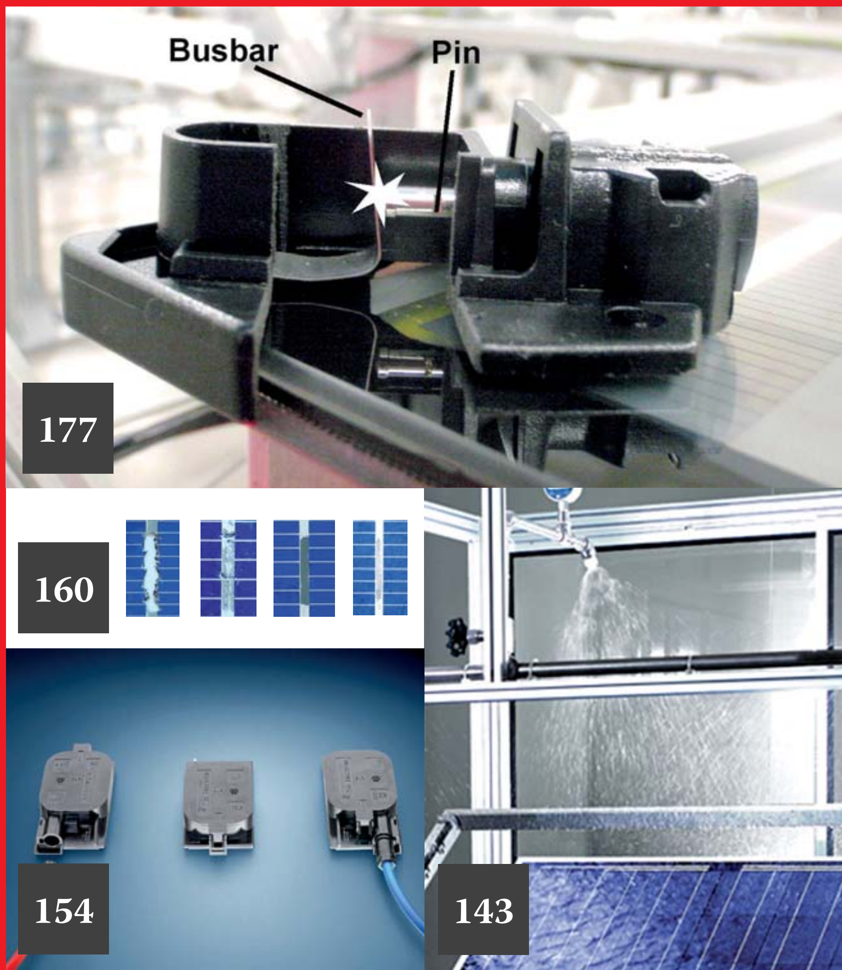

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ET Solar modules being used in UK firm's free solar offer

UK-based renewable energy generator 'A Shade Greener' (ASG) is the first of many companies expected to offer free solar photovoltaic installations to residents in the UK, while the company takes advantage of the feed-in tariff (FiT) payments. ASG has secured supply deals with China-based ET Solar for 185W monocrystalline modules (ET-M572185) and inverters from SMA Solar Technology for the residential rooftop market.

The company, which is based in South Yorkshire, started up in October 2009 with the aim of installing 2,000 PV systems on residential rooftops in select regions. However, since the introduction of the FiT and exposure on the BBC, interest has increased dramatically. A company representative told PV-Tech that customer requests have amplified by so much that they are actually now receiving five calls per second. Due to this unprecedented demand, ASG is expected to expand its workforce from its current northern locations down into the Midlands and the South-West regions of the UK.

Source: A Shade Greener.

A Shade Greener residential rooftop installation.

Module Production News

REC ships first module from Singapore to power plant in Zorbau, Germany

REC Solar launched its REC Peak Energy module at the Intersolar event in Munich, introducing it as the first commercial product produced at the company's new Singapore manufacturing facility. The company hails this module as having the ability to increase global capacity for module production up to four times. The module's first installation is a 1.2MW power plant in Zorbau, Germany. The plant utilizes 5,400 REC Peak Energy modules and was connected to the grid on May 27th, 2010. The plant was developed with Soleg over a six-week installation.

Photo: REC

REC Peak Energy module

Flextronics to help Petra Solar expand worldwide deployment of SunWave module

In an effort to position Petra Solar's SunWave modules to customers around the world, Flextronics has agreed to build Petra's modules. The SunWave module is a distributed solar power generation and management system. Petra's system provides three main aspects including monitoring and reporting the operation and health of the SunWave units, remote command and control of the units, and a cost-effective base for systems such as advanced metering infrastructure and load management or demand response programs.

Bridgestone set to increase EVA production to over 6,000 tons; invest ¥8.2 billion

In an effort to ramp up its ethylene vinyl acetate (EVA) film, Bridgestone will be investing ¥8.2 billion to increase production capacity at its Iwata City and Seki City plants. The investment and production increase will see the monthly production of the two plants go from 4,200 tons to 6,600 tons. The final production capacity should be completed sometime in 2012.

Module Sales News

ReneSola posts preliminary second-quarter results, upgrades guidance

ReneSola has released its preliminary unaudited results for the 2010 fiscal year's second quarter. Taking into consideration this quarter's results, the company expects total solar product shipments for the second half of this year to be in between 600MW and 650MW. Net revenue is expected to be around US$550 million to US$570 million, while gross project margin is predicted to be between 28% and 30% for the second half of the year.

The company expects total solar product shipments for the second quarter to be between 250MW and 260MW, showing a 3.1% to 7.3% increase from first quarter results. Net revenue for the second quarter should be in the US$245-$255 million range, representing an increase of 21% to 25.8% from the first quarter. The gross profit margin will end

Source: Bürkle

Bürkle's Ypsator laminator.

up between 28% and 30%, compared to Q1's 17.1%, according to the company.

pvXchange reports record trading results for first six months of 2010

As the photovoltaic marketplace expands by the day, pvXchange declared that after just six months of business in 2010 it has already brokered more modules and inverters than during the course of the whole of 2009. The online trading platform, which buys and sells solar photovoltaic equipment, has also seen a further 1,000 participants registering online since the beginning of this year.

Data collected up until the end of June 2010 shows that pvXchange has brokered PV modules with a total performance of more than 90MW in comparison to the 75MW from the whole of the previous year. In the case of inverters, an increase of almost 200% compared to the whole of 2009 was achieved by the end of June. In cooperation with its clients, pvXchange is preparing for a market situation that will potentially change from the fall onwards. Together with participating manufacturers and sales partners, the sector-wide rebate system CashBack for craftmans' businesses in Europe is also being set up.

Bürkle reports 30% growth: reaches €42m order total

Bürkle has reported a continuous receipt of orders since the beginning of 2010, culminating in a total of €42 million at the end of June. This order value trebles the figure reached in the previous year, leaving the manufacturer confident that it can reach its planned sales target of more than €85 million for 2010. After the economic crisis back in 2009, these figures amount to an increase in turnover of more than 30%.

Based on these figures, Bürkle chief Hans-Joachim Bender expects to be able to match the €115 million record year in 2008 by 2012 at the latest. The photovoltaics sector of the business currently earns the company 30% of its targets. More than 60 lines of the Ypsator and single-opening laminators have been sold since Bürkle's market entry three years ago. Due to the positive results recorded by the manufacturer for this period, the 480 employees at the sites in Freudenstadt and Mastholte will all continue in their positions.

Sunways expects to double solar module sales in 2010; inverter components shortages continue

During its annual general meeting (AGM) Sunways executives noted that they expect the company to double PV module sales in 2010, compared to the previous year. Demand in Germany has remained strong while overseas sales are also expected to continue to increase. However, shortages in inverter components would limit sales growth of its solar inverter range in 2010.

Sunways said that in addition to expanding its core competences in solar cells, solar modules and solar inverters as well as extending its distribution activities in Germany and abroad, the company is planning to enhance its project and consultancy work as well while developing additional, innovative business segments.

AT&T teams with Petra Solar for SunWave installation in New Jersey

Since the New Jersey Board of Public Utilities approved a contract between Petra Solar and PSE&G in July 2009 for 40MW of power through Petra's SunWave solar system, AT&T has announced that the solar units will be running on its wireless network. Petra's utility grade SunWave UP series operates on streetlight and utility poles and connects to the grid's secondary voltage lines on the pole for better power quality and grid management. The SunWave solar system will be installed on up to 200,000 poles in New Jersey throughout the state's six largest cities and 300 suburban communities. All will be running on AT&T's wireless network.

SunPower adds 20MW of installs for French retailer

French retailer Casino Group has again selected SunPower to supply modules for rooftop and parking area at its retail properties in France. The two companies had previously collaborated in 2009, which

Source: Petra Solar

Petra Solar's SunWave solar system.

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amounted to 15MW of installs. In total, 18 properties will have been fitted with modules. However, Casino Group has 11,000 stores in nine countries of which 9,031 are located in France. SunPower will employ its E19 Series solar panels, which have efficiencies of 19%.

Trina Solar and SolFocus selected for University of Queensland PV installations

The University of Queensland (UQ) will deploy both c-Si modules from Trina Solar and demonstration array from CPV firm, SolFocus at its St. Lucia campus in Brisbane. Four rooftop installations totally 1.2MW will use approximately 5,000 Trina modules for energy needs at the campus, while a ground-mounted 8.4kW solar array from SolFocus using its SF-1100S system will be used as part of a comprehensive research and training program at the University. Ingenero, an Australian renewable energy company is managing the project and was responsible for the donation of the SolFocus array system, according to the company. The Queensland Government is contributing a grant of AUD$1.5 million towards the AUD$7.75 million project.

Trina Solar is also expected to collaborate on research activities at the University. Ingenero also noted that it had been awarded a major solar project for the Alice Springs Airport. That 235kW facility is the first SolFocus CPV power plant to be installed in the Southern Hemisphere and will generate up to 28% of the airport's energy requirements.

Testing & Certification News

TÜV Rheinland opens lab in India

TÜV Rheinland has opened the doors to its seventh testing laboratory in Electronics City, Bangalore, India. The €2 million solar test centre will be focusing on India's solar industry and testing solar modules and systems. It boasts over 21,527 square feet of space, including an outside test field, five climate chambers and two sun simulators. As the country works its way to installing 20,000MW of PV power by 2020 and 100,00MW by 2030, TÜV Rheinland will be testing the quality and safety of modules and components as well as offering monitoring production quality.

TÜV Rheinland headquarters.

BioSolar completes testing on BioBacksheet

ThermTest has now completed its testing on the BioSolar BioBacksheet, claiming that it can improve the output of solar panels by dissipating heat faster. In the tests, the BioBacksheet is claimed to have reached a thermal conductivity 70% higher than current petroleum-based backsheets .

Calisolar modules receive TÜV Rheinland certification

Calisolar recently received IEC 61730 and IEC 61215 certification from TÜV Rheinland for modules built with Calisolar cells. The 60-cell modules passed all tests for their certification for proven demonstration to withstand in performance, durability, efficiency, stability and safety over extended periods of time. The certified modules produce up to 250W using Calisolar's multicrystalline solar cells with over 16% efficiency.

Tenesol pushes solar module guarantees to 10 years

As of July 1st, 2010 Tenesol solar modules will be covered by a 10-year manufacturer's guarantee, which falls inline with mainstream module manufacturers. Previously, the company had a 5-year manufacturer's guarantee. This covers all new PV modules in Tenesol's product range, except its 'dual-glass' modules. Tenesol also has a 25-year performance guarantee and is the only PV manufacturer in France to achieve the triple certification of ISO 9001, ISO 14001 and OHSAS 18001. Tenesol said that investments in manufacturing and quality control systems at its production plants enabled the company to double its coverage for customers.

Soliant Energy receives UL Listing for SE-500X

Soliant Energy's concentrated photovoltaic (CPV) flagship product, SE-500X, has officially received UL Listing from Underwriters Laboratories and has also been certified under the SU 8703 UL draft standard, a new code defined specifically to test safety parameters of CPV products.

AUO receives UL WTDP lab certification for its PV QRA Lab in Taichung

AU Optronics' (AUO) PV QRA Lab located in Taichung, Taiwan has officially acquired UL Witness Test Data Program (UL WTDP) lab certification. This marks the first laboratory in Taiwan to receive four certifications for professional testing including IEC 61215, IEC 61646, IEC 61730 and UL 1703.

Water spray test being conducted in AUO's Solar Reliability Lab.

"The lab will be able to conduct over 33 kinds of tests, all conforming to UL and IEC regulations. This demonstrates that AUO owns world-class testing capabilities, equipment and lab," said James C.P. Chen, senior associate vice president of the company's solar photovoltaic business unit.

Encros, pv recycling sign MOU for international photovoltaic waste collection

Tempe, AZ-based pv recycling and Encros have signed an MOU to develop collection and recycling systems in North America and Europe. Under the terms of the agreement, Encros will develop, test, and operate recycling technologies, while pv recycling will implement and manage areas related to administration, logistics, and regulatory compliance.

Spire receives DOE grant for development of LED-based solar simulator

Spire has been selected by the U.S. Department of Energy as the recipient of a Small Business Innovation Research grant to develop a next-generation solar simulator, based on LED technology. If successful, the LED-based system could provide advantages of accuracy, reliability, versatility, and cost, according to the company. Spectral, intensity, and spatial uniformity variations could also be achieved with system software and control electronics.

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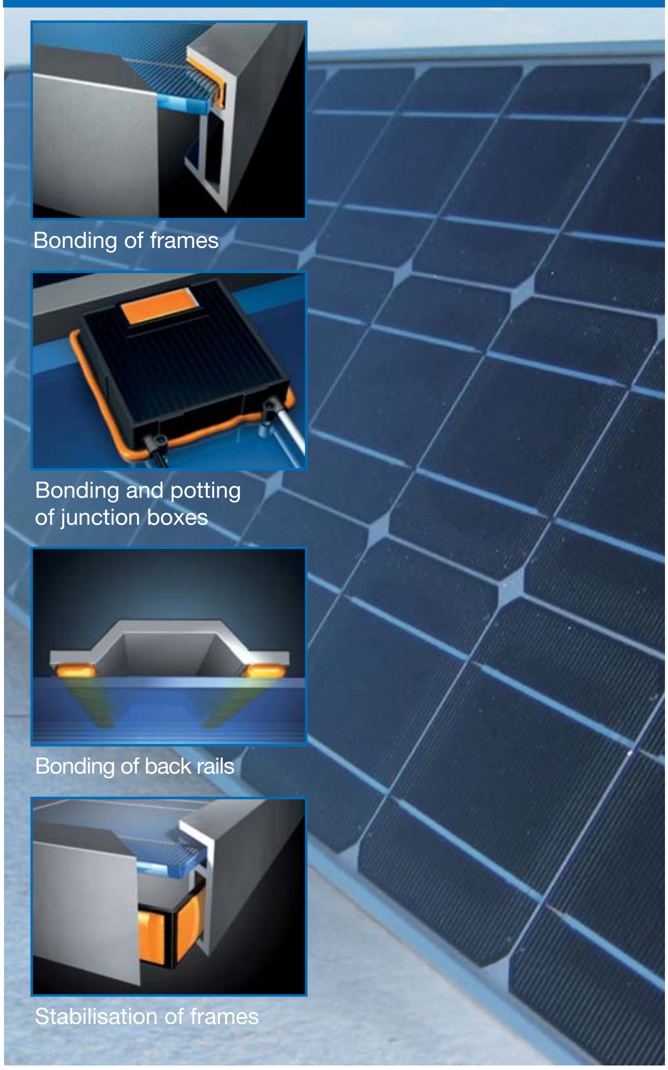

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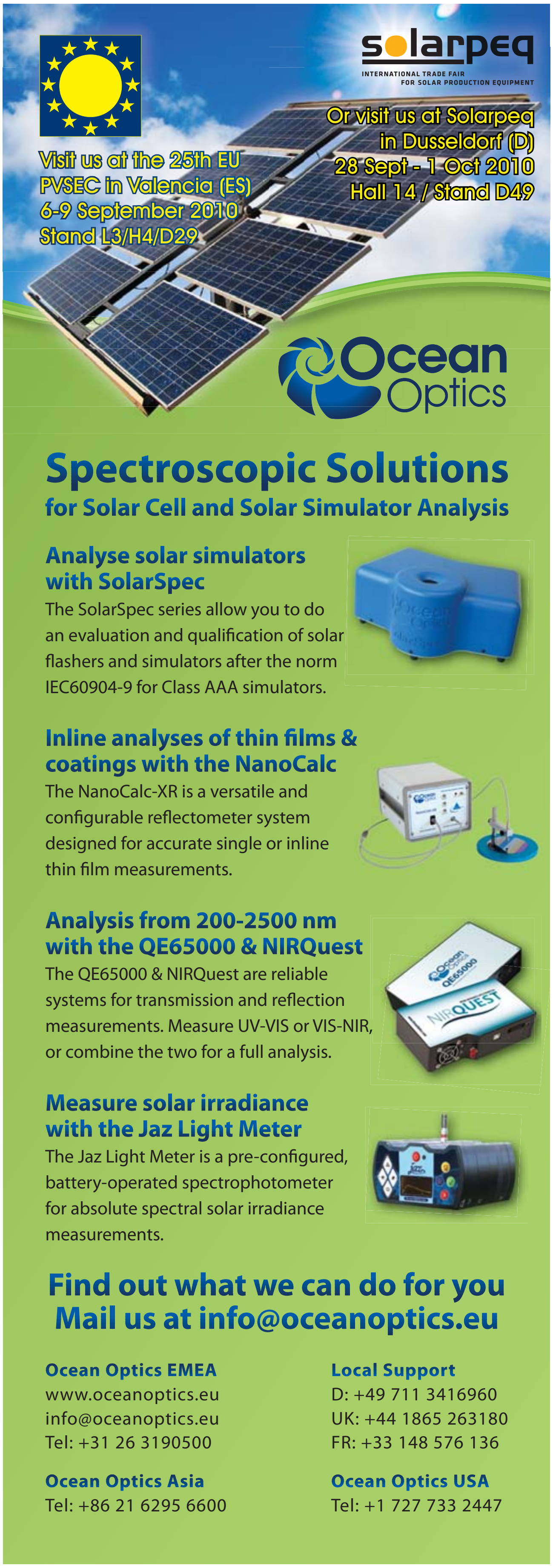


Start-up SunSil raises funds and grants to boost roll-out of innovative solar module

Off to a strong start after launching its innovative 'smart' solar module at InterSolar in Munich this year, start-up SunSil is expected to receive €8 million in Series A round of VC funding, €1.3 million in product development funding from the Danish government and interest from four corners of the world to license its innovative integrated module technology.

The new round of funding is expected to be used to speed up the purchase of equipment and order materials in advance of ramping its first fully automated module plant, noted Hansen to PV-Tech. Hansen said that initial production would begin in the fourth quarter of 2010 with volume production expected in Q1 2011. SunSil's integrated PV architecture means that the module can be assembled in a few steps with the use of a fully-automated and high-throughput manufacturing line with four to six times the output of standard PV module assembly lines being used by many module manufacturers in the world today.

At Intersolar Munich, the company was courted by potential new investors as well as by more than four 'major companies' interested in licensing SunSil's technology, according to Hansen. Although no deals have been finalized, Hansen was keen to move forward with such proposals as it would enable the technology to be ramped and gain traction in the market more quickly. Currently, the modules are being tested and should be completed in October this year.

Exel Group receives TÜV Rheinland certification for ESP-M, ESP-D product lines

Exel Group has received certification from TÜV Rheinland for its ESP-M and ESP-D series photovoltaic modules. The modules, which are being produced in Exel's new factory in the Industrial Area of Kilkis, weresubject to a complete inspection of the production processes based on specified raw materials and in regard to the method of production and measurement of the final product's output before the certification was awarded.

VDE presents Q-Cells with certificates for its Q.PRO and Q.BASE solar modules

During Intersolar 2010, the VDE Testing and Certification Institute presented Q-Cells SE with VDE certificates for its Q.PRO and Q.BASE crystalline solar modules. The new modules now been thoroughly tested by the VDE Testing and Certification Institute in Offenbach, Germany. The Q-Cells Module Test Centre has now signed a contract with VDE for preferential collaboration. This means that customers of Q-Cells solar cells can obtain faster certification for modules equipped with these cells via the VDE and the Fraunhofer Institut für Solare Energiesysteme (ISE).

Solon reveals global test site network

Solon has brought together locations in Tucson, Arizona, San Pietro, Italy and Berlin, Germany, for their Global Test Site (GTS) network. The three identical outdoor proving grounds will test and provide data for Solon to better understand regional affects on PV modules and related technologies for the best module and system design.

Solon will study various areas of performance on four platforms: fixed-tilt at 0 degrees, fixed-tilt at latitude, single-axis tracking, and dual-axis tracking. The GTS network will also test technology from potential partners. A custom data acquisition system (DAS) is used for measurement of voltage and current before and after the inverter, cell temperature, ambient temperature, irradiance (direct and diffuse), wind speed and humidity. Since the data are stored on a central server, Solon can access the data from around the world for further analysis.

Other News Focus

Hanwha Chemical to purchase 50% stake in Solarfun

Hanwha Chemical is to purchase a 50% stake in Solarfun for a total of 434.1 billion won (US$371 million) in order to diversify revenue sources. The company will purchase 208.3 million shares, including new stock. Hanwha shares advanced 3.7% to close at 21,250 won in Seoul trading, the highest since November 6, 2007. The benchmark Kospi Index gained 0.5%.

Solarfun's first-quarter 2010 revenue more than doubled in comparison to 2009 to US$216.2 million. The company said it plans to increase module capacity to 900MW by August 2010 to meet demand in the second half of the year.

SunPower modules used for Solar Decathlon Europe entries

Six out of the 17 university teams which participated in the Solar Decathlon Europe used SunPower solar panels to construct their designs. SunPower also supported teams from three of the five participating Spanish universities (University of Sevilla, CEU University Cardenal Herrera and Institute of Advance Architecture of Cataluna), as well as the University of Florida (USA), the University of Rosenheim (Germany) and the University of Paris Arts et Métiers (France).

Renowned architects and engineers made up the international panel judging the competition. Judges included the 2002 Pritzker Prize winner Glenn Murcutt; the president of Toyota Housing, Senta Morioka; Fiona Cousins, director of Arup New York; and Francisco Mangado and Manuel Toharia of Spain.

The University of Florida, showcasing the SunPower 230 solar module.

Trina Solar joins MIT's Industrial Liaison Program

An official letter of agreement was recently signed between Trina Solar and the Massachusetts Institute of Technology (MIT), which ties Trina Solar with the University's Industrial Liaison Program (ILP). The ILP is a program that looks to encourage university-industry collaboration and technology transfer.

The agreement will see the ILP provide Trina Solar facilitated access to MIT and its resources such as technology conferences. It also holds the possibility that Trina Solar will be able to directly access research opportunities with MIT researchers.

Eco Supplies Europe acquires Gällivare PhotoVoltaic; increases capital by €1.8 million

Eco Supplies Europe has completed the acquisition of Gällivare PhotoVoltaic (GPV), a Scandinavian producer of polycrystalline and monocrystalline PV modules. GPV's plant has a total yearly production capacity of 45MW and provides solar modules to SolarWorld, among other companies. Its revenues have reached €49.9 million.

In addition, Eco Supplies closed a fully-subscribed capital increase of €1.8 million. Existing and new shareholders supplied €1.8 million in new capital for the transaction. Swedbank, Norrlandsfonden, Almi and Export Kredit Nämnden have also made available €12.6 million in finance and credit lines.

Yingli signs module supply agreement with DC Power

Yingli Green Energy Americas, the subsidiary of Yingli Green Energy, has signed a strategic PV module supply agreement with DC Power Systems. The agreement will last through the end of 2010 and is one of the largest supply agreements in the U.S. for Yingli this year and the largest between the two companies to date.

Lagofrio Energy places 93MW module order with Fidelis Energy

Lagofrio Energy Solutions (LES), a wholly-owned subsidiary of TinSol Energy (TSEL) South Africa, has placed a US$210 million contract with Fidelis Energy to Supply 93MW of PV modules for several solar parks across Africa. Fidelis will begin shipments during the first quarter of 2011 as its module plant in China is expected to come on-stream during the fourth quarter of 2010. Fidelis said that it plans to expand its annual manufacturing capacity by 150MW in each of the next several years.

MEMC taps JA Solar for OEM modules to be used by SunEdison

Continuing to gain major OEM module supply deals for its high-performance, low-cost solar modules, JA Solar has signed a multi-year supply agreement with MEMC Electronic Materials. The supply deal will see MEMC subsidiary, SunEdison use JA Solar's OEM modules for projects starting in the third quarter of 2010 and going through 2012. The move means that JA Solar's modules will be used in commercial-scale and utility-scale projects in the future.

The module quantities involved in the deal were not disclosed, though JA Solar is ramping its OEM module production in the second half of the year and expects capacity to reach 500MW by the end of 2010. The modules will incorporate 19% efficient cells using metal wrap-through (MWT) technology licensed by ECN.

Astronergy to supply 2.2MW of PV modules for SPG Solar's Florida rooftop project

Astronergy and SPG Solar have reached a PV module supply agreement, in which the company, also known as Chint Solar, will provide 2.2MW of polycrystalline silicon modules for SPG's solar rooftop project in Florida. Shipment of the modules began in July. This agreement represents Astronergy's successful entrance into the Florida PV market. The companies said they will provide the varied projects with high-quality solar modules, including monocrystalline and polycrystalline silicon, as well as high-efficiency thin-film modules.

The partnership with SPG is a natural continuation of Astronergy's growing presence in the U.S., according to the Chinese company. SPG said that its confidence in the quality of Astronergy products was a key factor in securing the contract between the two companies. Financial terms of the agreement were not disclosed.

Universal Solar signs US$32.6 million sales contract with CEZ

The US$32.6 million sales contract signed by Universal Solar Technology and CEZ Group will see the delivery of 20MW of monocrystalline solar modules to CEZ by the end of this year. CEZ is one of the largest electricity producers in the Czech Republic.

CNPV to supply Photon Hellas with 20MWp of modules through 2012

CNPV Solar Power has entered into a long-term sales agreement with Photon Hellas for the supply of 20MWp of PV modules from 2010 to 2012. The agreement includes 3MWp of scheduled delivery during the second half of 2010, with the remaining 7MWp and 10MWp scheduled for delivery in 2011 and 2012, respectively.

REC to supply 1MW of residential installations in Singapore

REC has successfully beaten 13 companies in the competition for a 1MW tender to supply PV panels for residential rooftop installations on Housing Development Board (HDB) homes in six precincts in Singapore. The PV panels will be installed on approximately 25 housing blocks as part of HDB's solar capability building program. The project, which marks the largest solar initiative in the region, will feature REC Peak Energy Series modules. Installation is expected to begin in the fourth quarter of 2010.

Suntech to supply PV modules for utility-scale power plants in India

Suntech is to supply Azure Power with several megawatts of solar panels to develop utility-scale solar projects in India. The solar power plants will be owned, developed, and financed by Azure Power and will feature Suntech's 280W polycrystalline solar panels. The first project is already under construction, with additional power plants planned for early 2011.

Astronergy signs exclusive deal with Solco

Astronergy has signed an agreement with Solco that will see the latter take the role of exclusive distributor of Astronergy solar modules for Australia, New Zealand, Papua New Guinea and Nauru. Likewise, Astronergy will be the primary Chinese module supplier to Solco. No financial terms or shipment details were provided.

Products to be delivered by Solco include Astronergy's monocrystalline solar PV, polycrystalline solar PV, and silicon thin-film panels. The modules are expected to be used for PV projects ranging from residences and schools to government and larger-scale installations.

Solarfun to deliver 12MW of PV modules to Italy

Solarfun has entered into two photovoltaic module supply contracts, which together total 12MW. The first is with GranSolarGhella for 6MW in southern Italy; this order will be delivered in the second half of 2010. The second 6MW contract is with T.R.Z. Tozzi Renewable Energy, which will be delivered to central Italy in the third quarter of 2010.

EGing Photovoltaic Technology to supply 100MW modules to Payom Solar

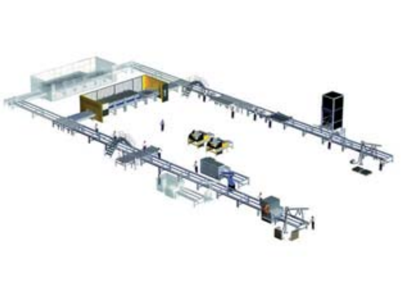
Payom Solar has concluded a framework agreement with Chinese module provider EGing Photovoltaics Technology for the supply of 100MW modules in the years 2011 and 2013. CEO Jörg Truelsen commented: "Besides the associated expansion of business, this new partnership is of enormous strategic importance for the Payom. We remarkably broadened the base for our purchasing possibilities now and are able to avoid possible dependencies on only few suppliers by this."

JinkoSolar to supply 24MW of modules to Enfinity Asia Pacific

JinkoSolar and Enfinity Asia Pacific have established an agreement that will see JinkoSolar deliver 24MW of solar PV modules this year to Enfinity. Module shipments are already underway and will continue through the rest of this year.

Product Briefings

Bürkle



Robert Bürkle offers flexible back-end line system for crystalline cell modules

Product Briefing Outline: Robert Bürkle has introduced a complete flexible back-end line for the production of crystalline cell modules. The company claims its stack lamination platform yields the highest throughput per square metre. The highly flexible line accommodates straight and U-shaped line layouts, according to individual requirements.

Problem: Due to market demand, manufacturers of solar modules have to adapt their production capacity. Capacity augmentation often requires the purchase of a new line, coupled with the further issue of possible space constraints brought about by the new equipment.

Solution: Bürkle's back-end solutions offers can be easily extended to a higher capacity and integrated into an existing line. The lamination line concept, for example, can vary from two to three presses, and can also incorporate another stringer. The Bürkle solution's stack lamination platform claims to yield the highest throughput per square metre.

Applications: Back-end line for the production of crystalline solar cell modules.

Platform: Different levels of automation are available. Module sizes of 1 x 1.7mm and 1 x 2mm can be accommodated. Cell matrix: 60 or 72 cells per module. Systems can be supplied in 25/50MW sizes.

Availability: Currently available.

Coveme

Coveme's dyMat PYE 3000 backsheet resists over 3000h of DHT

Product Briefing Outline: Coveme has developed a high-performance PET backsheet, the dyMat PYE 3000, which can resist over 3000h of DHT (Damp Heat Test), offering the best performance currently available on the market. The dyMat PYE range of Coveme laminates protects photovoltaic cells from humidity, atmospheric agents and chemical attacks, guaranteeing total insulation at high voltages.

Problem: Solar module manufacturers require backsheets that can offer adequate protection for high-performance PV modules. Due to water permeation of the outer layer, the inner PET layer suffers from hydrolysis, thus losing its original properties. Traditional backsheets are, to a certain extent, unbalanced, having a long-lasting outer layer while the inner layer suffers from early aging.

Solution: The dyMat PYE 3000 is the latest development within the well-known dyMat PYE range, which, on its launch in 2008, was one of the first fluoropolymer-free backsheets in the photovoltaic market. It effectively protects solar panels for over 25 years thanks to its superior hydrolysis and UV barrier properties. The dyMat PYE laminate is based on two layers of polyester film. The cell side is treated with a special thick primer which provides high bonding capability to EVA. The primer can be supplied in different colours and in transparent finishing.

Applications: dyMat PYE is suitable for thin-film and mono-/polycrystalline solar modules.

Platform: All dyMat products are available in customized rolls or sheets on request. PYE range uses high-grade PET films. DyMat backsheets are UL recognized and TÜV certified to IEC 60664 and in compliance with IEC 61215 and IEC 61730.

Availability: Currently available.

Huntsman

Huntsman Advanced Materials develops new encapsulating materials for hot climates

Product Briefing Outline: Huntsman has cooperated with industry partners to develop the 'Araldite' AY 4583/HY 4583 liquid system, which enables an energy-saving encapsulation process at low temperatures and eliminates the critical lamination process with EVA. The new technology is ideal for use in hot southern climates and deserts.

Problem: The decrease of efficiency with temperature, grid parity, cost factors and aging stability raise the demand for new innovative concepts for PV modules.

Solution: Heat conductive, electrical insulating adhesives enable a new module design and construction with improved heat transfer and efficiency. The system claims excellent strength and bonding properties, while the flexible and thermal conductive adhesives protect the flexibility of solar cells. 'Probimer' 77 White, a highly reflective, white solder mask, contributes to the increase of the efficiency of the PV module by enabling more and multiple reflection, thus increasing the ratio of sunlight reaching the cells.

Applications: Araldite AY 4583/HY 4583 enables an energy-saving encapsulation process at low temperatures and eliminates the critical lamination process with EVA.

Platform: The new materials and technologies have the potential to increase the efficiency of innovative PV modules by more than 50%. As processing is significantly simplified, costs are reduced and aging stability is improved.

Availability: The complete technology package will be commercially available by 2011.

Indium

Indium offers tabbing and bus ribbon kit range for traditional and low temperature applications

Product Briefing Outline: Indium has introduced a newly designed tabbing and bus ribbon kit range. The kits, which contain similarly sized tabbing and bus ribbon and fluxes, are available in three versions, including one with a uniquely designed Pb-free, bismuth-containing, low-temperature coating. Tabbing ribbon kits come with everything required to evaluate how Indium's materials will work with solar cells and assembly processes.

Problem: The kits are a valuable tool for scientists and engineers to efficiently experiment with different coatings and fluxes at traditional and low temperatures – a task that can be both complicated and costly.

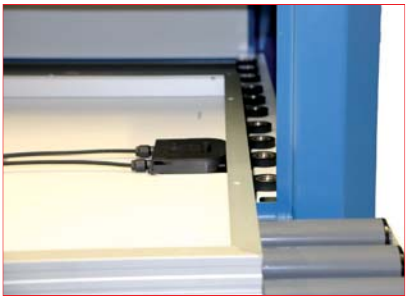
Solution: The easy-to-handle, low-cost kit system is available in three versions: tin/silver, bismuth/tin, and tin/lead/silver, and can be ordered via Indium's online ordering system. The tabbing ribbon kits come fully equipped to test the compatibility of the kit contents with various solar cells and assembly processes.

Applications: The fluxes are designed to work in both manual and automated assembly processes.

Platform: The ribbon itself is industry standard CDA 110 (99.9% Cu) core flat wire, coated with a precisely controlled layer of solder. Each ribbon is manufactured using proprietary softening processes to improve the yield of the stringing process without wafer breakage. Kits are available in Standard: 62Sn/36Pb/2Ag; Pb-free: 96Sn/4Ag; and Low-temp: Pb-free 58Bi/42Sn coatings.

Availability: Currently available.

mbj-Solutions



mbj-Solutions' electroluminescence inspection system offers flexible usage

Product Briefing Outline: mbj-Solutions is expanding its product portfolio with the SolarModule EL-Lab system, designed for module testing. The company's focus is on the development of electroluminescence (EL) inspection systems for in-line and standalone use along the PV production process.

Problem: Micro-cracks on solar modules are mostly invisible to the human eye, yet present a significant risk of decreasing the module's performance.

Solution: Using electroluminescence imaging provides valuable information about the overall quality of the solar module being tested, either during the production process before lamination, at the end of the production process, after shipment or right before installation at the customer's site. mbj's SolarModule EL module testing product family has similar mechanical designs across the product range, which makes it very flexible and very easy to operate. Roller tables provide effortless loading and unloading of the modules, which face down during the entire procedure. This design allows inspection of framed and non-laminated modules in various sizes and formats with only one machine and without any prior adjustments.

Applications: Laboratories or smaller factories. The system accepts both mono- and multicrystalline silicon solar modules of between 600 x 600mm and 1000 x 2000mm (w x h).

Platform: While the EL-Lab version captures all images in less than 90 seconds, the Basic version can capture the images three times faster. An upgrade of the EL-Lab version to the EL-Basic version is possible, which makes this solution sustainable.

Availability: Currently available.

National Semiconductor

National Semiconductor's SolarMagic chipset yields integrated smart modules

Product Briefing Outline: National Semiconductor has developed a version of its 'SolarMagic' chipset than can be fully integrated into a solar module. The SM3320 is the first analog-intensive power management chipset in a new category of in-panel electronics that improves power output and reliability of solar systems.

Problem: Conventional solar panels are prone to underperforming due to factors such as age, mismatch and shade. Real-world problems lead to a reduction in the power output of an array.

Solution: The SM3320 incorporates 10 proprietary analog and mixed-signal integrated circuits, which gives reliable digital control combined with analog sensing and communication. Proprietary algorithms apply localized maximum power point tracking (MPPT), extracting the maximum energy available by translating the input voltage and current to the best output voltage and current pair to maximize energy flow. The system can react and adjust accordingly to differences and fluctuations in input voltage and current throughout the array to achieve optimum string levels.

Applications: Integrated solar module power harvesting.

Platform: The SM3320 includes a highly integrated, 99.5%-efficient 350W tri-mode power converter. The board-level system, measuring 5" x 3.5" x 0.5" and weighing approximately 6.4oz, easily fits into a solar panel junction box. To achieve maximum energy harvest, the SM3320 can either boost, pass-through or lower the voltage of each panel. The SM3320 is released to market with UL and CE component-level certification and is in volume production.

Availability: Currently available; chipset is priced at less than US$0.1/w, depending on volume.

Product Briefings

SOMONT

SOMONT adds major productivity improvements to CERTUS stinger system

Product Briefing Outline: SOMONT has made further improvements to its CERTUS stringing system, designed for production capacities from 50–100MW per year. The CERTUS features a modular concept to match the desired capacity requirements, while also integrating all elements needed at the front-end of the module production line.

Problem: Changes to the system were necessary to address such issues as the need for a balance between higher-level module capacity while reducing overall manufacturing costs and enabling higher throughputs.

Solution: With the amendments to the system, space requirements are optimized and string handling is further reduced. In-process testing capabilities were added as was an automatic interconnection feature, while the output per hour and product quality were further increased. The stringer is equipped with new technology to apply the flux on the ribbons, with other features such as improved cell handling and temperature management. After cell soldering, the entire string is tested with a new, in-line test system. Those strings that matching specification are forwarded via a special transport system to the matrix lay-up station. Following lay-up completion, the entire matrix is forwarded to the interconnection which handles the required ribbons and soldering. The completed matrix is then tested and carefully placed on the glass plate.

Applications: c-Si solar cell stringing in module production.

Platform: CERTUS can be configured with a series of options and integrated in existing module production lines.

Availability: Currently available.

teamtechnik

teamtechnik's STRINGER TT1200 is fastest on a single track

Product Briefing Outline: teamtechnik is launching a new, more compact STRINGER TT1200, which can solder solar cell strings at 1200 cycles per hour on just one track. teamtechnik has focused on the efficiency optimization of this stringer technology and has improved the price-performance ratio further. Other improvements include shorter set-up times and a shorter delivery time of a maximum of three months. The system's power consumption and noise levels have also been reduced.

Problem: Module assembly is one the most expensive steps in c-Si cell/module production. Fully-automated and integrated tabber/stringer systems need to have high throughput and high yield to support PV manufacturers' cost reduction strategies.

Solution: teamtechnik uses a unique hold-down device in its systems to separate the actual soldering process from the cell handling process. This allows the company to guarantee 1200 cycles/hour on a single track. Single track means faster throughput for each soldering process, less complexity, with fewer replacement parts and fewer operators required. The hold-down concept makes for and minimal breakage rates at less than 0.3%.

Applications: Standard and back-contact cells (BC/EFG/film) of wafer thickness >160µm with 2 and 3 bus bars.

Platform: All teamtechnik stringers can be equipped with light or laser soldering technology or with an adhesive bonding process, depending on the job and the customer's requirements. In addition to the STRINGER TT1200, the TT900, which offers 900 cycles per hour, is available for smaller production units.

Availability: September 2010 onwards.

Tyco

Two-rail decentralized junction box from Tyco requires 50% less jumper cable

Product Briefing Outline: Tyco Electronics has created a new way for locating junction boxes on a PV panel. Compared to the commonly used centralized junction boxes in the PV industry, the new two-rail decentralized junction box requires 50% less jumper cable to connect to the next solar panel, as the junction boxes are located in the corner of the panels.

Problem: Through the decentralization of the two-rail junction boxes, panel manufacturers are able to use less and shorter cross connects (saving on labour and costs) because every string is protected by one junction box with one diode.

Solution: The decentralized junction box uses less cross-connects than standard centralized boxes, offers excellent thermal management capabilities and enables engineers to design new innovative solar panel layouts. The general design idea uses two small two-rail junction boxes separately located in the corners of the solar panels plus one small junction box in the middle. The common standard layout comprises one bigger four-rail junction box with three diodes in the centre of the panel.

Applications: PV module junction boxes.

Platform: With this new design concept, it is easy to enlarge solar panel layouts by just adding a junction box in the centre to protect additional strings. No complicated routing is required. The low profile design (only 18.5mm in height) of the two-rail decentralized junction box enables the device to be easily terminated with the slim line connector system by Tyco Electronics. The new decentralized junction box meets IEC 61215 ed.2 (VDE V 0126-5) specifications.

Availability: Currently available.

Snapshot of spot market for PV modules – quarterly report Q2 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.

The end of June 2010 brought with it a new record: pvXchange has already brokered more modules and inverters on the spot market in six months than during the course of the whole of 2009. Inverter sales, for example, saw an increase of almost 200% percent compared to the whole of last year. Based on the amount of customer enquiries and goods that have already been brokered and scheduled for delivery in late summer, it looks like the boom will last until the end of Q3 2010. Although the spot market is only one part of the international PV trade flow, the thousands of deals being finalized give us quite a representative impression of the market's development.

How is such a boom to be explained in the current climate, what with the falling prices experienced this past winter and the anxiety being felt globally in regard to how the German and Italian markets will develop after the announced reduction of FiTs in those countries? Is this only the "pull-forward" for the proposed reduction of the FiT?

> "Price offerings made in the morning on the spot market were snapped up that same evening."

In April 2010, module prices from all regions increased for the first time since the price fall of 2008. The manufacturers of these brands announced several months ago that they would be sold out by the end of June 2010. Their modules are now too expensive and therefore near-impossible to find on the market. Similarly, even second-tier manufacturers have been pushed to the limits of their capacity due to the rising demand. Many modules sold out in recent weeks at higher prices (~€15 cents/Wp more expensive), despite the fact that a few weeks previously, although favourably priced, the same modules found no buyers. Price offerings made in the morning on the spot market were snapped up that same evening, compared to the usual several-weeks-long negotiation processes. Most Asian manufacturers tend to announce weekly price increases.

> "In mid-June, the demand for PV modules and inverters was still extremely high."

Asia-produced modules were slightly higher in May than at the beginning of the year. Alternatives to higher-priced modules are available from some of the less popular module manufacturers in China, India, Taiwan and Europe. It seems the imminent reduction in solar subsidies has had little to no effect on these dynamics. European products – not traded on the spot market as frequently as Asian products – show a more stable price trend and were slightly cheaper in May than in January.

In mid-June, the demand for PV modules and inverters was still extremely high despite the uncertainty looming in regard to the level of tariff reduction in Germany. Most of the quotas, which are now mediated, will not be delivered before July. Prices had not changed significantly by mid-June compared to the previous month; however, as the companies' summer breaks end over the coming weeks, further increases are to be expected.

'Jumpy' price changes at the beginning of this quarter would suggest that many buyers are teetering between panic

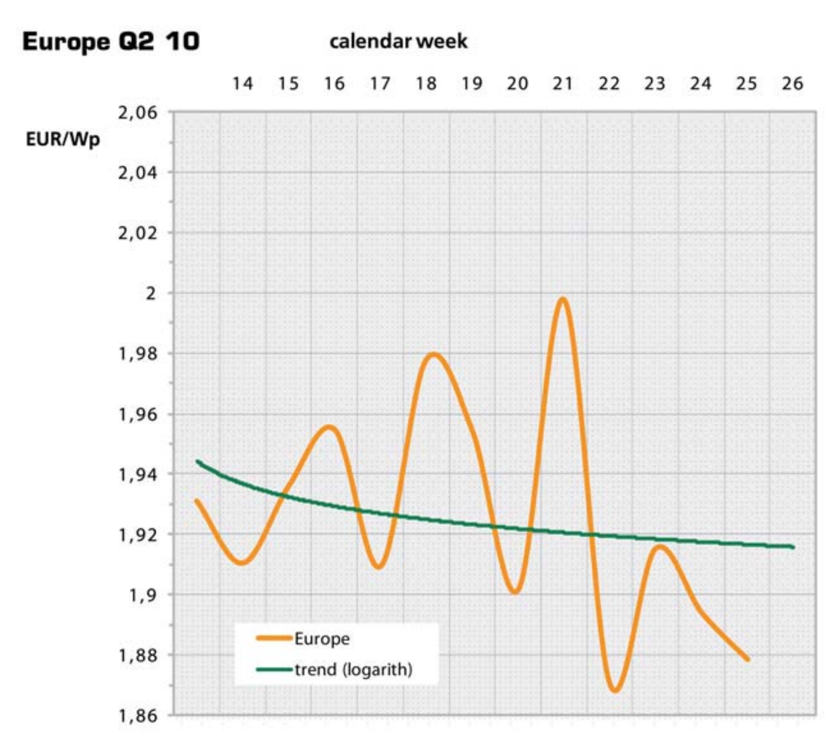


Figure 1. Development of module prices for modules produced by European manufacturers from April to beginning of July 2010.

and resignation, wondering whether they will get the modules or inverters they ordered on time, or if they will manage to finish their PV system by the date contracted. Nevertheless, dealers, consumers and investors do not seem to have been affected significantly by the political back and forth in Germany, Italy or even Spain, with its shocking announcement of a retroactive cut of the Spanish FiT.

Installers' order books are full up to the end of Q3, which is in accordance with demand remaining high. This situation will only serve to benefit those well-known thin-film producers and many Asian manufacturers, who are barely meeting the huge product demand. The hope is that after June 30th, buyers in Italy, France and the Czech Republic will see some benefit from demand in Germany not being fulfilled.

"Some analysts are expecting a doubling of installed PV in Germany to 7-8GW for 2010."

All of these factors point to the same conclusion: that global newly-installed PV capacity will grow strongly in 2010. Some analysts are expecting a doubling of installed PV in Germany to 7-8GW for 2010, even taking the drop in compensation into account. Despite the decline in demand in Germany and the looming financial problems of many EU governments, this year could see the installation of around 14GW of new PV systems globally. This will be the next record!

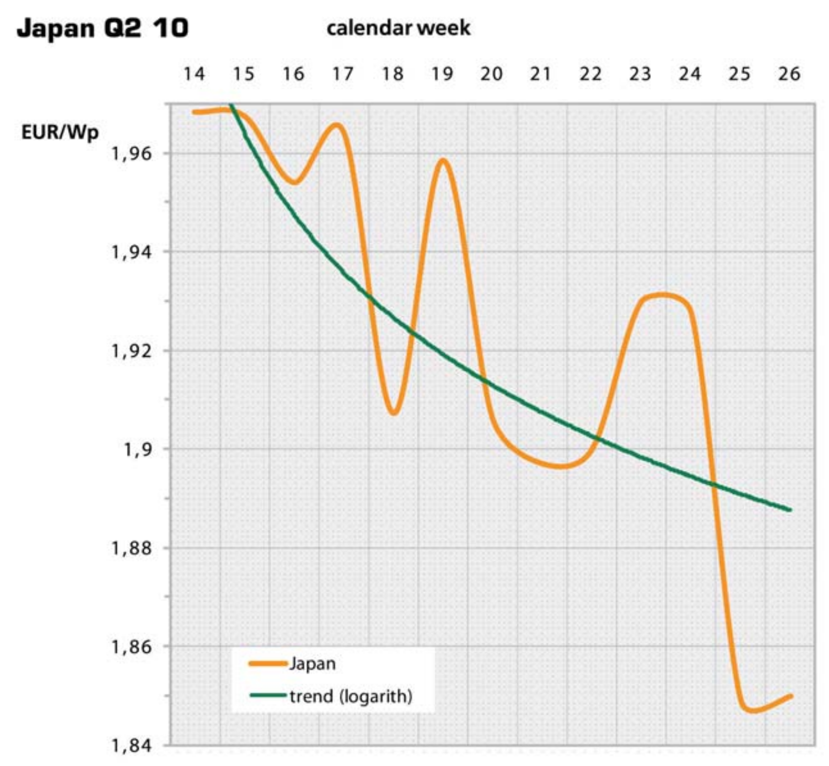


Figure 2. Development of module prices for modules produced by Japanese manufacturers from April to beginning of July 2010.

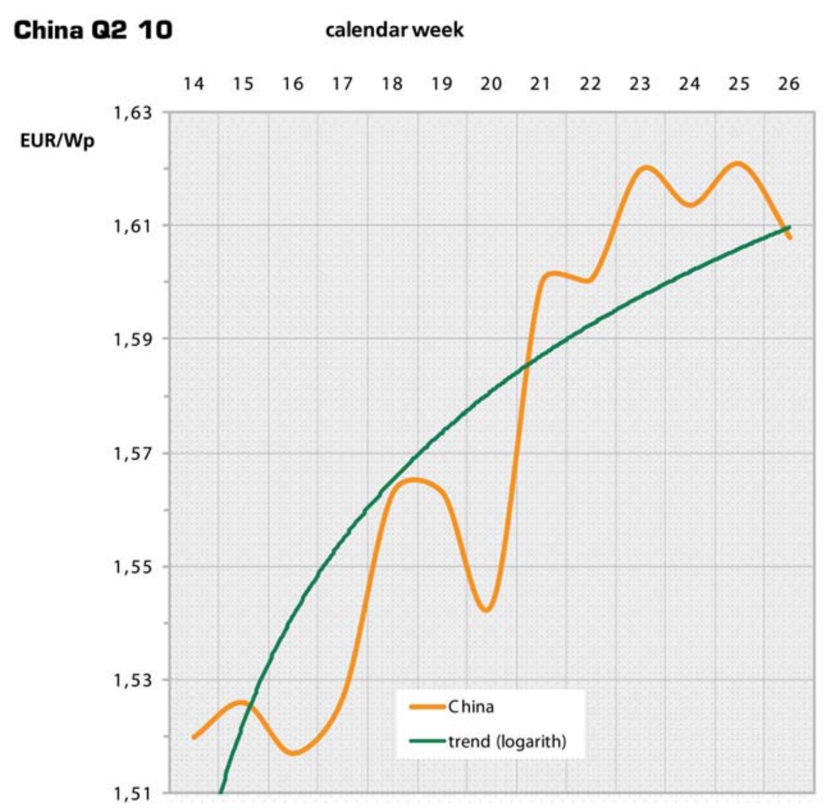


Figure 3. Development of module prices for modules produced by Chinese manufacturers from April to beginning of July 2010.

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 2009, the company procured solar modules with an output of around 75MW. 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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Tabbing-stringing quality control challenges

Dr. Harry Wirth, Dept. Materials Research and Applied Optics, Fraunhofer Institut für Solare Energiesysteme (ISE), Freiburg, Germany

ABSTRACT
Cell interconnection is recognized as the most critical process with respect to module production yield. If the process is not carefully controlled, cell cracking and subsequent breakage may occur. Many manufacturers promise breakage rates below 0.3-0.5% on their tabber-stringers, which applies for cells above 160-180µm thickness that are free from initial cracks. In real production, this figure strongly depends on materials, process parameters and throughput. This paper outlines some approaches that should be taken to avoid high levels of breakage in the cell interconnection process.

Automated cell interconnection on tabber-stringers

Solar cells are interconnected to a string (Fig. 1) using flat copper wires coated with solder. These ribbons are approximately 120-180µm thick and 1.5-2.4mm wide. Two-busbar cells require higher crosssections to limit serial resistance losses than three-busbar cells.

Most manufacturers still use leaded solder. Research backing the switching to leadfree options is ongoing, with the aim of preparing for compliance with future RoHS requirements for solar modules. The ribbons are applied on both sides of the solar cell, covering the silver busbars.

Flux is applied to the ribbons or the cell busbars. The solvent is then dried out. The solid flux melts during preheating, somewhat below the solder melting temperature. In its liquid, activated state, flux temporarily improves wetting

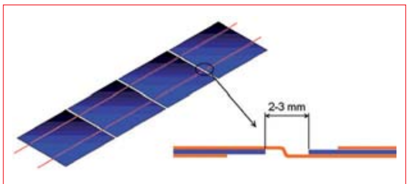


Figure 1. Cell interconnection scheme.

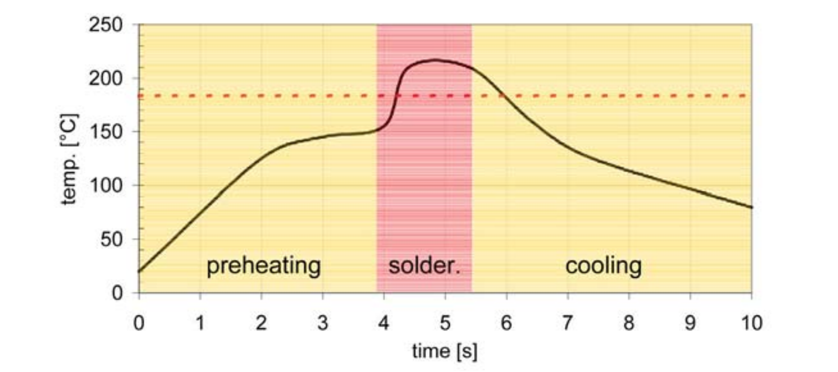


Figure 3. Schematic SnPb soldering temperature profile with preheating, soldering and cooling phase; solder is in liquid phase above dotted line.

by reducing oxidized top layers and by protecting the surface against new oxidation.

During soldering, additional heat is applied from one side of the cell to achieve a temperature that exceeds the solder melting point by 35-40°C (Fig. 3). The molten solder must wet the busbar and completely fill the gap between ribbon and busbar.

All solder joints of one cell are formed simultaneously or in a quick sequence. During cooling, the thermal mismatch in CTE (coefficient of thermal expansion) between ribbon and cell leads to mechanical stress. The copper with a CTE of 16.5^{e-6}/°C strives to contract much stronger than silicon (2.6^{e-6}/°C). If the solder solidification point, the cooling speed, the material crosssections and the ribbon ductility are not chosen carefully, cells may crack. Decreasing cell thickness will increase the cell stress. In cells soldered on one side only, the thermomechanical stress after cooling becomes visible as bimetallic effect (Fig. 4).

With finite element modelling, the stress on a silicon wafer induced by cooling can be calculated. In Fig. 5, the red areas indicated represent tensile stress, while the blue represents compressive stress. The deep blue areas indicate compressive stress caused by the joints between the copper wire and the wafer, a result of copper's larger CTE

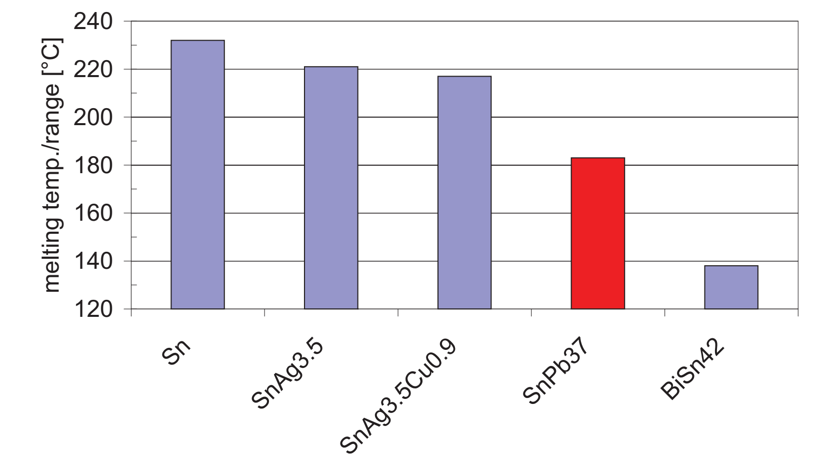


Figure 2. Melting points of eutectic solders.

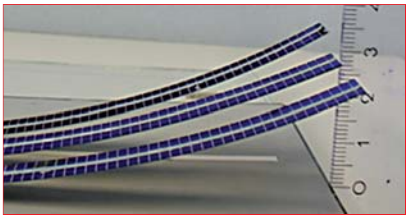


Figure 4. Stress visualization on unilateral soldered 160µm cell strips caused by CTE difference.

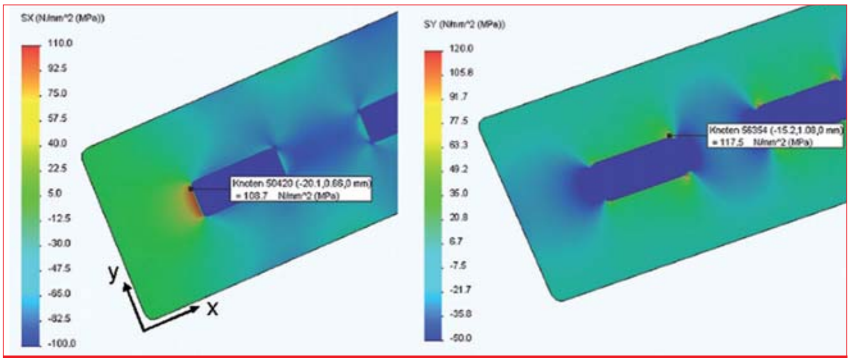


Figure 5. Calculated normal x- and y-directed stress in cell joints after cooling.

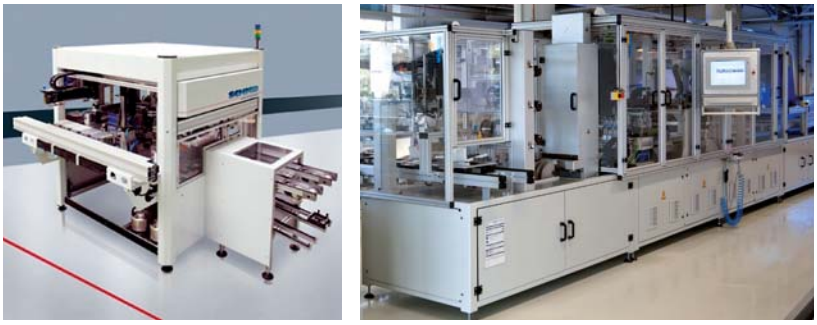
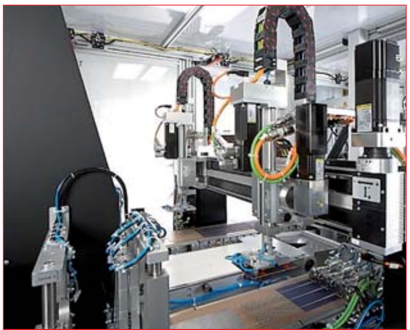


Figure 6. Tabbing unit from Schmid (left) and combined tabber-stringer from Somont.

which causes more extreme contraction than silicon. For the brittle silicon, tensile stress is critical.



Source: Somont

Figure 7. Vision system for initial cell alignment and control.

The solder joint over the busbar length may be continuous or interrupted. Interruptions longer than 15-20mm may generate series resistance losses, depending on the resistivity of the busbar.

The tabber-stringers used for fully automated cell interconnection work with a variety of heating technologies including contact, induction, resistive, lamp, hot air or laser soldering. Soldering is usually performed within a cycle time of approx. three seconds per cell on state-of-the-art machines. Automated cell interconnection is implemented as a onestep process or in two steps, with separate tabbing and stringing.

Initial cell inspection

The electric parameters of solar cells are always measured after their production, not least because STC power will eventually determine cell price. Module manufacturers usually check electric properties of incoming cells only randomly in an off-line procedure before string production.

For the module manufacturer, mechanical damage recognition in cells is a crucial task. In order to achieve safe automated handling and soldering, it is important to ensure edge integrity of the cells. Damaged edges are very likely to cause cell breakage during string and module production, leading to rejected strings, string repair or even machine down-time for cleaning. Many edge cracks will also cause power loss in the cell and ultimately in the string and module. Finally, clients may reject modules due to visible cell defects, even when they are getting the specified module power.

Visual inspection systems are used to check cell edges and busbars and to align cells for stringing (Fig. 7). A complete busbar print is required for proper soldering. Aligning cells through busbar recognition gives higher precision and handling safety than using mechanical edge contact. In Somont's Rapid and Certus stringers, the cells are aligned by servo motors during the transfer to the soldering belt, based on the vision system information.

Aside from broken edges and corners, less visible cracks inside the cell perimeter are also critical. Cracks usually extend into the cell surface, either on the emitter side, on the base, or both. A crack will nearly always increase the series resistance of a cell, depending on its length, its orientation and position with respect to the design current flow on the cell. If the crack occurred in wafer or cell production, and did not merit cell rejection, the electric damage will lead to a lower cell power classification. Cracks may also originate from transport and handling before cells enter the tabberstringer.

Even if cracks do not immediately weaken electric cell performance as specified by the cell supplier, they threaten future cell performance and durability. Mechanical loads during module production, transport, installation and operation can lead to crack growth. As soon as cell metallization is severely affected by a crack, it will increase cell series resistance and weaken cell performance. Due to the series interconnection of cells and common diode protection schemes, the weak cell will affect two strings, which usually account for one third of the PV module.

Therefore, the module producer must prevent cracked cells entering production and must ensure that the processes, especially the cell interconnection, will not produce cracks. If cracks are detected, their origin must be determined, as the processes being used may not only be revealing cell cracks, but causing them.

Small cracks pose a serious challenge

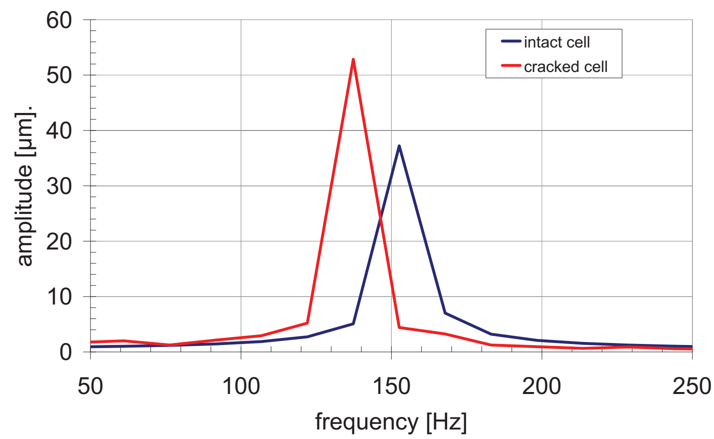


Fig. 8. Response spectrum of an intact cell and a cracked cell.

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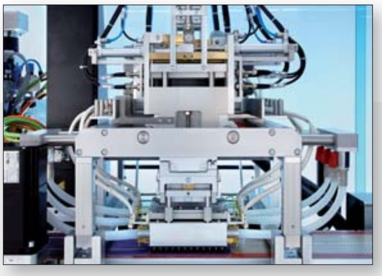

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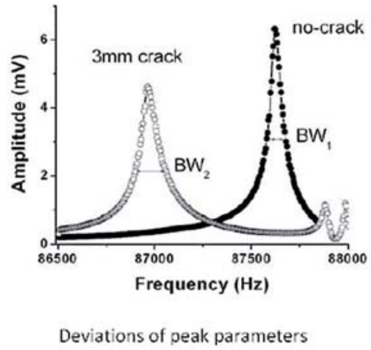
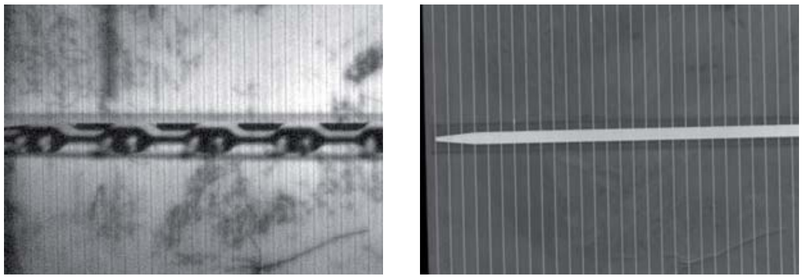


Source: RUV systems

Figure 9. Ultrasonic response spectrum of an intact and a cracked cell as recorded by the RUV crack detection system.



Source: GP Solar

Figure 10. EL image and contactless IR scanned image of the same cell showing several cracks.

to inline metrology, which has led to a multitude of technologies for initial crack detection (prior to soldering) being proposed. Crack length may grow if cells are bent. Longer cracks will then increase the bow of a cell under the same bending force. The approach of comparing the elastic response from two consecutive stress tests was followed in a crack testing device developed by Solarwatt; however, the device did not find its way into production lines.

Another approach comes from acoustics. Cracks may change the resonance frequency of cells subjected to sound excitation or they may introduce new frequencies in the response spectrum. Fig. 8 shows a reduction of the main resonance frequency by nearly 20Hz due to cell cracks, as recorded by a vibrometer. Some cracks also generate low-frequency noise. The measurements displayed in Fig. 8 have been performed on single tabbed cells.

RUV Systems offers a system for inline or offline crack detection based on acoustic resonance measurement [1], which uses ultrasonic frequencies, thus avoiding interference with other sound sources in the production environment. The inline implementation achieves a cycle time of three seconds.

Electroluminescence (EL) imaging has become a widely used tool for the recognition of defects in solar cells [2]. When a current flows through the cell, the recombination of electrons and holes emits radiation between 900–1400nm, peaking around 1150nm. This radiation can be registered by CCD detectors with spectral response ranging from approximately 300 to 1100 nm or by InGaAs detectors ranging from 900 to 1700nm. The latter offer better signal amplitudes, but have drawbacks in terms of lower image resolution and higher price.

Cracks appear as fine dark lines in EL images. Cracks that interrupt metallization and disconnect a region of the solar cell will appear as extended dark areas. In monocrystalline cells, cracks usually follow the crystal axis and are easily detected due to the homogeneous EL activity. In multicrystalline cells, grain boundaries and impurities render the automated detection more difficult (Fig. 10 (left)).

At present, initial EL imaging is not a common feature in automated tabber-stringers, possibly a result of the cost of inline EL implementation and the requirement of cell contacting. EL also requires a dark environment.

GP Solar recently presented a contactless IR inspection system for cells, the GP MICROD Vision, which is based on a line scanner that measures reflected IR radiation. In the reflected signal, material defects of mc silicon wafers do not show up, making the detection of cracks somewhat easier. The system measures on the fly with a belt speed of up to 400mm/s. GP Solar's crackdetection software claims very stable recognition due to the exclusion of grain boundaries and other bulk material defects.

Materials

Ribbon

The choice of an appropriate ribbon crosssection is influenced by contradicting requirements. A high cross-section is required for low serial resistance power losses, but will increase the mechanical stress on the tabbed cell; moreover, if the ribbon width exceeds the width of the cell busbar, additional shading losses are generated.

The use of ETP quality copper ensures high electric conductivity. Tin-based solder coating materials have a much lower electric conductivity than copper and will contribute little to the total conductivity. The mechanical properties of the ribbon are of huge importance to string durability from the string manufacturing all the way to module operation.

The yield strength (Rp0.2) has a direct influence on the thermomechanical stress, which is brought about by a mismatch in the coefficients of thermal expansion (CTE) of copper and silicon. The stress occurs immediately after soldering takes place, starting at the solidus temperature of the solder down to room temperature. It also occurs during module operation due to temperature variations, and, of course, in the temperature cycle test from -40°C to +85°C according to the IEC standard. Low yield strength will relieve this stress by supporting plastic deformation of the ribbon. At present, manufacturers are struggling to decrease Rp0.2 to values below 100N/mm^2, a 'softness' that is achieved by thermal annealing. In the stringer, the ribbon is cut and sometimes stretched to ensure straight alignment. This ribbon handling must ensure that yield strength is not significantly increased.

A second important ribbon specification is the elongation at fracture. Modules in operation will face deflections due to wind and snow loads, combined

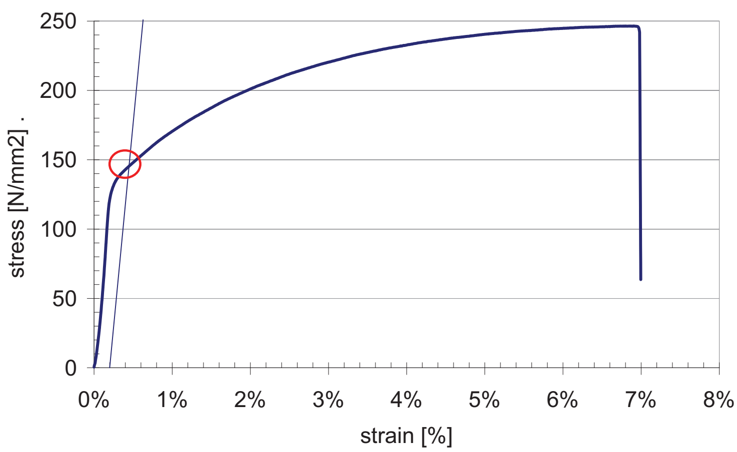


Figure 11. Stress-strain diagram of a ribbon.


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Figure 12. Wetting angle measurement for molten solder balls on cell busbar.

with temperature changes. As a result, the ribbon sections between the cells have to resist elongation. Typical specifications can guarantee elongation values at fracture above 25%.

The measured stressstrain data in Fig. 11 indicates an Rp0.2 point at 145N/mm². Tensile strength Rm is just below 250N/mm² (without correction for reduced cross-section) and elongation at fracture only reaches 7%.

Additional parameters influencing stress behaviour include ribbon aspect ratio (height/width) and ribbon design. Current developments are focussing on ribbons with reduced CTE and ribbons with a layer structure.

The copper core of ribbons is coated by hot dipping or plating with tin-based solders. Leaded qualities include SnPb 63/37 or SnPbAg 62/36/2; lead-free qualities include Sn100, SnAg 96.5/3.5 or SnAgCu 96/3.5/0.5. Low-melting lead-free solders show various compositions of tin and bismuth. Noneutectic alloys display a melting temperature range between their solidus and liquidus points instead of a singular melting point. Solder coating should have a uniform thickness over the ribbon length that is similar on both sides and research has yielded best results with solder layers of 10-20µm.

Solderability

During soldering, the molten material must spread over the busbar surface and fill the air gap between busbar and ribbon, which requires good wetting properties to ensure occurrence at temperatures not higher than 40°C above the melting point.

The interaction between busbar surface, flux and solder is responsible for the wetting process. Wetting quality is measured by specifying the wetting angle, which can be observed by applying solder balls on cell busbars in a chamber with inert gas, as shown in Fig. 12. Small values below 30° are considered good wetting in the electronics industry, but they are difficult to achieve on solar cell metallization. Good wetting will lead to high peel forces.

For good solderability, cell storage must ensure that the top layer of oxidized silver stays thin. Otherwise, soldering temperature and flux activity have to be increased and may lead to secondary problems.

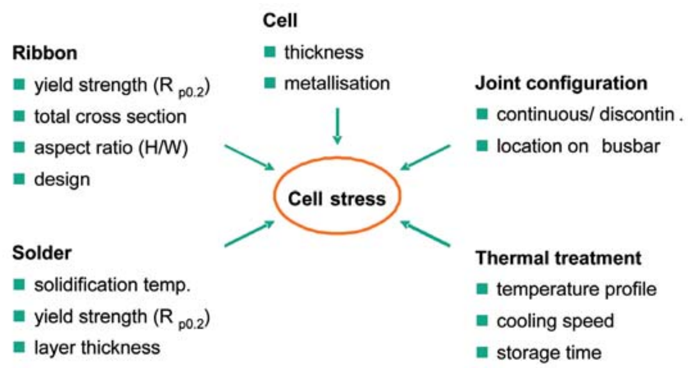


Figure 13. Cell stress parameters after solder cooling.

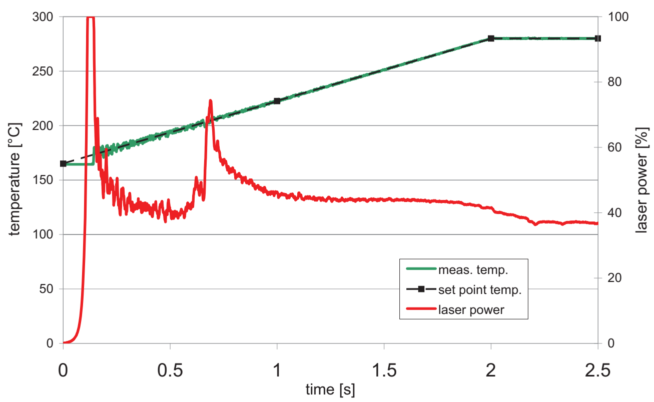


Figure 14. Laser soldering process with pyrometer control.

Fluxing

Cell soldering requires a no-clean, halogen-free flux that is deposited on the ribbon or on the cell busbars, usually occurring in the tabber-stringer just before soldering by using dilutions with very low solid content. The amount of flux needs to be carefully controlled, as excessive flux application contaminates the machine and the strings and may also cause adhesion problems in the laminated module. Insufficient flux may cause wetting problems during soldering, leading to incomplete joints.

Flux can be applied on the wire by transporting it through a flux bath. The Somont Certus stringer uses a flux jet technology, with optional selective fluxing on just the contact side of the ribbon. Other manufacturers favour the application of flux directly to the cell busbars.

Critical parameters for cell stress

As a result of CTE mismatch, soldered joints start to stress the cell immediately after cooling below the solidus point of the solder [37]. After the stringer step, this stress may lead to easily audible cell cracking. A multitude of parameters influence the magnitude of the thermomechanical stress and its evolution in time, depicted by the schematic in Fig. 13. Solder and ribbon are responsible for stress relaxation by plastic deformation. Since this relaxation takes some time, the joints are at their lowest strength immediately after soldering. This is also reflected by the fact that pull tests show better results when performed some time after soldering.

Quality control during soldering

Preheating just before the soldering step ensures the proper activation of flux. The cooling phase below the solidus temperature of the solder, essential for stress relaxation, involves the counteraction of two processes. The stress induced by the thermal mismatch between silicon and metals increases as the ambient temperature is approached; conversely, stress is relaxed by plastic deformation in the copper and the solder. After soldering, a slow, controlled cooling of the solder joints is required for thermo-mechanical stress

Figure 15. The Xinspect string inspection system by Komax Solar.

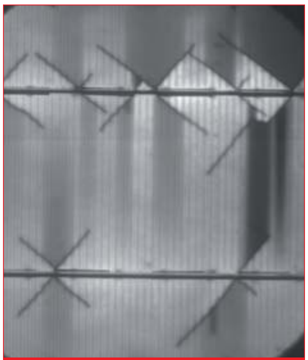


Figure 16. EL image of cell with heavy soldering-induced cracks.

relief. Preheating and cooling zones in the stringers will usually be equipped with one or more temperature control units.

During soldering, the control of the temperature profile in time and its spacial homogeneity requires great care. The time above the liquidus point should be kept short to avoid excessive diffusion. Pyrometers measure temperature contact-free and at fast rates down to 0.1ms intervals. However, their signals have to be corrected for emissivity variations. Pyrometers will only report temperature in one region of the cell if no scanning is used. Measurement on ribbons is difficult due to their low emissivity and corresponding weak radiation signal. Additionally, their emissivity may change in the course of the process.

Together with quickly responding energy sources like resistive heating, induction fields, laser beams or – to some extent – lamp irradiation, pyrometers offer the most accurate temperature control. Fig. 14 shows a perfect fit between the set temperature profile and the recorded temperature profile during a laser soldering process. Laser power (red line) has been dosed precisely to meet the specified profile.

Schmid's tabbing unit shown in the lefthand image in Fig. 6 is equipped with one pyrometer for each busbar that measures at time intervals of 5-10ms. Abnormalities in the relation between pyrometer signals and delivered power can give hints on disturbed heat transmission and may identify joint defects.

In contact soldering, the tool surface temperature is controlled at a much slower rate. Its thermal mass will hardly allow for any corrections in the course of the single soldering process, but it can ensure a uniform, reproducible heating. Care must be taken to avoid soiling on its contact surface, since this will change the heat flow.

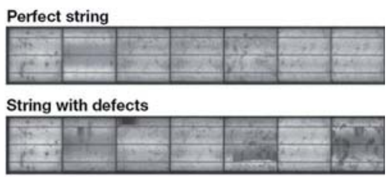
Quality control after soldering

Inline procedures

An inline visual inspection of strings can detect broken cells or misaligned ribbons and cells. Backlight visual systems basically analyze contours and can detect cracks in the cell area only in the case of the aluminium screen-print layer being affected. Interconnection continuity and the correct polarity of cells in one string is checked using dark IV-measurement, which can give information on dark series resistance of the string.

String flashing will reveal faults that lead to power loss. Since flashing in this stage is only intended to give a comparative evaluation of subsequent strings, there is no requirement on the spectral distribution of radiation. LED flashers or other light sources may be used, as long as they provide a reasonable spatial homogeneity and reproducibility. Komax Solar offers the 'Xinspect' series of string testers that verify electrical performance by a monochromatic I-V curve measurement. The system is not integrated into the tabberstringer, but in the consecutive string layup system, shown in Fig. 15.

String-testing systems from Berger Lichttechnik feature a single flash tube for sunny-side-down use which generates a two-phased flash for the assessment of series internal resistance. A resistance



Source: Komax Solar

Figure 17. EL images of strings.

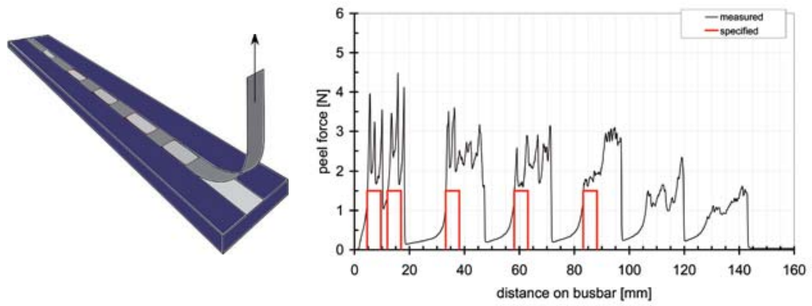


Figure 18. Example of peel test results.

increase may indicate poor contact to the ribbon or disrupted metallization, and must be addressed as it has the ability to weaken module performance.

EL imaging, as shown in Fig. 16, can show cracks in soldered cells; in this case, a very thin monocrystalline cell has been soldered to an SnAgcoated wire. Equipping the Xinspect system from Komax with an EL camera system allows inspection of strings. Fig. 17 shows an example without cracks (top, Fig. 17) and with defects (bottom, Fig. 17). Finger interruptions can cause a weaker EL signal on one side which makes the image darker. The contactless GP MICROD Vision system mentioned earlier is also intended for use in string inspection.

Offline procedures

Peel test and fracture analysis

The peel test is a widely used procedure to assess the strength of the solder joints and the fracture appearance. The EN 50461 standard, entitled “Solar cells – Datasheet information and product data for crystalline silicon solar cells” [8] requires a minimum peel force of 1N per millimetre width of the solder joint.

Generally, there are no accepted terms for the peel procedure, but the usual approach is to perform the peel test at constant speed and at a 90° peel angle, which yields a registered peel force as shown in the graph in Fig. 18.

Although this kind of peel load will not occur in module operation, the test design is used for ease of accomplishment and tradition reasons. Very thin cells and special metallizations may require different testing procedures. The peel test should be performed on automated equipment as shown in Fig. 19. Since stress relaxation after soldering is a continuous process, peel results will differ strongly if the test is performed five minutes or five hours after the process. For reliable peel results, the test is usually performed 24 hours after soldering.

Fracture appearance is as important as the recorded force. The most common fracture mechanisms include (see Fig. 20, left to right): wafer breakage, wafer chipping, paste peel-off (adhesive failure) and paste breakage (cohesive failure).

Metallography, SEM and EDX

Analytical methods from the electronics industry are used for analysis of joint integrity, composition and morphology. For example, metallographic preparation requires cutting and several polishing steps. A polished cross-section can be observed in an optical microscope (Fig. 21, left), or for better resolution, in a Scanning Electron Microscope (SEM). Fig. 21 (right, from top of image) shows the wafer, the busbar, the solder joint and the copper ribbon. Complete wetting and filling of the gap was achieved; no cracks or adhesion defects are visible. In the left image the solder layer contains dark primary lead crystallites in a grey tin matrix.

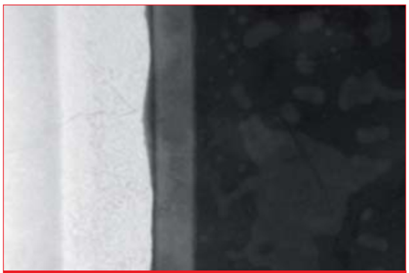


Figure 22. X-ray image of a soldered cell.

With energy-dispersive x-ray spectroscopy (EDX), chemical elements can be identified together with their distribution in the sample’s crosssection. Metallographic preparation is also used to assess diffusion and phase growth processes caused by (accelerated) aging [9].

X-ray imaging

Solder joints on solar cells are mostly hidden in between the cell and the ribbon. Using a highresolution x-ray unit enables

Figure 19. Peel testing device.

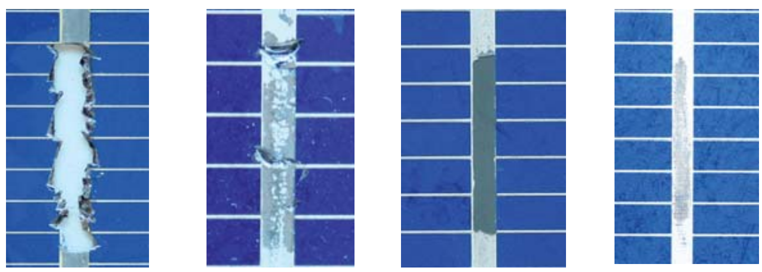


Figure 20. Peel fracture modes, left to right: wafer breakage, wafer chipping, paste peel-off (adhesive failure) and paste breakage (cohesive failure).

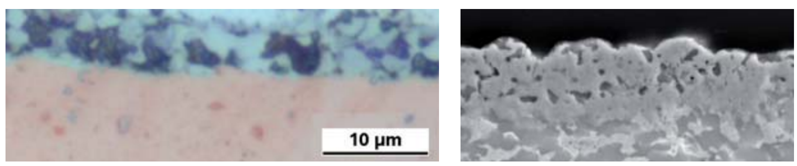


Figure 21. Metallographic images from optical microscope (left) and SEM (right).

the study of the integrity of the cell metallization and the joint homogeneity underneath the ribbons without destroying the cell. Fig. 22 shows the intersection of a finger with the busbar, where the broader p-busbar, the ribbons and the n-busbar overlie each other.

Conclusion

The process of solar cell interconnection has not yet reached the maturity evident from other industries, neither in terms of quality assurance nor in theoretical understanding. With current challenges from lead-free soldering, thinning wafers, new cell metallizations and increased line throughput, cell tabbing and stringing will have to adopt efficient metrology. The essential process parameter is the temperature profile experienced by the cell, as long as gentle handling is taken for granted. This profile will require more precise control especially during soldering and cooling. Ideally, cell integrity and functionality are assessed twice: initially and in the tabbed state. A data comparison will then reveal quality problems arising from interconnection. With respect to back contact cells, sequential tabbing and stringing needs to be replaced by simultaneous processes, for technical and economical reasons. This generates totally new challenges for quality control in cell interconnection.

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Evaluation of encapsulant materials for PV applications

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ABSTRACT
Encapsulant materials used in PV modules serve multiple purposes. They physically hold components in place, provide electrical insulation, optically couple superstrate materials (e.g., glass) to PV cells, protect components from mechanical stress by mechanically de-coupling components via strain relief, and protect materials from corrosion. To do this, encapsulants must adhere well to all surfaces, remain compliant, and transmit light after exposure to temperature, humidity, and UV radiation histories. Encapsulant materials by themselves do not completely prevent water vapour ingress [1-3], but if they are well adhered, they will prevent the accumulation of liquid water providing protection against corrosion as well as electrical shock. Here, a brief review of some of the polymeric materials under consideration for PV applications is provided, with an explanation of some of their advantages and disadvantages.

Types of encapsulants

Many types of encapsulant resins have been considered for use in PV modules. When PV panels were first developed in the 1960s and 1970s, the dominant encapsulants were based on polydimethyl siloxane (PDMS) [4,5], chosen because of its exceptional natural stability against thermal- and ultraviolet light-induced stress. However, in an effort to reduce module costs, alternative materials were investigated and developed, leading to the emergence of ethylene vinyl acetate (EVA) as the dominant PV encapsulant.

Recently, there has been renewed interest in using alternative encapsulant materials. The common alternatives are shown in Fig. 1. Most of them, including ionomer, EVA, and polyvinyl butyral (PVB), have a backbone consisting of only carbon-carbon (C-C) bonds. Alternatively, thermoplastic polyurethane (TPU) formulations have nitrogen and oxygen incorporated into the backbone in the form of a urethane bond. All four of these structures incorporate an ester bond (R-COOR'), which is susceptible to hydrolysis. The presence of hydrolytically unstable bonds in the backbone is nevertheless of greater concern because depolymerization can facilitate significant reduction in viscosity, allowing creep and/or delamination to occur more easily [6]. If the side groups of PVB or EVA become cleaved, one would expect to see stronger hydrogen bonding between polymer chains and surfaces. This can lead to embrittlement of polymers; however, a substantially greater extent of hydrolysis (compared to breaking of the backbone bonds in TPUs) must occur for these effects to be significant.

In contrast, PDMS has a backbone consisting of alternating atoms of Si and O. Because the silicon atom is much larger than oxygen or carbon atoms, there is greater freedom of motion for rotation and bending of Si-C side-group and Si-O back-bone bonds for silicone-based polymers compared to hydrocarbon-based polymers. This enhanced mobility in PDMS results in polymers with extremely low glass transition temperatures and with lower mechanical modulii (so long as the cross-link density is low). Additionally, the bond dissociation energy of Si-O is ~108kcal/mol compared to 83kcal/mol for C-C bonds, corresponding to photons with wavelengths of 263 and 343nm, respectively. The fact that no terrestrial solar radiation is present at 263nm relative to that ordinarily present at 343nm is one of the reasons for the exceptional UV stability of PDMS.

> "The use of chemical cross-links enables more effective use of primers to promote adhesion at surface interfaces."

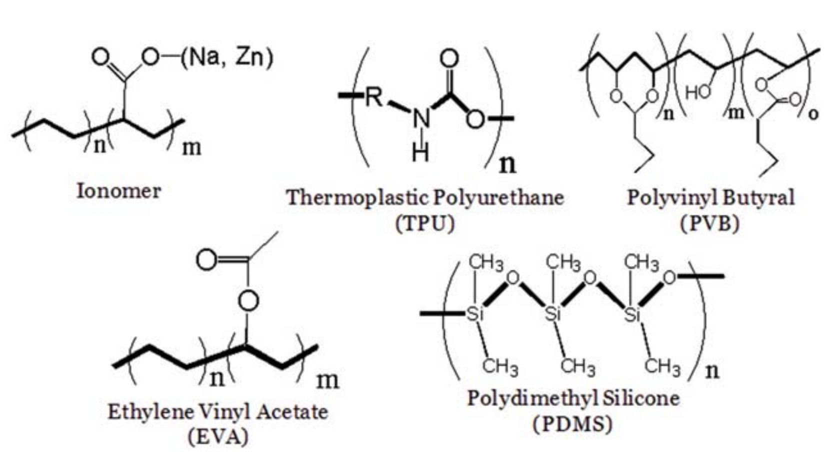

Figure 1. Structures of PV encapsulant resins.

Typically, ionomers, TPUs and PVBs are formulated as thermoplastic (non-cross-linked) materials. For PVBs, plasticizers are also added to lower their mechanical modulii and to tailor their phase-transition temperatures. As is also summarized in [6], TPUs and PVBs typically have a glass transition around or below room temperature and are therefore in a rubbery state during much of their use, which makes them more susceptible to shear-induced flow. TPU and PVB are typically formulated to have a high viscosity at PV operating temperatures to reduce creep [6].

Ionomers are also typically thermoplastic, but often have a melt transition around 90° to 100°C. Below the melt temperature, polyethylene segments are aligned forming physical cross-links, the formation of which is reversible upon heating. The dramatic changes in viscosity upon heating through the melt transition, where viscosity can be decreased by orders of magnitude, must be considered for modules deployed in environments/mounting configurations prone to reaching the melt temperature.

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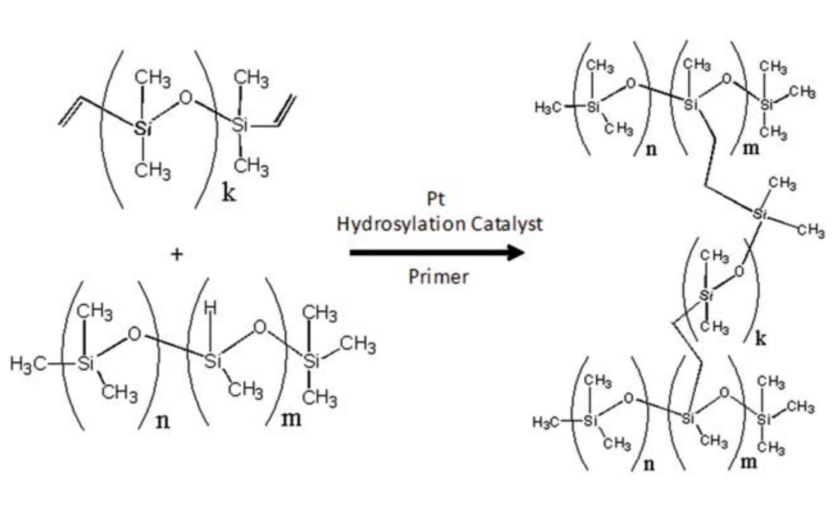

Figure 2. Schematic of curing chemistry of PDMS-based encapsulants [7].

To overcome concerns with polymer creep/flow at elevated temperatures, EVA and PDMS materials are typically formulated to form chemical cross-links. For PDMS, a Pt-based catalyst combines vinyl groups (of vinyl-terminated PDMS) to silane groups of a poly(dimethyl-co-methylhydrogensiloxane) (see Fig. 2). This chemistry will proceed at room temperature, but is significantly accelerated at elevated temperature. Chemical cross-linking restricts material flow to only occur when mechanical stresses are large enough to break chemical bonds. Additionally, the use of chemical cross-links enables more effective use of primers to promote adhesion at surface interfaces.

Thus, a cross-linked system will be chemically bonded to surfaces, whereas thermoplastic systems must rely on a combination of ionic, hydrogen, and/or van der Waals forces for adhesion. When water reaches an interface between the polymer and an inorganic material, the polar water molecules will compete with the less polar polymer at adhesion sites. If the polymer is displaced by the water, delamination will occur. In contrast, with a chemically bonded encapsulant, chemical bonds must be broken in addition to the physical bonds, making it easier for chemically bonded, cross-linked encapsulants to be formulated for durable interfacial adhesion.

PDMS-based materials are inherently UV and thermally stable, but hydrocarbon-based materials (EVA, TPU, PVB, and ionomer) require stabilizers to be durable. An EVA formulation is not just simply EVA resin, but a complex mixture of components. A typical EVA formulation is shown in Fig. 3 [8,9]. The majority of the material is the EVA resin. Typically, a 33 wt% vinyl acetate EVA is used to balance its characteristics, which include: a low glass transition, low modulus, low crystallinity/highly light transmittance resin, and a convenient melting temperature (45°C to 65°C), enabling easy melting for processing. EVA resins are also designed with molecular weight distributions and branching characteristics to facilitate extrusion into a film, which will minimize shrinkage in subsequent laminations.

> "A trialkoxy silane is used to promote adhesion between EVA and inorganic surfaces."

About 1 to 2 wt% of an EVA film is a thermally-activated peroxide used for cross-linking at elevated temperatures during lamination. The peroxide decomposes to produce radicals, which react with the polymer using non-specific chemical pathways to form cross-links. At temperatures above 140°C, a typical peroxide such as tertbutyl-2-ethylhexyl-peroxycarbonate (TBEC) will decompose sufficiently to facilitate the cure within two minutes [10]. The time required to heat the polymer in a module to this temperature range is therefore the most significant factor limiting the speed of lamination.

A trialkoxy silane is used to promote adhesion between EVA and inorganic surfaces. The silane end tends to be attracted to polar surface hydroxyl groups and is able to react with them, creating methanol as a leaving group and forming a covalent chemical bond in place of the hydroxyl group [11]. The other two alkoxy groups may react further with other surface groups or with other trialkoxy silane groups, forming a three-dimensional network that ensures good adhesion. This interfacial structure also helps to passivate inorganic surfaces against corrosion by limiting the movement of corrosion by-products away from the interface.

The effects of UV radiation are mitigated by the inclusion of a UV absorber such as benzotriazole. Early EVA formulations used benzophenone-based UV absorbers. However, it was later determined that an interaction between benzophenone, lupersol 101 (peroxide), and a phenyl phosphonite had a significant tendency to form chromophores, imparting a yellow colour to EVA upon outdoor exposure [12]. These early formulations resulted in extreme degradation of the historically sizable installation of PV panels at Carrizo plains. Initially, the loss in power of the modules was attributed primarily to EVA discoloration [13], but subsequent analysis demonstrated that solder joint breakage was the more significant problem [14].

Finally, a hindered amine light

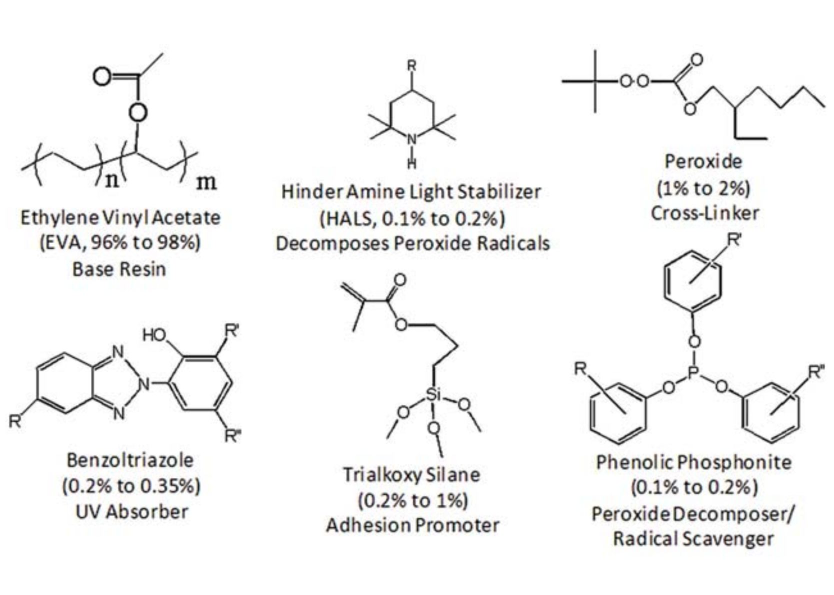

Figure 3. Example formulation of EVA for PV.


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Encapsulant	Transmission to Cells through 3.18 mm glass and 0.45 mm Encapsulant	Comments
	%	
GE RTV615	94.5 ± 0.3	PDMS, Addition Cure
Dow Corning Sylgard 184	94.4 ± 0.3	PDMS, Addition Cure
Dow Corning 527	94.4 ± 0.3	PDMS, Addition Cure
Polyvinyl Butral	93.9 ± 0.4	
EVA	93.9 ± 0.4	
NREL Experimental	93.4 ± 0.4	Poly-α-olefin
Thermoplastic Polyurethane	93.3 ± 0.3	
Thermoplastic Ionomer #1	92.3 ± 0.4	Copolymer of Ethylene and Methacrylic acid
DC 700	91.7 ± 0.3	PDMS, Acetic Acid Condensation Cure
Thermoplastic Ionomer #2	88.4 ± 0.4	Copolymer of Ethylene and Methacrylic acid

Table 1. Solar photon (300 to 1100nm) weighted average optical density determined from transmittance measurements through polymer samples of various thickness (1.5 to 5.5mm) laminated between two pieces of 3.18mm-thick, Ce-doped, low-Fe glass [15].

stabilizer (HALS) and possibly a phenolic phosphonite may be added as antioxidants. The HALS acts to decompose peroxide radicals that may form due to thermal or UV exposure. In this process, the HALS is not consumed as opposed to the phenolic phosponite, which is oxidized to produce phosphate and phenols. These phenols are able to further react with radicals and thus have additional antioxidative effects.

Polymer light transmittance

PV encapsulants optically couple PV cells to a transparent superstrate such as glass; therefore, high transmittance is desirable. Hemispherical transmittance of light through encapsulant samples laminated between two pieces of 3.2mm-thick glass was measured to enable comparison of different materials, as detailed in Table 1 [15]. From these and similar measurements of bare glass, the photon transmission through a glass superstrate and 0.45mm of encapsulant to a hypothetical cell was estimated. Of the materials measured, the PDMS samples had the best transmittance, about 0.6% better than the best hydrocarbon-based materials. Part of this difference is attributable to the absence of UV absorbers in PDMS. This analysis considered only normal transmittance. A more thorough analysis by McIntosh et al. [16] using ray tracing models and considering multiple reflections, non-normal incidence, and reflections off the backsheet between cells, estimated this difference to be as high as 1.5%. Of the materials currently being considered for PV applications, PDMS has the best transmittance.

UV durability

Depending on its composition, glass may block much of the UV-B radiation, but typically blocks very little of the UV-A [13,17]. Therefore the UV stability of the encapsulation material used in front of the cell is important. Fig. 4 shows the results of a highly accelerated stress test designed to investigate the possible use of non-silicone-based encapsulants in medium-concentration PV applications [18]. Sample encapsulants were laminated between two pieces of low-Fe, UV-transmitting glass while monitoring the solar/quantum efficiency-weighted transmittance. They were exposed to 42 UV suns at a temperature between 80° and 95°C. In this scenario, none of the five different PDMS silicone samples demonstrated any significant loss in transmittance after up to 6000 hours of exposure. Under the same conditions, the four different EVA formulations showed very significant degradation after only 750 to 1700 hours of exposure, demonstrating the inherently greater stability of PDMS relative to EVA.

Fig. 4 also illustrates the great variation in performance of the EVA formulations provided by different manufacturers. This is attributable to changes in either the type or the amount of the different additives described in Fig. 3. Considering the extreme conditions of this test, these formulations performed quite well.

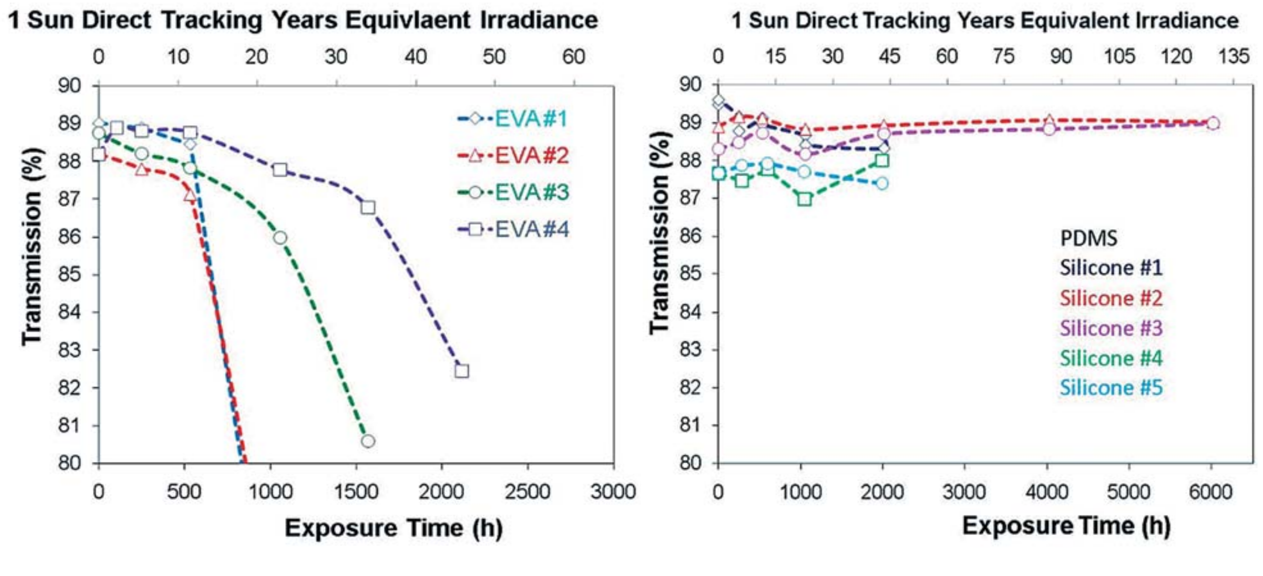

Figure 4. Solar and x-Si quantum efficiency-weighted transmittance of test samples exposed to 42 global-UV suns in a Xenon arc Weather-Ometer. Samples consist of 0.5mm encapsulant laminated between two 2.5cm-square, 3.18mm-thick, low-Fe, non-Ce glass samples (i.e., highly UV transmissive glass). Prior to sample discoloration, sample temperatures were maintained from 80° to 95°C during aging. The top axis corresponds to the amount of UV radition that would be seen with a system tracking the sun and utilizing only the direct spectrum.

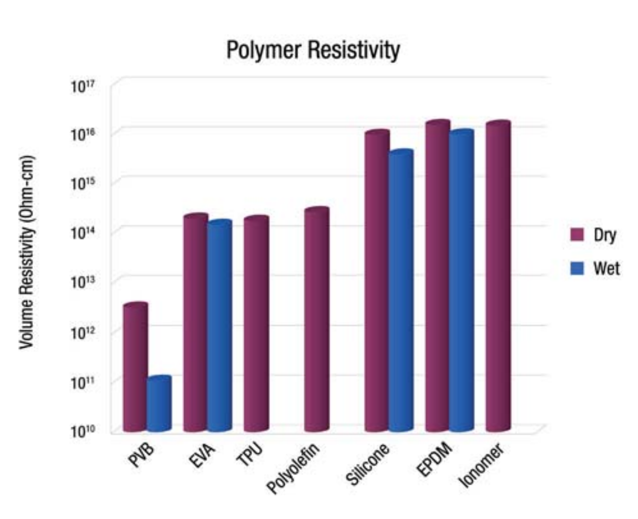

Figure 5. Volume resistivity measured using alternating DC polarity +/- 700V.
'Wet' samples were immersed in water at 40°C.

Similar experiments were also performed with PVB, TPU, and ionomer formulations [18]. In this experiment, PVB performed exceptionally poorly, TPU was comparable to EVA, and the ionomer was more durable than EVA. It must also be kept in mind that this test addressed only light transmittance, which is only one of several important characteristics such as adhesion.

Resistivity

The resistivity of encapsulants is relevant to electrical insulation, although the backsheet properties are a greater determining factor for a module. More importantly, relatively low resistance in encapsulant materials has been linked to electrochemical corrosion [20,21]. The volume resistivity of several candidate encapsulant materials is shown in Fig. 5. Measurements were performed using the DC alternating polarity method with some of the samples preconditioned by soaking them in water at 40°C. For most materials, saturation with water versus dry measurement did not significantly impact resistivity. PVB, which can absorb as much as 8% water at this temperature [19], was most affected by saturation with water. Mon et al. [19,20] found that, for PVB and EVA, temperature had a much greater effect on resistivity than absorbed water. The EVA, TPU, and poly-α-olefin examined demonstrated resistivities about 100 times greater than PVB, and the silicone, ionomer, and EPDM were about 10,000 times more resistive than PVB. Mon et al. were also able to find good correlation between degradation induced by electrochemical corrosion and total leakage from cells to the frame in amorphous-Si-based PV modules. There is a great range in the value of resistivity among polymers, which can be a significant determining factor for electrochemical corrosion processes.

Conclusions

This work discussed many of the attributes to be considered when selecting a polymer as a PV encapsulant and how different polymers are designed to meet these needs. An encapsulant provides optical coupling of PV cells and protection against environmental stress. Polymers must perform these functions under prolonged periods of high temperature, humidity, and UV radiation. The base polymer structure is the first thing to consider as it dominates subsequent properties. However, encapsulant films of the same base polymer have varying amounts and types of stabilization additives, resulting in different durabilities among manufacturers.

While some discussion was presented relative to maintenance of transmission after accelerated stress, getting good correlation of lab results with field results is very challenging. This is particularly true when one considers retention of adhesion strength, where there is a great variety of interfaces that are easily affected by trace amounts of surface contaminants. Ultimately, to have good service life prediction, long-term durability studies comparing indoor to outdoor tests are necessary to provide good confidence in the choice of encapsulant.

EVA is currently the dominant encapsulant chosen for PV applications, not because it has the best combination of properties, but because it is an economical option with an established history of acceptable durability. Getting new products into the market is challenging because there is not room for dramatic improvements (e.g., transmittance), and one must balance initial cost and performance with the unknowns of long-term service life.

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About the Author

Dr. Michael D. Kempe is a scientist in the PV Module Reliability Group of the National Center for Photovoltaics at the National Renewable Energy Laboratory, where he studies the factors affecting the longevity of photovoltaic cells and modules. His work is concerned primarily with both modelling and measuring moisture ingress into PV modules and studying its effect on polymer adhesion, device performance and component corrosion. He is also studying the effects of UV radiation on the stability of PV components. Dr. Kempe graduated from the California Institute of Technology with a Ph.D. in chemical engineering.

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Establishing a reliability methodology for thermal-cycle failure modes for CIGS modules

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ABSTRACT

This paper describes a methodology used to establish reliability of a CIGS thin-film photovoltaic module component based on identification of a failure mode through product thermal-cycling. The initial observation of the failure is described as part of a larger reliability program that progresses from failure mode and effect analysis through a test-to-failure program that has an objective of understanding the ultimate consequence of specific applied stresses on product performance. Once the specific failure mode was discovered, four means of characterizing the mode were applied and are discussed: tensile testing and material analysis, computer modelling, coupon rapid thermal cycling, and mechanical fatigue testing. This work identified the relevant root cause for failure and facilitated a materials change, which itself was subjected to an accelerated testing program to quantify the improvement and determine success of the design. The means of verifying success included meeting an endurance thermal-cycle limit for a collection of samples and subjecting corrected designs to a mechanical fatigue test, where the correlation between thermal cycle and mechanical fatigue were compared using Weibull analysis.

Introduction

Terrestrial field applications of solar photovoltaics have a history that stretches back more than three decades; however, the science required to create a uniform suite of product and component tests that results in the probability of survival over the product service lifetime remains elusive. In the PV industry, these service lifetimes are typically taken to be the manufacturer's warranty, which covers product performance over a span of time that is frequently more than 20 years. It is understood that these warranties are somewhat of a market-driven phenomenon, with most manufacturers adopting their competitor's warranties in order to remain market competitive.

As such, it is natural for some customers to express concern that without a strong reliability methodology, too much emphasis is placed on certification to the PV module qualification standards. In fact, in the absence of a uniform reliability methodology, manufacturers often state that their products exceed multiples of the key stress tests contained in the qualification test standards, yet the question remains of whether or not this is sufficient to claim a reliable product. The top four such qualification test standards (hereafter referred to as the qualification tests) used for product certification are as follows:

- IEC 61215: Crystalline Silicon Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval
- IEC 61646: Thin-Film Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval
- IEC 61730-1, -2: Photovoltaic (PV) Module Safety Qualification
- UL 1703: UL Standard for Safety for Flat-Plate Photovoltaic Modules and Panels.

Osterwald and McMahon provide a detailed history behind the development of the qualification tests, but make a point that successful completion of these tests cannot be misrepresented as predicting service lifetime [1]. Even so, the qualification tests have arguably improved overall PV module field reliability. For instance, a 10-year assessment of PV systems from 1979–1990 indicated a disparaging five-year PV module failure rate of almost 50%, which subsequently dropped to approximately 1.5 failures per 10,000 modules per year with the development of key stress tests, the majority of which remain in the qualification standards [2].

Recent assessments of PV module failure rates in the field are difficult to find in anything other than anecdotal information [3], although Wohlgemuth presents data on the experience of BP Solar that indicates a rate of failure that equates to one module in every 4,200-module years of operation [4].

A key difference between the tests contained in the qualification standards and reliability tests is that the qualification tests were built around the purpose of rapidly detecting known failure or degradation mechanisms [1]. A second difference is that the standard qualification tests contain a definition of failure that all manufacturers' designs must pass in order to enter the marketplace, regardless of design differences and without reference to warranty conditions. As such, these standards cannot assess reliability for unique failure modes that may occur at some point over a particular module's lifetime.

The qualification tests set a minimum expectation for durability or for changes in key performance or safety metrics over time, and contain stress tests such as thermal cycling and damp heat that continue to be indicative of design weaknesses [5]. It is these two key stress tests – thermal cycling and damp heat – that form the basis for a test-to-failure (TTF) program reported by Osterwald and adopted by MiaSolé [6].

Once a TTF program uncovers a failure mode, the reliability engineer's job is to address several key questions:

- What is the root-cause failure?
- What stress or combination of stresses excites the failure?
- Does this stress exist in the field and, if so, to what levels, where, and when?
- Is there a relationship between the level of applied stress and the time to failure?
- Can a process be established to address the root cause and demonstrate that the failure will not occur with unacceptable frequency over the service lifetime?

This paper addresses these questions for an observed failure that occurred at 200% of the standard qualification thermal cycle testing duration.

Failure mode and effect analysis

Failure mode and effect analysis (FMEA) is used to focus resources on those issues deemed by a company to represent an unacceptable risk. A detailed reference on the subject comes from Stamatis [7], but a concise overview is provided by McDermott [8]. FMEA typically takes the form of a design or process review, with a cross-functional team assessing the ways that a part or process could fail to serve its function and the consequences of the identified failure modes. The key outcome of an FMEA is a consensus agreement on how the team's identified risks should be prioritized based on the severity of the failure mode, the probability of its occurrence, and the ability to detect each failure.

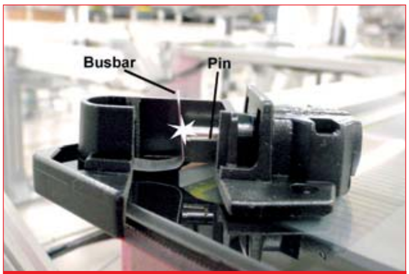

Figure 1. Junction box with a portion of the wall removed to visualize the failure mode of interest.

During the product-design stage, the manner of electrically connecting the PV cells to the junction-box electrical connector pin was evaluated for various failure modes (Fig. 1). Historically, the means of connection between the PV cells and the junction box have exhibited field failures that are attributed to thermal-cycling stress [3, 4, 9].

The failure mode of highest concern was the development of an open circuit having minimal separation distance between the busbar and the junction-box pin connection point that could lead to arcing. The FMEA process concluded that of four different methods of connection (spring clip, screw clamp, soldering, welding), only welding represented the lowest risk for MiaSolé's automated manufacturing process; however, the failure mode itself required testing to better understand its severity.

Failure mode risk assessment

The maximum system voltage of a PV module represents a limit on the number of modules that can be connected together in series, *n*, and can be used to coordinate the voltage insulation ratings for all equipment required in the PV system (cables, fuses, enclosures, inverters, etc.). The number of modules that can be connected in series is determined by local codes or good design practice and is based on the open-circuit voltage, V_{oc}, of the module. Modules delivering maximum power result in an approximate 20% voltage reduction from V_{oc} and at the module level, which is referred to as V_{max}. An arc can be caused by the difference between open-circuit voltage caused by a faulty component and maximum power voltage present during normal operation. At the system level, this voltage is defined as

$$V_x = n^*(V_{oc}-V_{max})$$

The company's FMEA severity assessment used a V_x of 250V DC, which was based on a conservative series connection of modules with a safety margin applied to the voltages. Specially constructed samples were built that could generate a maximum power current arc inside the potted junction box at a voltage that could go as high as 250V. The sample was subjected to repeated internal arc ruptures until oxidation build-up occurred and further arcing was prevented. The outcome suggested that the polymer potting compound did a satisfactory job of containing the arc, but thermal damage to the junction-box enclosure itself was evident. This work was repeated on a second sample with similar results and suggested that the main consequence was thermal damage to the junction box.

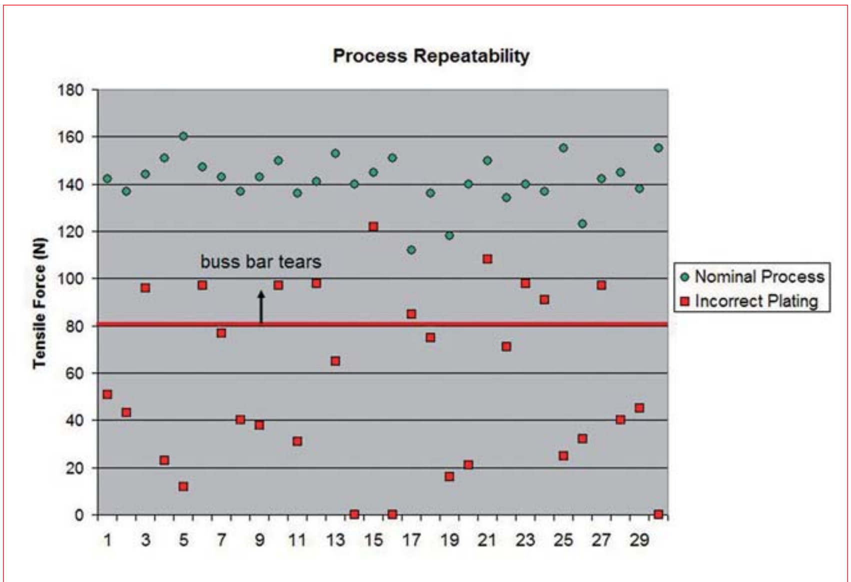

Figure 2. Welded-joint strength repeatability with threshold for busbar tearing identified as red line.

Process development and observation

Based on a clear understanding of the risk, production controls for a fixed combination of pin and busbar materials were developed for the welding method based on a design of experiments (DOE), with key controllable process parameters of current through the joint in amperes, duration of current flow in milliseconds, and clamping pressure on the pieces to be welded in bars.

The key performance metric was the tensile strength of the completed welded joint. Within the process control limitations of ±0.1 bar pressure, ±0.05 amp, ±1 milliseconds, the DOE indicated that current had the largest effect on weld strength and guided the process window to an initial state where repeatability was assessed, as indicated by the nominal process data points in Fig. 2. During process-window development an important demarcation between tensile testing failure modes was observed and is shown in Fig. 2 by a heavy red line. Samples having a tensile strength below this line failed with a clean interface between the pin and busbar. Those failing with a tensile strength above the line always tore the busbar and left busbar material behind on the junction-box pin. This observation became useful in diagnosing a thermal-cycle failure.

Test-to-failure program

Following process development, samples were taken from production and subjected to a TTF program for thermal cycling. (The company's TTF scheme also includes damp heat and humidity freeze testing regimes not discussed here.) The thermal cycle chosen was based on the UL qualification thermal cycle test, which has temperature limits and rate of change of +90°C to -40°C and 120°C/hr, respectively. It should be noted that the IEC qualification standards have an upper temperature limit of 85°C and limit the rate of temperature change to 100°C/hr. Failure was defined as anything constituting a major visual defect according to the qualification standard (i.e., IEC 61646, clause 7) or a maximum power less than 80% of the initial product power (i.e., warranty limit). Detection of the failure and when it occurred was facilitated by running maximum power current through the PV module in a

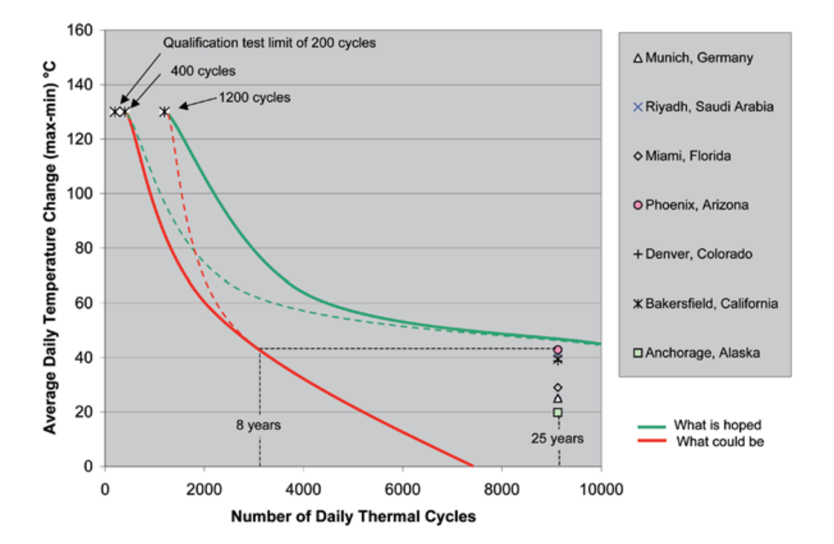

Figure 3. Comparing the qualification thermal cycle to 25-year average daily field thermal cycling.

forward-bias direction and using a data-logger to monitor the current and product temperature throughout the testing duration.

Within six months of initiating the TTF program, several modules had surpassed up to six times the qualification test requirement (1,200 cycles) and were still undergoing testing, but one module had exhibited an open-circuit failure at 400 cycles. Although 400 cycles represents twice the qualification test requirement, it was unclear if this was sufficient for a 25-year product lifetime. The fundamental concern (illustrated in Fig. 3) centres on possible failure curves scenarios as functions of temperature range during the thermal cycle. The chart depicts an estimate of a PV module's average daily field temperature-cycling range for a number of geographical locations and compares it to the qualification temperature change range of 130°C. The field temperature estimate is based on a method for a PV module having a glass-on-glass construction installed in an open rack at an inclination angle equivalent to local latitude and assuming a local 25% ground albedo [10].

> "Although 400 cycles represents twice the qualification test requirement, it was unclear if this was sufficient for a 25-year product lifetime."

When comparing the different temperature change ranges shown in Fig. 3, it is reasonable to expect that the qualification thermal-cycle test will require fewer cycles to cause failure. The problem, however, is that the actual shape of the failure curve remains unknown. To generate such a curve, several different temperature change ranges are required. This quickly becomes a daunting task because even liquid nitrogen-assisted thermal cycling chambers have difficulty exceeding 30 cycles per day because of a module's thermal mass. As such, once a failure is detected, it is typically prudent to develop a faster means to understand the reliability implication based on a clear understanding of root cause and the ability to confirm that an accelerated test appropriately excites the desired failure mode.

Figure 4. View of the junction-box pin following the first occurrence of a failure in thermal cycling.

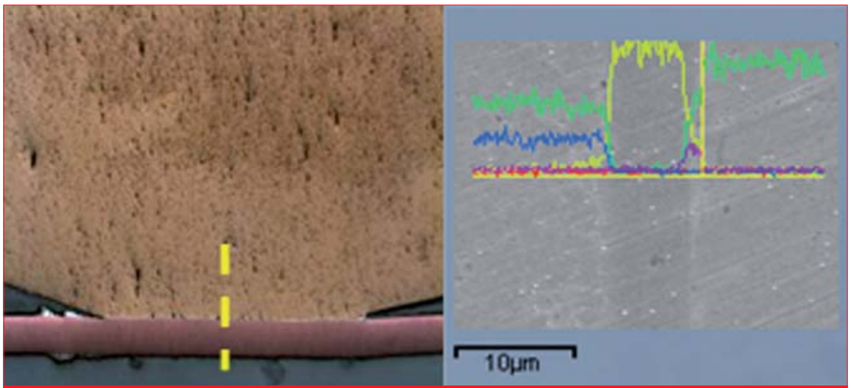

Figure 5a. EDXRS of a polished cross-section of a welded joint from a batch containing an incorrect plating layer which was found in a sample that failed in 400 thermal cycles.

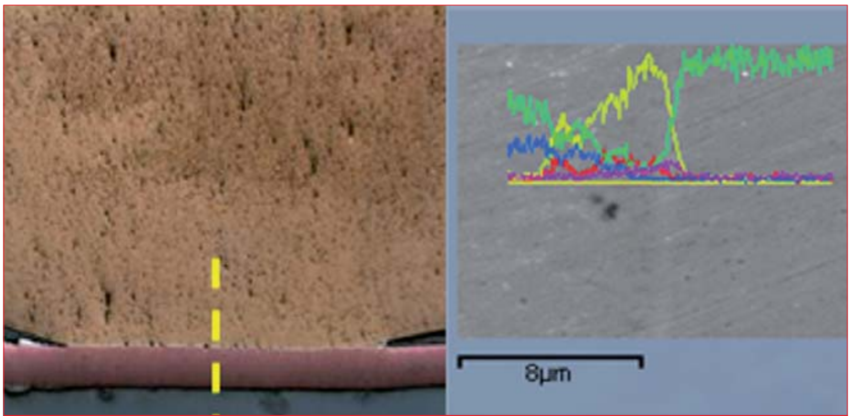

Figure 5b. EDXRS of a polished cross-section of a welded joint from a batch with correct plating layers found in modules that had not exhibited a failure in 1,200 thermal cycles.

Root cause for failure

An autopsy of the module revealed a weld failure between the busbar and the junction-box pin. The busbar itself did not exhibit damage but appeared to be simply separated from the pin. A close examination showed that the original FMEA failure mode of concern was present in the form of arc scoring at the tip of the pin, as depicted in Fig. 4. Note that this arc residue was made visible because the maximum power current was flowing through the module during the test. Although applying current to the module during thermal cycle is not required according to IEC 61646, the technique proved useful in this example of fatigue failure.

Review of the FMEA suggested that a process violation had occurred. It was quickly tied to an incoming material variance in a particular plating layer of the junction-box pin that was confirmed via several methods, two of which – tensile testing and energy dispersive x-ray spectroscopy (EDXRS) – are briefly described in the following sections.

Tensile testing

Tensile testing is an effective means of providing rapid feedback on a fatigue-related failure mode. It has limited value in diagnosing root cause and by itself is insufficient to predict lifetime. However, the speed of its results enables rapid feedback on a DOE test. Computer modelling suggested that the failure mode would be best evaluated by a pull test that placed the weld joint into a combined shear-tensile stress. This method of testing confirmed that a change in weld strength could be tied to lot difference from the part supplier. Consequently, EDXRS allowed identification of a specific layer in the plated pin that was different between incoming lots. Those lots exhibiting low tensile strength additionally showed large piece-to-piece variance in weld strength as the 'Incorrect Plating' data indicate in Fig. 2.

EDXRS measurements

EDXRS was performed on several cross-sections of welded joints. The measurements allowed visualization of chemical layers involved in the weld and a specific plating layer that limited the degree of metallic mixing taking place at the weld joint (Figs. 5a, 5b). This combination in a mixed metal weld joint (e.g., copper to brass) has been correlated to bond strength. As Fig. 5a illustrates, each elemental layer of the welded joint shows up as a discrete colour trace associated with its chemical identity, while the sharp transitions between the colour traces indicates that very little mixing took place. In Fig. 5b, when the correct plating was present and under the same set of welding conditions as the sample in Fig. 5a, there was a smoother transition from one chemical identity to the next. This smoother transition also correlated with samples that had greater than 80N tensile strength and failed by tearing of the busbar, leaving busbar material at the weld joint.

Reliability analysis

Because the TTF program had resulted in only one failure, little was known about the nature of the failure mode other than that it was linked to incomplete weld penetration. It was, therefore, necessary to understand whether this failure represented either an infant mortality distribution characterized as having a high initial rate of failure with the rate decreasing over time, a random distribution that exhibits relatively constant failure rates over time, or a wear-out failure where the frequency of failures increases over time. It was suspected, and later supported via Weibull analysis, that insufficient weld penetration should lead to an infant mortality failure mode, and that this was a preferred scenario because correct pin plating should improve the joint strength and therefore increase the number of cycles before fatigue failure occurs.

Coupon thermal cycling

Additional thermal-cycling failures were necessary to understand the nature of the failure distribution and to put some context behind the first failure that occurred at 400 cycles. To increase statistics on the failure mode, specially

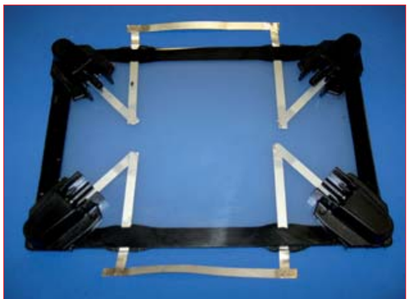

Figure 6. Sample coupons used to understand the nature of the failure.

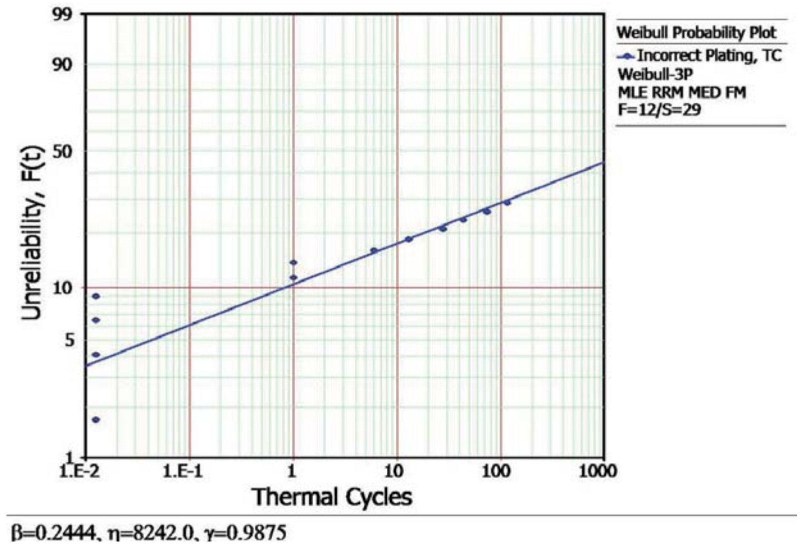

Figure 7. Weibull probability plot for welds from parts anticipated to have low thermal-cycle lifetimes.

constructed samples were made, with four junction boxes each, and current was injected across each weld joint to capture an open-circuit fatigue failure during the thermal-cycle test. The cycles until detection of an open-circuit failure were

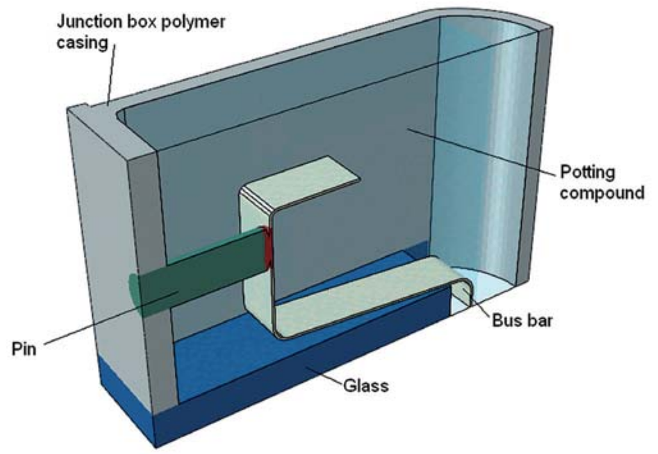

Figure 8a. Simplified geometry used for finite element model.

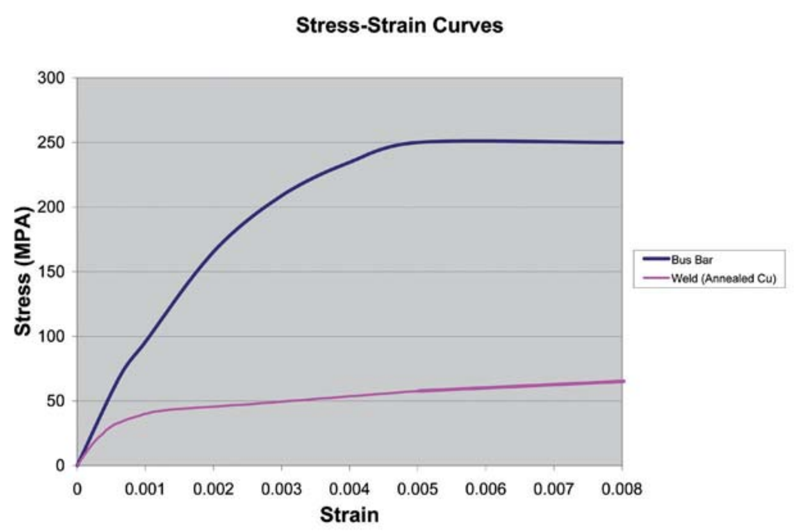

Figure 8b. Stress-strain curves used in the FEM.

obtained from a data-logger recording the voltage present across each welded joint. Once 12 failures had been observed within a 200-thermal cycle program, the samples were autopsied to verify that the failure mode was consistent with the originally discovered 400-thermal cycle failure. A Weibull life-data analysis was conducted (see Fig. 7). This analysis is based on the Weibull distribution, which is an extremely flexible frequency distribution that can reproduce positive, normal, or negative distribution skewness and has been used to characterize wide-ranging phenomenon [11], although its use here was strictly to analyze the observed fatigue failures.

The slope of the data in Fig. 7 is referred to as the shape factor, β, which is used to help classify the condition as being either infant mortality, random, or wear-out failure. Given the number of low thermal-cycle failures, β was calculated to be 0.24, which confirmed an infant mortality failure mode – generally the case for β of less than 1. Additionally, the curve indicates that approximately 50% of parts should fail by 1,000 thermal cycles, which put the observed 400 thermal-cycle failure in context. The conclusion was that while some parts may fail at hundreds of thermal cycles, 3.5% of samples will fail at the onset of thermal cycling. In this particular case, the observed 400-thermal cycle failure was clearly unacceptable because of its association with a wide distribution.

Computer modelling

A finite element model (FEM), developed using ABAQUS, was selected to drive understanding of the fatigue failure and to facilitate development of an accelerated testing method [12]. The level of modelling sophistication required depended heavily on objectives set forth. In the case of the junction-box weld, the objectives were to identify the deformation mechanism by which failure of welded joint occurs in thermal cycling, and to enable development of an accelerated test for the joint that can mimic the behaviour in thermal cycling.

> "Modelling the system in an elastic-plastic regime was important to understand joint failure through thermal cycling."

Based on the nominal geometry of the joint, an FEM of half of the junction-box assembly was developed (as depicted in Fig. 8a), with appropriate boundary conditions to represent symmetry. Based on initial calculation, it appeared that modelling the system in an elastic-plastic

Material	Modulus (MPa)	Poisson's Ratio	CTE
Junction-box polymer	2.35×10^{3}	0.38	7.02×10^{-5}
Busbar (Cu)	1.15×10^{5}	0.33	1.70×10^{-5}
Junction-box material	9.70×10^{4}	0.35	1.87×10^{-5}
Glass	7.31×10^{4}	0.22	9.03×10^{-6}
Potting compound	3.00×10^{-1}	0.45	3.32×10^{-4}

Table 1. Material properties used in analysis.

regime was important to understand joint failure through thermal cycling. Fig. 8b shows stress-strain curves used to model material behaviour for the busbar and weld region [13].

The potting compound that the company selected for its CIGS modules is a highly deformable polymer and the junction box is comparatively rigid. Given the fairly large temperature range of the qualification thermal cycle, it was anticipated that the material characterization would be complex. While dynamic mechanical analysis and other sophisticated techniques are available, it was instead decided to view the system as exhibiting an elastic-perfectly-plastic behaviour. For polymers, the ratio of yield stress to modulus can be as large as 5% [14]. In the present case, significant stress relaxation was anticipated since the loading cycle is slow, and at higher temperatures the material stiffness is expected to be reduced.

The bulk modulus was assumed not to change since the material was considered incompressible. For this study, a representative yield stress was taken to be 1% of the modulus. As the material properties in Table 1 show, the high thermal expansion of the potting compound and elastic-plastic deformations at the welded joint represent key elements for understanding the fatigue behaviour of the welded joint in the thermal cycle.

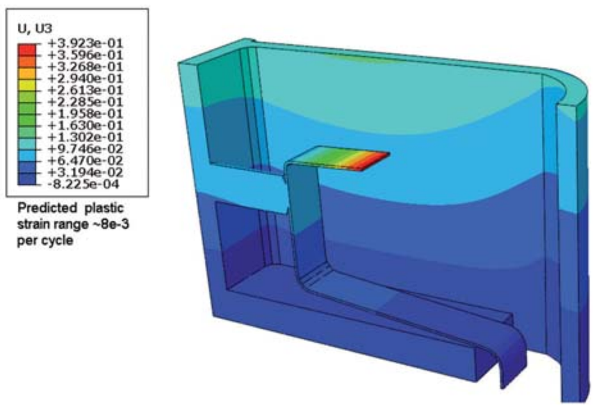

Figure 9a. Mode of deformation predicted by FEM. Note that the folded tab-end of the busbar is the source of stress.

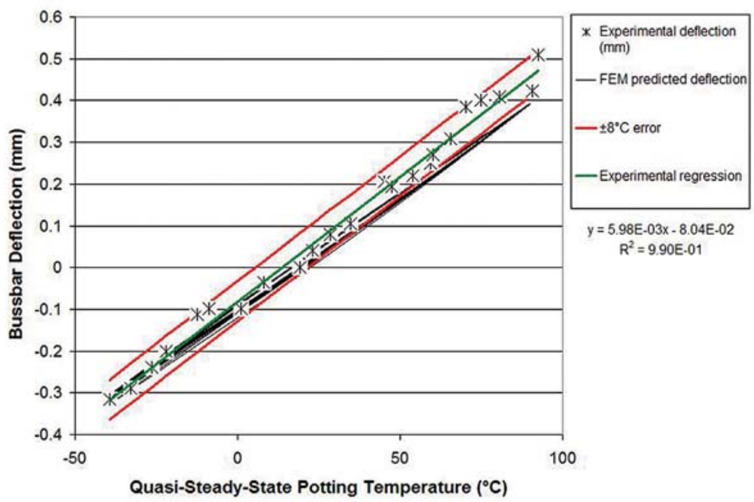

Figure 9b. Comparison of displacements predicted by FEM and experimental measurements described in the text.

Fig. 9a illustrates the mode of deformation from the FEM during thermal cycling and predicted plastic strain at the weld, while Fig. 9b shows a comparison of busbar deflections during thermal cycling predicted by the FEM going through a sequence of 10 cyclic displacements and compared to experiment. The slight change in slope between experiment and model is probably caused by the differences between the actual material used in the product and the material properties assumed for the analysis. Overall, the agreement is considered to be good.

Main insights gained from the FEM are:

- Cyclic deformations of the top bend in the busbar result in high stress/strain amplitude at the welded joint.
- If the welded joint is weaker (due to incomplete penetration), the failure would occur in the joint, whereas in a good joint the plastic strain would propagate in the vicinity of the joint.
- Deformation of the top bend is primarily driven by large expansion and contraction of the potting compound coupled with volumetric constraint offered by junction-box enclosure.

According to the model, the top bent portion of the busbar as well as the geometry of the 'notch' at the welded joint have a large influence on the stress and strain to which the welded joint is subjected.

In principle, FEM-derived calculations can be used to predict fatigue life of the joint by relating plastic strain amplitude to number of cycles to failure using the following relation [15]:

$$\frac{\Delta\varepsilon_p}{2} = \varepsilon_f (2N)^c$$

Where

$\Delta\varepsilon_p$ = Plastic strain amplitude
ε_f = Fatigue ductility coefficient
2N = Number of strain reversals to failure
c = Fatigue ductility exponent

Representative values of $\varepsilon_f = 0.5$, $c = -0.6$, and $\Delta\varepsilon_p = 8 \times 10^{-3}$ were used to estimate joint life of 3,125 thermal cycles. Although this compared favourably to experimental results, the insights gained from the FEM proved the most useful in developing an accelerated test method.

Accelerated test method

The mechanical fatigue test, guided by the FEM study, had to replicate the actual deflection experienced by the busbar as a function of temperature. A special sample was made to measure the deflection and consisted of a junction box and a small deflection-indicating pin extending up through the potting compound (Fig. 10). The displacement of the pin was measured at various temperatures. The data indicated in Fig. 9b are considered quasi-steady state since the sample had to be removed from an environmental chamber to room temperature conditions to make the measurement. As a result, some noise associated with transient heat-transfer and other uncertainties during the deflection measurement arises, amounting to approximately ±8°C around the regression line.

The Fig. 9b regression equation indicates that a busbar tab (approximately 9mm long) will deflect a total of 0.7mm (±0.35mm) when going from -40°C to +90°C in the thermal cycle test, and this deflection results in a reactionary force at the weld. To conduct a mechanical fatigue test using a reasonable actuator displacement of ±0.5mm at the end of the busbar tab, the weld-reaction force was held constant and used to calculate an equivalent length of busbar required.Special coupons were also created to undergo mechanical fatigue testing. All coupons used unpotted junction boxes that were additionally modified to allow easy access to the end of the busbar tab (Fig. 11). The tab was trimmed to a calculated length, and the mechanical tester was carefully positioned so that the piston would apply the required deflection at the tip. The testing equipment counted the number of cycles applied, and stopped the test whenever electrical continuity between the busbar tip and the junction-box pin was disrupted by an open circuit that might have been indicative of a fatigue failure.

Following the test's completion, each sample was visually examined to note the failure location and specifically check whether or not the failure had occurred at the weld. Some samples with the incorrect plating layer exhibited a second failure mode, consisting of a cracked busbar tab adjacent to the weld. This was a benign failure since it did not affect the electrical continuity of the busbar-to-pin joint and, therefore, would not have affected the power output from a PV module. Examination of the data in Fig. 2 suggests that this finding was consistent with the earlier tensile testing work, because some incorrectly plated parts had welded joints with tensile strengths above 80N – the tensile force required to cause tearing of the busbar material. The large variation of tensile strengths exhibited by the incorrectly plated pin meant that two failure modes should occur and were, in fact, observed.

Figure 10. Coupon prepared to allow busbar deflection measurement as a function of quasi-steady state temperature.

Figure 11. View of fatigue tester with junction box.

The Weibull analysis shown in Fig.12a confirmed that the nature of the mechanically derived failure mode was similar to failures observed in coupon thermal cycling. The result of the analysis indicated consistency between the thermal cycling failures and the mechanical-fatigue failures. This finding is illustrated in Fig. 12b, where the Weibull shape (β) and scale (η) parameters at the 95% confidence level overlap.

The mechanical fatigue testing of

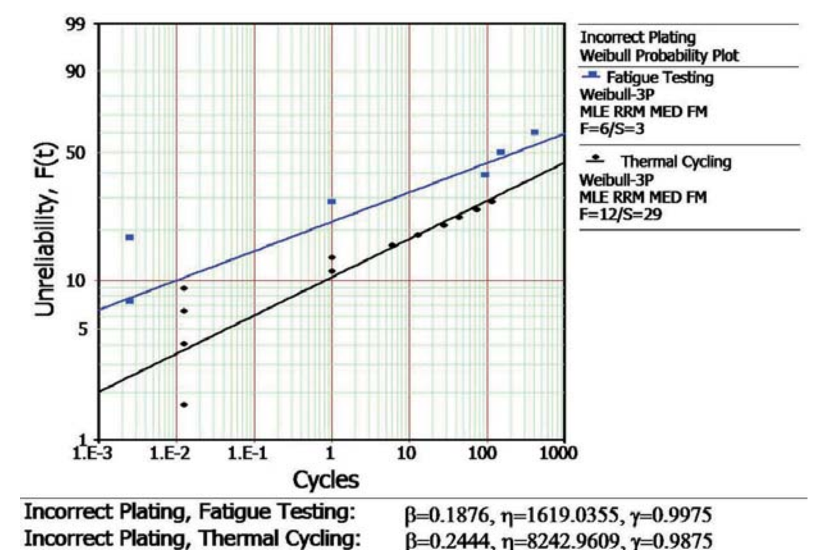

Figure 12a. Comparison between mechanical and thermal-cycle derived failures on a Weibull probability plot.

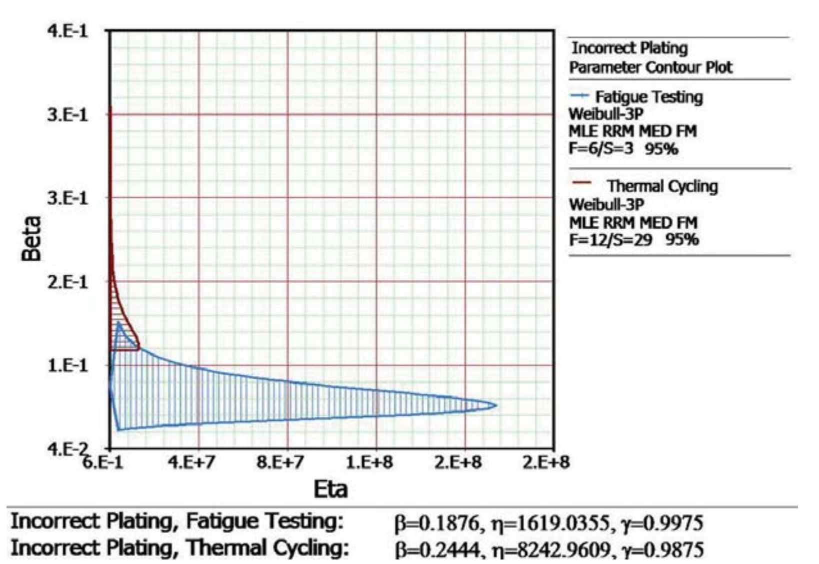

Figure 12b. Mechanical and thermal-cycle derived failures on a Weibull parameter contour plot: overlapping contours indicate they are consistent datasets.

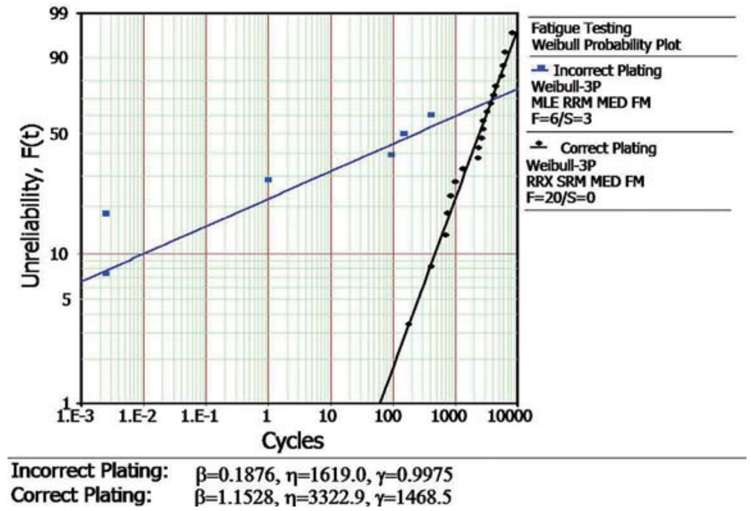

Figure 13. Comparison between infant mortality and benign wear-out failures on a Weibull probability plot.

incorrectly plated parts resulted in a Weibull shape parameter of β of 0.19 that was comparable to the thermal-cycle shape parameter of β of 0.24 and again supported the previous findings that incorrect pin plating created an infant-mortality failure mode. The most important conclusion, however, was that one could stimulate a thermal-cycle fatigue failure mode through mechanical testing. This insight enabled a faster path toward understanding the weld reliability under the aggressive deflection requirements of the qualification thermal-cycle test and eventually supported development of a service lifetime estimation for correctly plated parts that deflect in a manner consistent with anticipated field deflection.

=Twenty samples, each with the correct pin plating, were fatigue-tested to failure using deflection based on the qualification thermal-cycle test. The results supported the original hypothesis that pins having the correct plating fostered stronger weld joints that could sustain more fatigue damage before failure. In fact, visual inspection following failure detection indicated that all fails were of the benign type and that none occurred at the weld joint itself. The Weibull probability plot (Fig. 13) also reveals that the nature of the failure has changed from an infant mortality to a wear-out failure where the shape parameter, β, is now greater than 1. A Weibull parameter contour plot for comparing correctly plated pins to incorrectly plated pins was found to be impractical since the parameters were too different from each other to be presented in the same space.

Fig. 13 also shows that the correct plating curve indicates a percentage of parts exhibited benign fatigue failure prior to reaching the 25-year daily cycle limit of 9,125 cycles. Two metrics of interest in defining reliability are the median lifetime and failure-free lifetime. In Weibull analysis the median lifetime represents the centroid of the distribution, and is defined as:

$$B_{50} = \gamma + \eta(\ln 2)^{1/\beta}$$

Where β is the shape, η is the scale parameter previous described, and γ is the location parameter. The median lifetime for correctly plated parts was calculated to be 3,900 cycles, which compares favourably to the FEM prediction of 3,125 cycles. On the other hand, the location parameter, γ has the effect of shifting the failure distribution in time (or in this case, shifting by cycles), and serves as an estimate of the failure-free operating period for the part. For welds made with correctly plated parts, the failure-free operating period is estimated to be 1,468 cycles at the qualification thermal-cycle level and is clearly less than the 25-year daily cycle limit of 9,125.

“Twenty samples, each with the correct pin plating, were fatigue-tested to failure using deflection based on the qualification thermal-cycle test.”

The benign failure mode discovered did not pose a safety, performance, or cosmetic risk for warranty return. Thus, it was tempting to avoid testing at smaller deflections that would be more indicative of anticipated field conditions; however, work done to mitigate a specific failure mode inevitably results in slight process changes that, if unstudied, can result in unpleasant surprises.

Service lifetime estimate

To estimate the lifetime of the correct plated pin-to-busbar weld, 10 samples were subjected to an equivalent field cyclic stress condition. Average daily temperature swings for Phoenix, Arizona, were selected based on comparison of several locations (Fig. 14) and converted to an equivalent deflection using the Fig. 9b regression equation. A safety factor of 2 was multiplied to the result to take into account the possibility of more aggressive daily temperature swings elsewhere. Coincidentally, this methodology resulted in a test with 50% of the deflection of the qualification thermal-cycle test.

The results shown in a reliability plot format on Fig. 15 indicate that under service conditions, the initial onset of a benign failure mode (based on location function) occurred at 20,900 cycles, well over the expected service lifetime of 9,125 cycles. This effectively meant that as long as the welding process and material stay within specifications, this failure mode

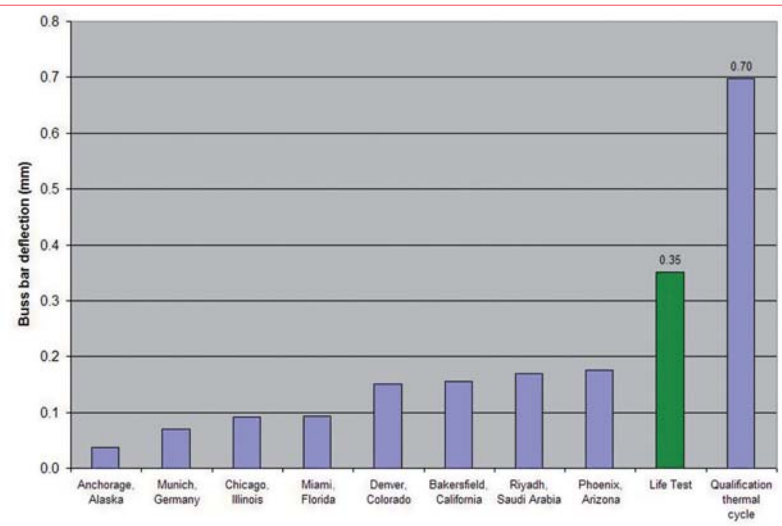

Figure 14. Busbar deflection estimates for various locations with the lifetime test deflection coloured green.

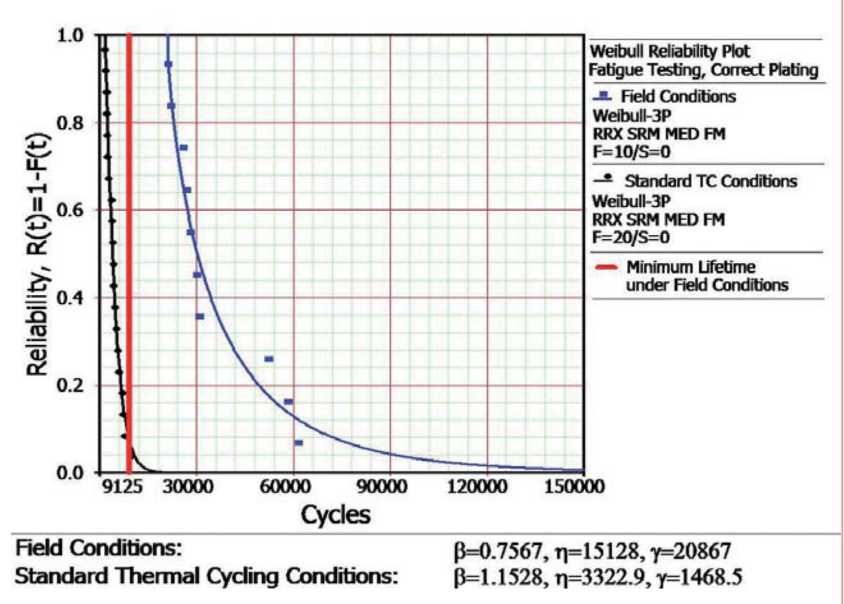

Figure 15. Comparison of fatigue testing results replicating qualification thermal-cycling stresses and anticipated field stresses on a Weibull probability plot.

would not pose a significant warranty risk over a 25-year service lifetime.

Conclusion

The intent of this paper has been to outline a reliability evaluation process used on a specific thermal-cycle failure mode encountered by MiaSolé and because of an absence of general photovoltaic tests that result in a product lifetime estimate. It cannot be concluded that such a process is generally applicable to PV modules, but some principles may be useful in other situations. In this example, the reliability approach began at design and continued through service lifetime estimation for a specific discovered failure mode. Although the work presented here indicated that service lifetime requirements could be met with minimal risk, continued vigilance over the process and additional testing of this failure mode will be required for as long as products with this busbar-to-pin design continue to be deployed.

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Power Generation

UK energy provider to supply 1,100 schools with free solar systems

The UK's leading energy supplier, British Gas, has launched a £15 million project to supply 1,100 primary and secondary schools with free solar systems worth between £20,000 and £40,000 per school over the next five years.

British Gas estimates that the scheme will generate approximately £1.3 million in revenues per annum under the UK feed-in tariff, which will be reinvested by the British Gas Energy For Tomorrow Trust, a 'not-for-profit' organization, established by British Gas to invest in low carbon projects. These funds will be used by Energy For Tomorrow to fund further free installations at schools across the country.

The energy company will use its own subsidiary of trained staff to undertake all the installations, and told PV-Tech that it is also in the final supplier selection phase for the program and a decision will be made soon. It would not say whether the company was evaluating a range of solar technologies such as thin-film for these planned projects.

Based on the retail worth of each of the solar system installations, British Gas could be installing between 4MW and 7MW in total over the first five-year phase. Schools with sufficient funds to install similar sized projects could see a revenue return from the FiT of between £40,000 and £85,000 over the 25-year tariff period. This amount also includes the energy saved by not having to purchase a certain amount of electricity from their supplier. The cost of the solar system would, however, have to be recouped from the revenue generated.

British Gas will supply 1,100 primary and secondary schools across the UK with free solar systems.

U.S. Region News Focus

eSolar, B&W selected by DOE for CSP plant development funding

eSolar and Babcock & Wilcox Power Generation Group (B&W PGG) have been selected by the U.S. Department of Energy (DOE) to receive up to US$10.8 million in funding for the design, construction and testing of a modular, baseload molten salt power plant using concentrated solar power (CSP).

The program has been designed with the aim of achieving the lowest levelized electricity cost of any utility-scale CSP plant. The company's approach to the plant's design will involve building the components in a factory and shipping them fully assembled to the plant site, thereby simplifying the plant permitting process. The project is expected to be complete by the end of 2012.

DOE offers conditional commitment offer for a US$1.45bn loan guarantee for Abengoa Solar

The U.S. DOE has offered a conditional commitment for a US$1.45 billion loan guarantee to Abengoa Solar. The loan, which was announced by President Obama in a weekly address, will support the construction and start-up of Solana, a 250MW CSP plant in Arizona.

The DOE's Title XVII Loan Guarantee program was created to support the deployment of innovative clean energy technologies pursuant to Section 1703 of Title XVII of the Energy Policy Act of 2005 (Title XVII). Title XVII of the Energy Policy Act of 2005 was amended by the American Recovery and Reinvestment Act of 2009 to create Section 1705, a new program for the deployment of renewable energy and electric power transmission projects. Solana is eligible for a loan guarantee under both sections of Title XVII. The plant will be located 70 miles southwest of Phoenix, near Gila Bend, Arizona and will produce enough energy to serve 70,000 households. Abengoa Solar has signed a power purchase agreement with APS, the state's largest electric utility, to sell the energy produced by Solana for a period of 30 years.

Obama has also pledged a further US$400m in loan guarantees to Colorado-based Abound Solar, to manufacture advanced solar panels at two new plants, creating more than 2,000 construction jobs and 1,500 permanent jobs. A Colorado plant is already being built and an Indiana plant will be set up in what is now an empty Chrysler factory.

Source: eSolar

eSolar concentrated solar power plant.

SoCal Edison issues request for offers for solar, other small renewable energy generators

Southern California Edison has launched a request for offers for more renewable contracts from small generators, seeking the participation of companies working in all forms of clean energy technologies that can develop generating facilities of 20MW and under. The solicitation marks the utility's first open, competitive call for additional renewable power contracts under the Renewables Standard Contracts program.

The goal of the initiative is to streamline the process by providing a standardized contracting process that minimizes the time required to complete an executed power purchase agreement, according to SCE. The solicitation seeks out long-term contracts for projects powered by solar, wind, biomass, biogas, oceanic, hydroelectric, and geothermal fuels located in California. SCE said it is particularly looking for viable projects that will begin operating within three years of contract approval.

Proposals are due Sept. 8th; SCE will host a web conference for interested parties on Aug. 10th. The utility said it expects to execute contracts from the solicitation in November and submit completed contracts to the California Public Utilities Commission for approval by January 2011.

Nautilus Solar to build 3MW solar project for William Paterson University

Nautilus Solar Energy has signed on to finance the construction and operation of the first 3MW of a 3.5MW solar energy project on the rooftops and parking lots of William Paterson University (WPU) in Wayne, NJ. Upon its completion the project will be one of the largest university solar installations in the U.S. The construction and term financing is provided, in part, through a US$5 million, 10-year loan with New Jersey Economic Development Authority (EDA).

The project is expected to be online this summer with Nautilus owning and operating the solar facility under a 15-year power purchase agreement. WPU will purchase the renewable energy at a reduced rate without any upfront costs. Construction will be completed by SunDurance Energy.

Source: Nautilus Solar Energy

Nautilus Solar's William Patterson University installation.

Adema to build 5MW solar system with Frito-Lay

Adema Technologies will be spearheading its newest solar system project at Frito-Lay's Casa Grande, Arizona, facility. The 5MW solar system will use Gloria Solar's 225W and 230W solar modules. Frito-Lay purchased the first 1.7MW of the contract with its own funds. The project will include a 240kW parking lot installation, 25kW at the corporate headquarters and 1.435MW as a solar power plant. Adema will engineer, design, procure, construct and provide quality control for the project.

Eaton to create solar power system for New Mexico VA Health

Eaton Corporation is to design and install a 3.2MW turnkey solar photovoltaic system at the Albuquerque, New Mexico Department of Veterans Affairs (VA) Health Care System. The federal stimulus funded US$20 million contract includes carport and roof-mounted arrays, as well as a building-integrated system. Once complete, this will be the largest PV system in New Mexico.

KACO and Sungevity expand state availability for iQuote

Colorado and Arizona are the newest states to whom KACO and Sungevity have extended their iQuote online sales tool availability. The system allows for homeowners to import simple data points into the Sungevity online portal and receive an iQuote within 24 hours. Many of the iQuote systems have been installed with Blueplant inverters from KACO.

Pro-Tech, NSC Technologies and Whitman to help U.S. armed forces in energy savings

Pro-Tech Energy Solutions, NSC Technologies Worldwide and Whitman Engineering have come together as a team for turnkey solutions and services in renewable energy and energy efficiency for the U.S. government and armed forces. Solar and wind will be the primary focus, with energy efficiency being maintained with energy audits and advanced lighting technology. The trio aims to provide resource management, engineering and construction services for the betterment of the U.S. government and armed forces energy use.

Pro-Tech will provide different turnkey energy solution services for the commercial and government sector while NSC will be responsible for contract administration, human capital, resources and information technology. Whitman will provide ongoing support with professional, environmental, engineering and MEP services.

PowerFin Partners extends funding capacity to over US$100 million for solar projects in North America

PowerFin Partners has reached capacity to fund over US$100 million in commercial and utility-scale solar projects in the U.S. and Canada. The company provides the PPA, EPC, O&M and site lease contracts along with engineering for the full operation of a solar generation facility. For integrators, developers and others seeking capital for solar projects, the PowerFin is looking for projects over 2MW for which the permission process is near completion. A single project can cover a minimum of 300,000 square feet, which can be spread across as many as four different sites.

Former nuke test site chosen for Department of Energy's CSP-oriented solar demo zone

A portion of a former nuclear testing ground in Nevada has been chosen as the site of the U.S. Department of Energy's Solar Demonstration Zone, where new concentrating solar thermal power technologies will be tested as part of efforts to link advanced technology development and full-scale commercialization efforts.

The lands, consisting of more than 25 square miles in the southwest corner of the site, are owned by the Department of Interior's Bureau of Land Management (BLM) and administered by DOE's National Nuclear Security Administration. An interagency memorandum of understanding has been signed between the departments of Energy and Interior to establish the centre.

The Solar Demonstration Zone will complement BLM's establishment of 24 Solar Energy Study Areas on public lands across the U.S. Southwest by helping to ensure that the most advanced CSP technologies are ready for commercial deployment, according to DOE. Plans are under way to create a new DOE funding opportunity for demonstration projects at the Nevada Test Site that will include matching investments from the private sector.

DOE said it chose this site after reviewing 26 possible locations, evaluating factors such as solar conditions, suitable terrain, and existing infrastructure to support solar projects. BLM and DOE are also closely coordinating with the U.S. Air Force to identify and address potential problems with locating and operating the Solar Demonstration Zone at the Nevada Test Site, which will also serve as a test bed for other solar projects proposed near military installations throughout the desert southwest.

Premier Power to build 1.9MW of solar power at two Southern California locations

Premier Power Renewable Energy has teamed with PUMA North America, lessee of Brookvale International, to build 1.9MW of solar electric generating capacity at PUMA's Carson and Torrance, California, warehouse and distribution facilities in Southern California. Premier will design, engineer and build the roof-mounted solar PV electric generating systems in the third quarter with an estimated finish date sometime in the fourth quarter of 2010.

REC Solar to offer Tigo Energy Maximizer in installations across U.S.

REC Solar and Tigo Energy have reached an agreement whereby REC Solar will offer the Tigo Energy Maximizer in its commercial and residential installations across the U.S. REC began the program for Tigo's Maximizer with REC's San Francisco Bay area installations in February and extended its reach to Los Angeles, San Diego and Colorado. By the summer of 2010, all U.S. territories will have the Tigo Maximizer available for installations. The Energy Maximizer is said to yield as much as 20% more energy production, active management capabilities and enhanced safety for utility, commercial and residential solar arrays.

Source: Tigo.

The Tigo Maximizer.

European Region News Focus

M+W Group will construct 14.5MW plant in Macerone, Italy

M+W Group is to plan and construct a 14.5MW photovoltaic power park in the province of Macerone, Italy. The plant is expected to have an annual output of around 18,900MWh, which will be supplied to approximately 6,000 households in the region. M+W Group will utilize around 72,500 multicrystalline photovoltaic modules, assembled across a 50 hectare plot for the project, which is anticipated to be connected to the national grid by the end of 2010.

Conergy to build five solar installations for BluSerena

BluSerena, an Italian hotel group, has contracted Conergy to build five solar installations at their five beach resorts. The installations will have a total power output of 3.6MW and will help the hotel group benefit from guaranteed state funding. Located in Apulia, Sicily, Sardinia and

News


Source: Conergy

BluSerena's carport installation in Calabria will feature 3,454 Conergy PowerPlus 225P modules.

Calabria, three of the power stations are currently under construction.

The installation in Calabria will be built upon the carport at the resort using 3,454 Conergy PowerPlus 225P modules. The constructed area will be around 118,000 square feet with an energy output of 800kW. Three Conergy IPG 300K invertors will feed the electricity into the power grid. BluSerena's hotel, Torre Canne di Fasano, in Apulia will use over 2,700 Conergy PowerPlus modules for 850kWh of solar energy. All the installations will be equipped with Conergy modules and invertors.

ISIS Solar will install 18,000 free rooftop solar systems in the UK

Taking advantage of the UK's feed-in tariff, Oxford-based ISIS Solar is to install 18,000 rooftop solar systems, free of charge. The company will begin by installing the systems in the south of the country, but will move north as the year progresses.

Each system will be 3.3kW, covering an area of 24m^2, on a roof which must be roughly south-facing and relatively unshaded. A system of this size would usually cost the customer around £16,000. By installing the panels for free, ISIS saves the homeowner this upfront cost, as well as cutting approximately £300 a year off their energy bill.

ISIS will be using UK-based installer the Mark Group, which is certified under the country's microgeneration certification scheme (MCS). Mark Group will be installing Mitsubishi 1.85kW modules and Fronius inverters for the 18,000 systems.

The company will earn its investment back through the country's feed-in tariff, which pays 41.3p/kWh of energy produced. The UK's Department of Energy and Climate Change (DECC) estimates that the scheme will cost the country £8 billion over 20 years and add £8.50 a year to the average household electricity bill.

Canadian Solar, Green City Energy complete 1MW installation in Germany

Canadian Solar and Green City Energy have jointly completed the installation of a 1MW photovoltaic system, which is part of the Burgersolarpark project, located in the city of Haertensdorf in Saxony, Germany. The Munich-based project company, Green City Energy, completed the project within two months of construction.

SMA Solar guides solar market to top 14GW in 2010: raises sales target to €1.8 billion

The solar inverter market leader, SMA Solar Technology has made a significant upward revision to its revenue guidance for 2010 on the back of strong demand. The company said it expected revenue to be between €1.5 and €1.8 billion for the year. Previously, SMA Solar guided revenue to be between €1.1 and €1.3 billion. The worldwide solar market could reach 14GW installed, compared to previous expectations of the market reaching 9GW to 11GW in 2010.

The upward revisions to both revenue and global market growth suggest the critical shortages of inverter components, primarily semiconductors, is expected to ease in the second half of the year as IC suppliers increase production allocations to customers such as SMA Solar to better meet booming demand. SMA Solar noted that delivery times for its inverters would gradually improve in the second-half of the year. The company previously noted that recent capacity expansions at facilities were underutilized due to the shortages in components. The company said that sales topped €800 million for the first six months 2010 and sold more than 3.1GW of inverter output. However, SMA Solar noted that it expected a decline in the


Source: SMA Solar Technology

SMA Sunny Boy inverter.

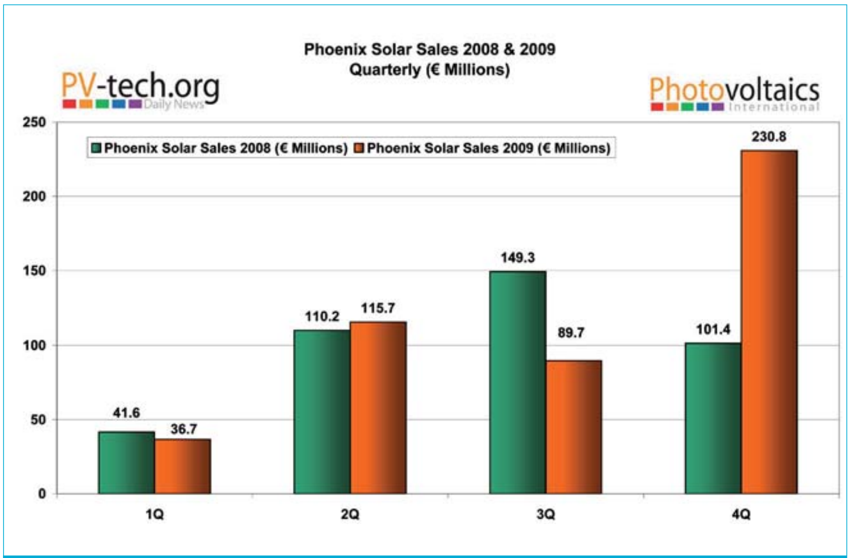
German market and a stronger growth of foreign markets in 2011.

Premier Power's second 1MW solar plant operational and connected to grid

Premier Power Renewable Energy's second 1MW solar power plant in the Puglia region of Italy has become operational and connected to the power grid. The project is part of a series of solar project by the company for Italian customers. This solar plant is connected to the Enel electric power grid at a medium voltage of 20kV. The solar plant uses Canadian Solar 230W crystalline silicon (cSi) modules and Power One 330kW Aurora Inverters.

Phoenix Solar says 2010 revenue could reach €700 million

Up until recently Phoenix Solar has not been prepared to give a 2010 revenue forecast due to the uncertainties over German FiT cuts. Now that a compromise deal with the German Bundesrat has seemingly been secured, the company said that it expects a substantial increase in consolidated revenue of between €660 and €700 million for 2010. The major project developer and system integrator posted revenue of €473 million in 2009, up from 2008's €402.5 million. Phoenix Solar said that it expected 20% of revenue in 2010 to come from its growing international business and that EBIT (earnings before interest and taxes) was also set to rise substantially to between €36 and €40 million.



Phoenix Solar Sales 2008 & 2009 quarterly (€ millions).

News

Sky Solar, Zongyi Solar complete 3.178MW plant in Germany

China-based Sky Solar and Zongyi (Cayman) Solar Electric Power have now completed and grid connected a 3.178MW photovoltaic power plant, located in Ansbach, Germany. The project

Source: Sky Solar

Sky Solar's 3.178MW photovoltaic power plant, located in Ansbach, Germany.

design, engineering, installation and commissioning took place over a total of 30 days. Italy-based Unicredit Bank will provide Sky Solar with a credit line of €100 million for the project. This funding agreement marks the first instance of a Chinese firm gaining such credit in Europe.

Asia News Focus

Enfinity selects Thailand for 40MW solar farm

Belgium-based renewable energy company, Enfinity, has chosen Thailand as the first location in Asia under its US$300 million investment program planned for the region this year. The location of the 40MW solar farm, which will cost the company US$82 million, is yet to be confirmed. Enfinity will also invest in projects in South Korea and Taiwan this year; construction of the Thailand plant is expected to begin by the end of 2010.

Suntech to supply modules for 44MW solar plant near Bangkok

Suntech is to supply 34.5MW of solar panels for the first phase of the largest photovoltaic solar power plant in Thailand and Southeast Asia. The 44MW plant will be owned and operated by Bangchak Petroleum Public and integrated by Solartron Public, and will be located just outside of Bangkok. The plant, which is expected to be complete by the end of 2011, will represent a major milestone in Thailand's goal of sourcing 20% of its energy consumption from renewable sources by 2022.

Chint Group to develop 1GW of solar energy, 200MW of manufacturing capabilities in Gansu Province

Astronergy's parent company, the Chint Group, has officially signed a strategic cooperative framework agreement with the Gansu Development and Reform Commission for the investment of 1GW of solar energy projects and in 200MW of manufacturing capabilities. This agreement marks the official launch of the province's push to develop its solar industry.

The ceremony accompanying this agreement was attended by the secretary of the CPC Gansu Provincial committee Lu Hao, the vice secretary of the CPC Gansu Provincial committee Liu Weiping, member of the standing committee Feng Jianshen, secretary-general Jiang Xinzhi, Chint chairman Nan Cunhui, and dean of the China Foreign Affairs University Zhao Jinjun.

Mitsubishi Electric's power IC capacity expansion to ease solar inverter component shortage

Although only one of many markets for semiconductor power devices, the solar inverter industry has been struggling with severe component shortages since mid-2009 as the semiconductor manufacturers that make the necessary products timidly started ramping fabs again after a severe downturn. However, one of these key suppliers, Mitsubishi Electric is going a further step and actually increasing capacity to meet demand.

The company plans to invest ¥6.5 billion to expand its 200mm wafer production capacity for power devices by approximately 2.5 times that of the previous fiscal year. The expansion, to be conducted in several stages, will be completed by April 2011. The company will also invest ¥3.5 billion yen to increase its assembly and testing capacities. Recently, iSuppli Corp. noted that various key commodity electronic components are now are in a state of critically short supply causing prices to rise and delays in deliveries of parts to customers.

The supply situation is even more critical for standard logic ICs and power management discretes such as low-voltage MOSFETs and tantalum capacitors, which now are experiencing shortages and effectively are on allocation status, meaning suppliers are unable to respond to unforecasted demand. The lead time in June was 20 weeks for power MOSFETs, according to the market research firm. In comparison, normal lead times for such products typically run to approximately 10 to 12 weeks.

Although the expansion plans by Mitsubishi Electric will take shape until next year, other semiconductor firms are expected to follow with increased production, which should in turn help the inverter manufacturers meet growing worldwide demand next year. SMA Solar recently noted that component shortages were expected to ease slightly in the second half of 2010.

Other News Focus

Solar Semiconductor and Conex to develop over 300MW of solar applications

Solar Semiconductor and Conex Energy will be working together at various California and Ontario, Canada locations for the development of over 300MW of solar opportunities, which will use Solar's PV panels and related equipment for ground-mounted and rooftop applications. The agreement will also see the two companies collaborate for applications in selected international locations. Solar Semiconductor will be responsible for the design, as well as the supply of PV solar panels and balance of system equipment. Conex will manage the development activities, including the optimization of project energy sales, negotiation of interconnection arrangements, project financing and tax planning opportunities.

SunPower completes largest solar tracking system installation in Australia

SunPower has completed a 505kW solar power installation for Horizon Power, the government-owned utility, providing power to remote and regional communities and resource operations in Western Australia. The project, which marks the largest solar tracking system installation in the country, will power the world's first high-penetration, hybrid solar-diesel power station.

The ground-mounted SunPower T20 Tracker installation is located over two sites, Marble Bar and Nullagine in the east Pilbara region of Western Australia, and was commissioned earlier this year. The power stations will generate approximately 1,048MWh of solar energy per year and will produce 60–90% of daily electricity needs. This project is supported by the Australian Government through the Renewable Remote Power Generation program and implemented by the Office of Energy in Western Australia.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BIPV News

Solyndra develops commercial greenhouse BIPV system test site with CeRSAA in Italy

In a move that could see Solyndra expand market opportunities outside commercial rooftops, the copper-indium-gallium-(di) selenide (CIGS) thin-film firm has developed a building integrated photovoltaics (BIPV) greenhouse system that is being tested by Centro Regionale di Sperimentazione e Assistenza Agricola (CeRSAA) to validate Solyndra's agricultural credentials. The project covers an area of 400m^2 at the CeRSAA research center in Albenga, Italy. Solyndra designed and built the BIPV system, while Solar ReFeel has coordinated the research among the involved parties. Installation support and electrical contracting was provided by Enerqos Group.

The project is designed to last for 24 months to validate the crop-growth benefits of Solyndra's technology. The study will measure and evaluate the production of several crops common in the Mediterranean region when grown under the greenhouse structures with the integrated solar system.

Source: Solyndra

Solyndra's BIPV greenhouse system.

Installation of the Lumeta PowerPly modules.

Source: Lumeta

Dyesol, Corus complete industrial development phase of DSC on steel project

The executive and project management team from Dyesol and Corus met with Welsh Assembly Government representatives on July 7, 2010 to present the achievements of the two-year R&D project to industrialize dye solar cell (DSC) technology on steel, for the continuous manufacture of integrated building products.

During this phase of development, the companies completed the production of BIPV modules for long-term comparative testing both in the indoor sun testing facility and within the outdoor facility at the PV Accelerator centre on the Corus site in Shotton, North Wales. The aim of this extensive R&D was to demonstrate the LCOE (levelized cost of energy) of these integrated photovoltaic products. The Dyesol and Corus teams are now working on the business case for volume production, aiming for completion by the end of 2010.

Lumeta receives UL 1703 certification for PowerPly BIPV modules

Lumeta has received CSA International (CSA) certification for its PowerPly roof-integrated photovoltaic solar module in accordance with UL 1703. The 400W product combines a DuPont Tefzel frontsheet and lightweight composite substrate with high-efficiency monocrystalline silicon solar cells to increase power density, eliminating the glass and aluminum frame structure of conventional modules. Lumeta PowerPly is being manufactured in Suntech's building-integrated photovoltaic (BIPV) facility in Wuxi, China.

Bosch Solar Energy closes 38MW cell deal with System Photonics

System Photonics has completed a three-year deal with Bosch Solar Energy for the supply of a total of 38MW of Bosch's high-performance monocrystalline solar cells. The cells will be used in System Photonics' solar tiles, which can be used as a roof covering or façade skin and integrated into the building design.

Pythagoras Solar announces PV glass unit and three new business partnerships

Pythagoras Solar is planning to commercialize its PV glass unit (PVGU) technology, which combines energy efficiency with solar power generation in a solar window. PVGU products will be available for curtain walls, skylights and windows during the second half of this year. In addition to the commercial offering of its PVGU technology, Pythagoras has also announced its partnerships with Arkema, China Sunergy and Flextronics to help the company scale its operations in preparation for commercial production and distribution.

GTM Research cites the BIPV market ready and willing for global expansion

In GTM Research's report, 'Building-Integrated Photovoltaics: An Emerging Market', the company hails the BIPV market as on the brink of a global expansion in its installed capacity. The report forecasts installed PV on the whole to reach over 20GW globally by 2013, with the cost of PV panels falling to US$1.20 per watt around the same date. With such a large expansion in the PV world, BIPV will have a prime opportunity for new BIPV solar components.

The expected growth opportunity for the BIPV sector is attributed to maturing energy-efficiency codes, feed-in tariffs and supply-side product development. Currently, BIPV has been a specialized industry, but its development is beginning to reach a more global audience.

BIPV installation in China arrives on time

China Energy Conservation and Environmental Protection group has now completed one of the largest BIPV installations in the world. The 6.68MW system is fully integrated into the awning at the Hongqiao high-speed railway station in Beijing, Shanghai.

The 160 million yuan (US$23.6m) system covers a total roof area of 61,000m^2 with 20,000 solar panels, which have produced 300,000kWh of power since the project was completed in early July. The Chinese government is also tendering for bids to develop 13 solar projects with a combined capacity of 280MW in the western regions. The move follows last year's bidding for a 10MW solar power plant in Dunhuang, Gansu Province. The government has set a target to install 20GW of solar energy capacity by 2020.

Burger King completes energy efficient restaurant in Germany

Burger King has unveiled its energy efficient restaurant located in Waghäusel, Germany, developed in cooperation with Wirsol Solar. The restaurant features several forms of renewable energy, including solar photovoltaics. The PV aspect of the design include 720 solar photovoltaic modules, generating over 53,500kWh of electricity per year. The modules are spread out across separate areas of the restaurant building, including a BIPV shelter and roof-mounted panels.

EcoTemis partners with Cadmos for BIPV development in France

French BIPV company EcoTemis has formed a strategic partnership with Cadmos through a capital increase. Through the affiliation, the companies will build a BIPV customization facility in France, to design and manufacture versatile BIPV solutions of high architectural quality.

Solon, CBS Energy to supply PV modules for Bright Generation's SolarCombi

Solon and CBD Energy, its Australian representative, have formed a new partnership with Murdoch University-based start-up Bright Generation, for the supply of Solon Black 130/04 solar modules. Bright Generation will integrate the modules into its product, SolarCombi, which combines photovoltaics and solar thermal power in the single streamlined system and is marketed to home owners in Australia.

Bright Generation's SolarCombi.

Source: Bright Generation

Product Briefings

SunSil

SunSil's Integra solar module offers embedded electronics, micro-inverter and software

Product Briefing Outline: SunSil has launched its Integra solar module, a fully integrated system that is claimed to increase yields by 30% or more while also reducing initial costs, making solar.

Problem: The current architecture of a standard solar PV system is grossly ineffective in maximizing yield under different conditions throughout the day. Due to the fact that it is a distributed architecture consisting of several different components from panel to the wiring and on to the inverter, the ability to cost-effectively manufacture and assemble everything into one unit and install in a few steps on the roof has also not been possible.

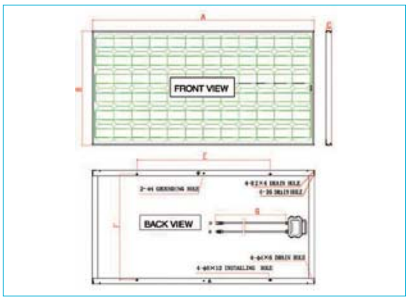
Solution: The Integra combines all of the components of a standard PV system into one 230V 300W AC module using embedded electronics, micro-inverter and software to harvest the maximum amount of electricity. Current solar panels are made from 'strings' of solar cells, i.e. they are wired up in series. However, if one of the cells is weaker or shaded, the output of the whole string can drop significantly, compromising the entire panel. SunSil laser cuts each six-inch square cell into microcells. Each is monitored and dynamically controlled by SunSil's patented 'Dynamic Microcell Optimisation' technology to provide the optimum output for the whole module.

Applications: A wide range of potential applications from commercial to residential markets.

Platform: SunSil's integrated architecture means that the Integra can be assembled in a few steps with the use of their fully-automated and high-throughput manufacturing line in Denmark.

Availability: Q4 2010 with volume in Q1 2011. The units (€900 each), are currently undergoing certification by Intertek.

CNPV



CNPV launches 'premium' 156 x 156mm monocrystalline cell-based modules for utility-scale applications

Product Briefing Outline: CNPV Solar Power has launched the company's 'premium' PV modules series made with high-efficiency 156 x 156mm monocrystalline cells for utility-scale applications. The modules have power outputs ranging from 295Wp to 305Wp, and are suited to a wide variety of applications ranging from commercial and industrial installations to utility-scale facilities.

Problem: Utility-scale PV power plants have traditionally selected some of the highest output modules to ensure the maximum ROI. However, cost-effective monocrystalline cells have been in short supply for large-scale projects and previously used more in commercial and residential projects.

Solution: The 72-cell premium module features large-area, high-efficiency monocrystalline silicon solar cells, anti-reflection coated glass and high conductivity interconnected materials. The larger diameter (200mm) of the cells outperforms the industry average by 8%, which translates to a module efficiency of 15.50%+. The enhanced anti-reflection coated glass ensures 94% transmittance at STC level and provides an additional 3% performance at field level installations. The use of soft, ductile and high-conductivity interconnected ribbons ensure minimal resistive power losses both at standard testing and field levels. The net effect is increased power without increasing surface area required for installation.

Applications: Commercial and utility-scale plants.

Platform: CNPV markets the modules with the classification CNPV-285M to CNPV-290M as standard series and CNPV-295M to CNPV-305M as its premium series. The modules have IEC61215 Ed2 & IEC61730 certification.

Availability: Currently available.

SunPower

SunPower offers first modular solution for building utility-scale solar power plants

Product Briefing Outline: SunPower has developed the SunPower Oasis Power Plant, which it claims is the industry's first modular solar power block that scales from 1MW (AC) distributed installations to large central station power plants. SunPower Oasis is said to provide a fully integrated, cost-effective way to rapidly deploy utility-scale solar, streamlining the development and construction process.

Problem: As power utilities continue to build larger, more sophisticated solar power plants, it is critical that a seamlessly integrated solution is offered. SunPower Oasis streamlines the entire power plant development process, from permitting through construction and financing.

Solution: SunPower Oasis is engineered from the ground up to optimize use of available land. Each power block integrates the SunPower T0 Tracker with the high-efficiency, 400W utility solar panel, pre-manufactured system cabling and the Oasis smart inverter and operating system. SunPower Oasis also features the company's advanced Tracker Monitoring and Control System (TMAC) for wireless control of the power plant. Advanced controls maximize energy production, anticipate and protect the array from storm conditions, and enable efficient operation and maintenance. The power block kits are shipped pre-assembled to the job site for rapid field installation, and are claimed to offer the highest capacity factor and the most reliable long-term performance.

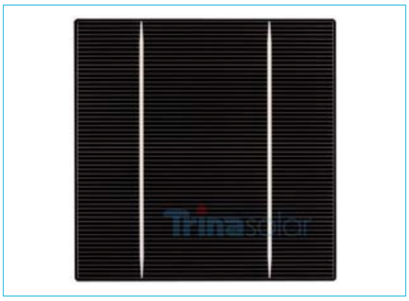
Applications: Utility-scale power plants.

Platform: The SunPower Oasis operating system is designed to support future grid interconnection requirements for large-scale solar power plants, such as voltage ride-through and power factor control.

Availability: Currently available.

Product Briefings

Trina Solar



Trina Solar's Quad Max cell technology boosts module power output by up to 8%

Product Briefing Outline: Trina Solar has announced it will be manufacturing a high-performance monocrystalline module, the 'TSM-DC80'. The module, which uses Quad Max technology, will primarily target the rooftop and small-scale ground-mounted systems market segments.

Problem: The product's square shape allows the monocrystalline cell to harvest more sunlight by avoiding surface area loss typical with conventional octagon-shaped cells.

Solution: The TSM-DC80 features high-efficiency, square-shaped monocrystalline cells with Quad Max technology, and is expected to boost module power output by up to 8% when compared with conventional monocrystalline modules. The 72-cell premium module is also expected to have a maximum power output of over 200W, making it potentially popular for rooftop PV applications, including residential installations where a high power-to-space ratio is a priority. Trina Solar developed Quad Max technology using innovative manufacturing processes and proprietary, state-of-the-art metallization and passivation techniques, which have allowed Quad Max cells to yield conversion efficiencies of up to 18.8% in test laboratory production.

Applications: Rooftop and small-scale ground-mounted systems.

Platform: The modules will conform to IEC61215 and Safety Class II IEC61730 & UL1703 electrical and quality standards, and are UL1703 safety rated for high wind pressure, hail impact, snow load and fire. Integrated bypass diodes will protect the solar cell circuit from hot spots during partial shadowing.

Availability: Scheduled to be on sale in Europe and North America in the first quarter of 2011.

Converteam

ProSolar outdoor inverter from Converteam offers high power density and low BoS costs

Product Briefing Outline: Converteam has introduced the ProSolar outdoor inverters, which are available for a power range from 500kW to several megawatts. ProSolar central inverters are optimized for use in MW-scale PV parks. The number of PV strings in the system varies according to the individual requirements.

Problem: In some cases, when grid foults occur, the immediate disconnection of PV parks is unavailable.

Solution: The ProSolar central inverter avoids grid disconnection as it meets all the new requirements of the BDEW Technical Directive. The three-level topology of the power electronics and potential input voltage in excess of 1,000V can increase efficiency to 98%, thus minimizing the investment costs for pipelines, buildings, fuses and power electronics. The liquid-cooled inverter with patented active cooling can handle temperatures up to +55°C without derating work. The integrated data logger records electrical input and output variables, while optional diagnostic functions include long-term evaluations of components and overall system.

Applications: Solar plants ranging from 500kW to several megawatts.

Platform: The Control & Monitoring System has a data logger integrated in the ProSolar inverter, which enables time-defined logging of electrical input and output variables. Unexpected as well as pre-defined events can be transmitted immediately across the ProSolar system via the internet or SMS. An optional diagnostic function detects the system components and generates long-term analyses. An isolating transformer is used to electrically isolate the DC supply and the mains connection.

Availability: Currently available.

a+f

SunCarrier 120 from a+f is designed for low installation height requirements

Product Briefing Outline: The SunCarrier 120, from a+f GmbH is a single-axis tracking system that permanently aligns the module surface with the current sun position via a vertical axis. This ensures an ideal angle of incidence for sunlight and provides an additional yield of 30% compared to fixed installations. Depending on the module type, an output of up to 24kWp can be installed on a module surface of around 120m^2.

Problem: Many tracking systems face the problem of height restrictions. Some countries even ban installations if they are too large. Tall tracking systems also face the problem of wind and weight load.

Solution: Due to its reduced height of 4.3m, the system can be implemented easily in countries with installation height restrictions. This also results in a reduced wind load, enabling an increased focus on lightweight construction weight reduction of the steel beam construction. The required drive for the tracking is provided via a planetary gear (engine output of 0.37kW, with brake, drive ratio: 1:1,595, form-locked chain wheel on anchor chain). The power input amounts to 0.40kWh per day. A maintenance-free computer-assisted control has also been implemented.

Applications: Can be equipped with solar modules from most module manufacturers. The system is especially suited for deployment between the 25th and 55th northern and southern latitude lines.

Platform: The SunCarrier 120 is extremely robust and can withstand wind speeds of up to 121.3km/h according to the national UNI EN1991-1:2005-07 standard. It has a maximum rotating angle of 220° (June 21st) in summer and a minimum angle of 110° (December 21st) in winter.

Availability: Currently available.

The first megawatt: SolFocus, Victor Valley College dedicate North America's only 1MW CPV array

By **Tom Cheyney**

As solar PV project sizes increasingly reach double-digit megawattage with triple-digit just around the temporal corner, a single-megawatt system doesn't have quite the allure it had just a few years ago. But sometimes a megawatt's more than just a measure of installed generating capacity – reaching the million-watt mark can have potent symbolic as well as practical value, especially for a technology transitioning into the commercial realm.

Case in point: SolFocus's recently dedicated 1MW (AC) high-concentrator photovoltaic installation located on the campus of Victor Valley College in the high desert of Southern California northeast of Los Angeles, which is the largest (H)CPV deployment in North America to date and the Mountain View, CA-based company's biggest project as well.

The neatly ordered grove of 122 SF1100S double-axis tracker arrays, posted in the dusty ground on a six-acre parcel where carrots and rabbit brush once grew, is divided into three "subfields" serviced by a pair of Satcon 500kW inverters and one 250kW model, and monitored by a SunEdison SEEDS system. Within a half-hour of sunrise, the ground-mounted systems are cranking at full power, following old Sol and carrying that broad-shouldered performance curve over the course of the day until an hour or so before dusk.

Each 8.4kW-rated array is made up of 28 300W panels, which are in turn composed of 20 power units containing the high-efficiency solar cells and reflective glass optics that facilitate that whopping 650x concentration factor and superior power density (at least when the conditions are right). On the stationary pole holding the tracker, a control box hangs down at eye level in the back, while an anemometer and solar radiance monitor perch on the top of the system.

The front of the arrays bear little resemblance to a crystalline-silicon or thin-film PV system, their eye-catching series of optical/cell assembly components producing an upside-down funhouse mirror quality when you get up close. The backside of the panels resemble rows of oversized muffin pans, the metal coffering

a design change for the power units from the original flat surface, one that has translated into 30% less aluminum being used and an easier-to-ship form factor, according to SolFocus.

In a sense, the VVC site is as much a Spectrolab project as it is SolFocus's, since each square-centimeter-sized cell assembly in every one of those units – over 68,000 triple-junction III-V cells in all (that's a lot of muffins) – was fabricated by the venerable cell manufacturer. The patch of desert also represents one of the Boeing solar division's biggest terrestrial PV installations to date and is only an hour-plus drive from the company's Sylmar, CA, production fab.

The higher the cell efficiency goes, the better that all-important metric – levelized cost of energy (LCOE) – gets for a CPV system. Current conversion efficiencies are nearly 39%, translating to SolFocus panel efficiencies of 26%.

When the cell numbers reach 40% (which Spectrolab says will happen by late 2010, with much more headroom for continuous improvement), then the panel efficiency will pop to about 26.7%. This calculation allows that for every 1% of increase in cell efficiency, about a 0.67% jump in system efficiency will follow (with more possibly squeezed out via optical enhancements and other schemes to reduce light losses), explained Nancy Hartsoch, SolFocus's energetic VP of marketing and oft-quoted spokeswoman of all things CPV.

From an LCOE standpoint, if the levelized costs were, say, 14.9¢/kWh, for example, then the 1% increase in cell efficiency would drop LCOE by 2.3% to less than 14.6¢/kWh, she said. The LCOE numbers for the US$4.46 million VVC project over its 25-year lifetime? An estimated 8.5¢/kWh, going down to 1.5¢/kWh when performance-based incentives factor in, according to company documents.

The power-output reality on the ground at VVC is that although the panels carry the IEC-certified and CEC-listed 300W rating, they actually perform closer to 315W. During a follow-up phone interview after the well-attended dedication ceremony in late May, she explained the case of the bonus wattage.

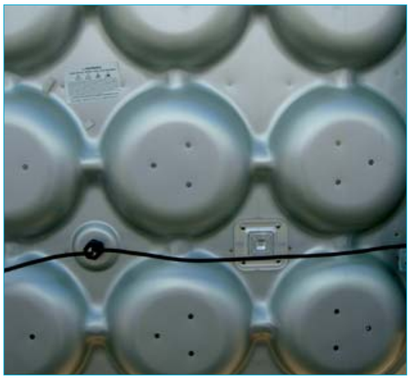
"Once we started running in decent volumes at our [50MW] factory [in China], where every panel that comes off the line is flash tested on our own solar simulator and so every panel we know the power rating of, what we started discovering is – and we believe a lot had to do with quality and automation – that even with the same rated cells, [that there is] a steady increase in the number of watts these panels [showed]."

"At the point where we got enough data to say 'look, they're all fluctuating at ±5% right at 315W,' it didn't make sense to keep selling them as 300W panels because they were performing better than that," she noted.

Another positive: the extra wattage could lead to higher-than-predicted performance-based incentives, a key part of the California Solar Initiative-backed project's financial foundation, and will also provide a cushion for the CPV firm in meeting its own five-year performance guarantee.

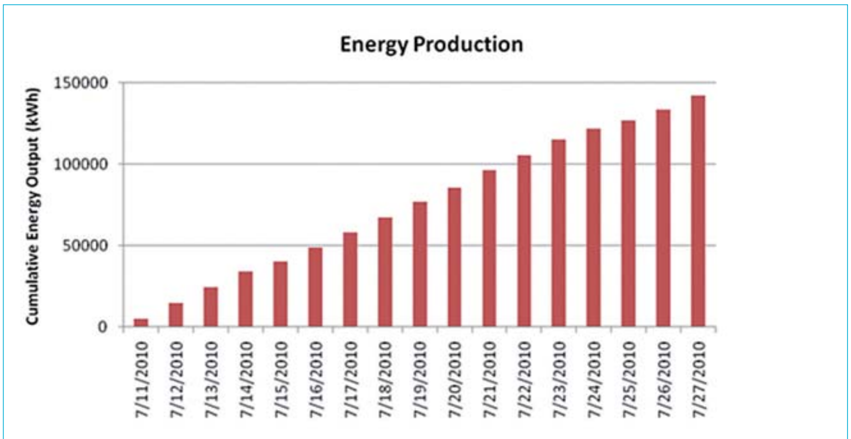
SolFocus has its panels in for recertification at TÜV, but she's not sure if that process will be fast-tracked soon or have to go through the whole regimen of testing again and take longer; once the tests are done, the company will be able to get its higher-rated panel listed with CEC.

If one assumes that each panel is actually 315W and thus each array more like 8.8kW, the installed capacity of the field goes up to 1.076MW, or the equivalent of adding another half-dozen panels. Since there is plenty of inverter redundancy built in – a total of 1.25MW – all of the potential DC energy generated should be captured and converted into AC and then sent through the rest of the system to rest of the VVC campus, where it will supply about a third of the college's electrical demand, or about 2.6MWh per year.



The decision to scale the inverters in such a way came via learning garnered from a demo system that SolFocus set up for a proposed project in Colorado that never panned out, recounted Hartsoch.

"It's very easy with CPV to undersize inverters because they're based on average power," she said. "Often your DNI (or direct normal irradiance, the measure of solar energy pouring down on a specific



Cumulative energy output for the Victor Valley College CPV power plant for two weeks in July.

The SolFocus-equipped CPV power plant project under construction in Crete.

location) is higher than your average DNI, so if your average DNI for the year is 7.2 (which happens to be the VVC site's irradiance), there's a lot of days of the year well above that. If you don't size your inverters for maximum energy you potentially can generate, you're going to be throwing energy away."

One little secret not uttered during the opening ceremony speechifying was the fact that the VVC's CPV field was actually not quite 100% operational and online at that point.

In late July, Hatsoch told me that "the system went on line in late May. We did some additional testing, inspections, and then [went through the] customer acceptance period, and officially turned the plant over to Victor Valley College during the last week of June. The systems have been performing well."

For the 30 days leading up to that late July update, the VVC system had offset more than 246,109 lb (868kg) of carbon dioxide, 65lb (29.5kg) of nitrogen oxide, and 12lb (5.5kg) of sulfur dioxide, equivalent to the output of 248 cars or 179 homes, according to data shared by the company exec.

The cumulative energy production chart for the July 11-27 period (shown in the graph) reveals the system's steadily growing power output, climbing close to 150,000 kilowatt-hours.

The purpose of the new solar power system is not just to produce energy but to generate interest in green and sustainable career paths, and play a key role in academic and vocational programming at the community college. Hartsoch told me the company hired a summer intern, actually a middle school teacher (part of a local program), to work with VVC on ways to fold SolFocus's technology into existing coursework.

She also noted that as part of the arrangement, some company folks would periodically guest lecture at the campus, and that students will likely be recruited to help with gathering/monitoring and analyzing data from the field. The school itself, which has had PV design/installation and other courses in its curriculum for several years, plans to use the new teaching resources to help build a broad-based program in sustainability.

SolFocus hopes to showcase its system at VVC and sign up more community colleges and other centers of higher education for more (ad)ventures in concentrator PV. Hartsoch believes two or three similar projects could "start in the ground" in California before year's end, with another one possible in Arizona.

Of course, the company is not just hitting the books in the academic sector: she cited several, smaller demo-scale installations just built or being built in Mexico, South Korea (not the first place that comes to mind with CPV, the VP admitted), Colorado, and elsewhere.

The long-postponed 10MW project in Greece has started to move forward, but there's been a change in the developer company. Environ has taken over from Samarus, Hartsoch told me in a late July update. She also sent me a recent photo of the project, which is set in the hills among the olive trees on the island of Crete.

"We have begun installation of 1.24MW of the project," she said. "The poles are in but the arrays are not yet up. This is one of about 15 sites in the project, which are each around 80kW. You'll note how steep the terrain is in the one photo, where anything that wasn't tracking on two axis would have been an issue. We anticipate power generated there by mid-August at the latest."

She also updated me on the status of the Alice Springs Airport 235kW project in Australia, noting that developer Ingenero "has completed system installation," but that "the trenching and electrical interconnection has been delayed due to floods."

"I believe that it will be completed in the next couple of weeks," she said in late July, "and our engineers (SolFocus is the equipment supplier on this one) will be onsite in mid-August for the commissioning." As the accompanying photo shows, the "systems are in but the project is not yet complete."

Hartsoch had to cut one of our chats short, being called to the boss's office to help with a presentation for some visiting Chinese government officials. A few minutes before the final interruption, she quipped that "twice a week there's someone here with grandiose ideas. Yesterday, we had someone here with 500MW to deploy in a country I've never heard of. And you know, some of those might happen."

When and if megascale CPV projects start to go from dream to reality, one can look back to installations like Victor Valley College, where it all started with that first megawatt.

VVC photos by Tom Cheyney; other photos courtesy of SolFocus.

This feature is a revised and updated version of a blog that originally appeared on PV-Tech.org.

The Alice Springs Project in Australia features 235kW of CPV arrays.

Large-scale PV power plants – new markets and challenges

Denis Lenardič, PV Resources, Jesenice, Slovenia

ABSTRACT

Despite the collapsed Spanish market and the general state of the world's economy, the past year was not a bad year at all from the perspective of installed power capacity of large-scale PV power plants. Installed power capacity surpassed expectations while also bringing new markets into the spotlight, which means that the traditional market leaders of Spain, Germany and the U.S. are no longer the only 'key' markets. With the exception of Germany, the past year's most noteworthy market boost was seen in the Czech Republic and Italy, with similar shake-ups seen in the Asian tiger countries of China and India. With many large-scale PV power plants recently brought into commission in these countries, China and India are brimming with potential for the near future.

Earlier this year, worldwide cumulative power capacity surpassed 6GW (taking into consideration only PV power plants >200kW DC). Europe still holds the largest market share at 87%, but in comparison with the figures scored in 2008 [1, 2], the U.S. increased its market share to 7%. Estimated annual installed power capacity worldwide for the period from 2000 to 2009 [3] is presented in Table 1. The data are based on detailed figures taken from more than 3,400 large-scale PV plants put into service in recent years that had cumulative peak power capacity of more than 6GWp.

Due to a shortage of reliable databases and national or international sources of statistical information concerning large-scale photovoltaic power plants, the statistical data presented here should be considered "conservative". However, some national statistical sources of note include those provided by some Italian [4] and German [5] agencies.

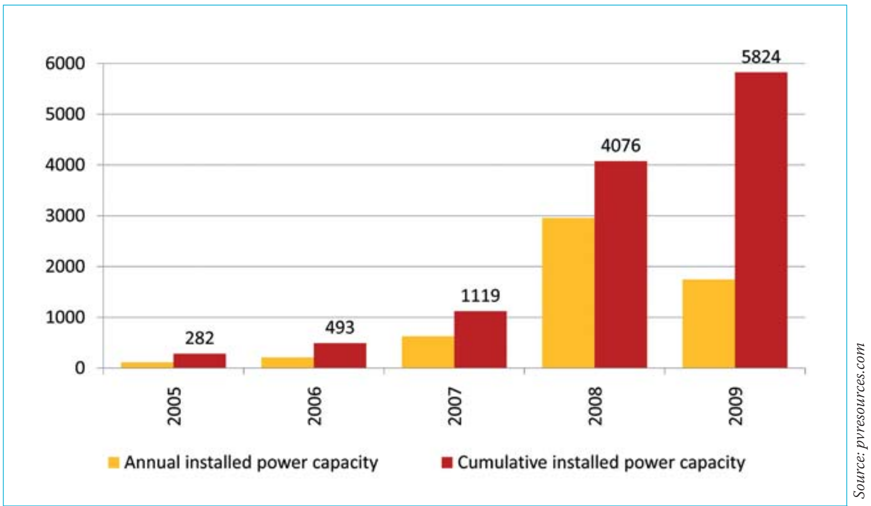


Figure 1. Annual installed power output capacity (MWp) from 2005 to 2009, taking into consideration PV power plants >200kWp.

Annual and cumulative installed power output capacity

It is estimated that more than 1.7GW large-scale power plants were constructed and put into service in 2009 (Fig. 1) [3]. Market leader Germany has more than 650MW installed (see Fig. 5 for more details), followed by Italy with about 250MW and the Czech Republic with about 200MW installed power capacity. Fig. 2 shows a Europe-wide breakdown of installed cumulative power capacity as at December 2009.

The market share of large-scale grid-connected PV power plants has been increasing continuously in recent years (see Fig. 3) in comparison with total annual installed PV power capacity [6]. In 2005, market share comprised less than 10% of the annual installed PV power capacity, while in 2007 market share of large-scale PV power plants reached almost 25% of the annual installed power capacity. In 2009, this figure was close to 30%.

New markets

Significant progress was not restricted to the key markets of Germany and Italy, however. It is now estimated that the Czech Republic has about 200MW of new power capacity installed (large-scale PV power plants), with a resulting third-place ranking after Germany and Italy. Data for the most important new markets is presented in Table 2.

Belgium, one of the most interesting new markets, is a prime example of regionally-driven policy. While the Flemish region has seen more than 80MW (rough estimate) of large-scale PV power plants commissioned in 2009, other parts of the country have thus far only shown slow progress.

As expected, developments in Bulgaria and Greece have resulted in the commissioning of some large-scale PV power plants. Small markets like Slovakia and Slovenia have also made first steps toward joining the prestigious "MW-range Club".

Progress in the French markets was lower than expected, but with the recent commissioning of some large-scale power plants, cumulative power

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Annual installed	4.2	9.4	20.3	29.8	81.9	111	211	626	2957	1748
Cumulative installed	29.1	38.5	58.8	88.6	171	282	493	1119	4076	5824

Table 1. Estimated annual and cumulative installed power output capacity [3] worldwide of large-scale photovoltaic power plants (>200kWp) from 2000-2009.

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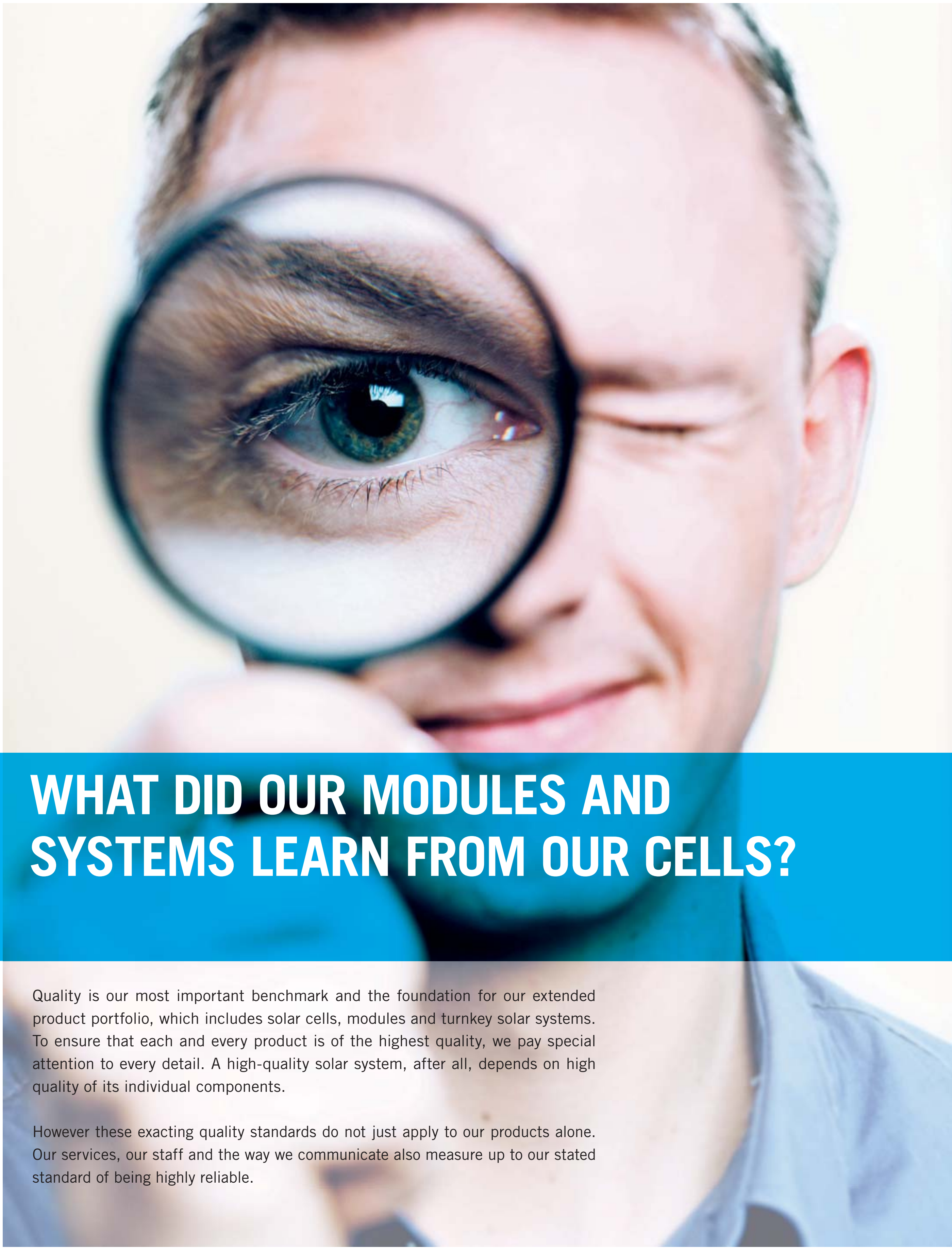

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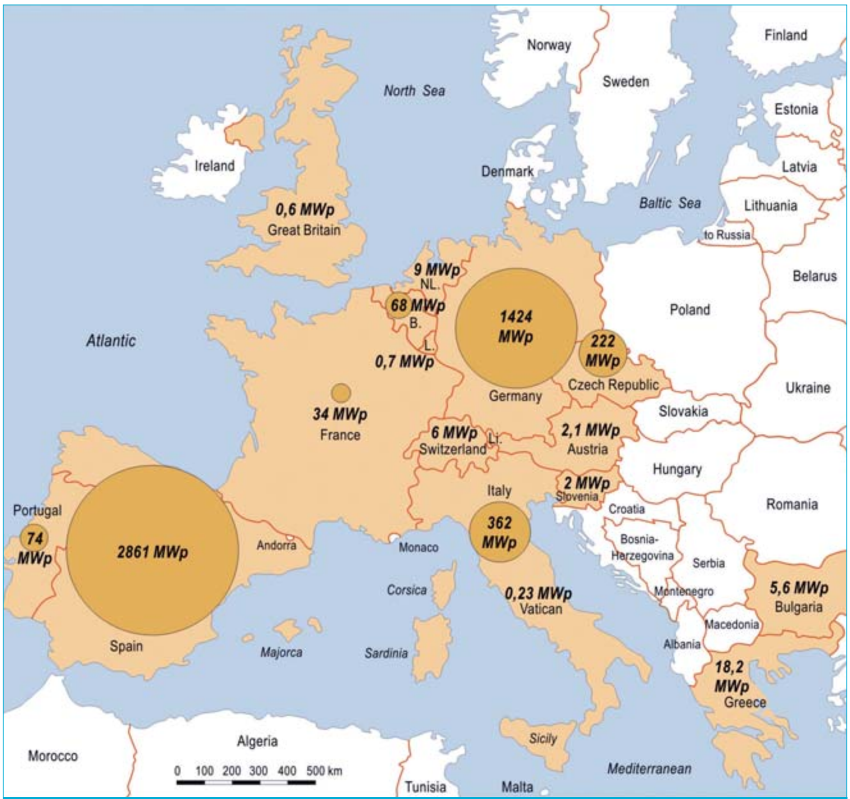
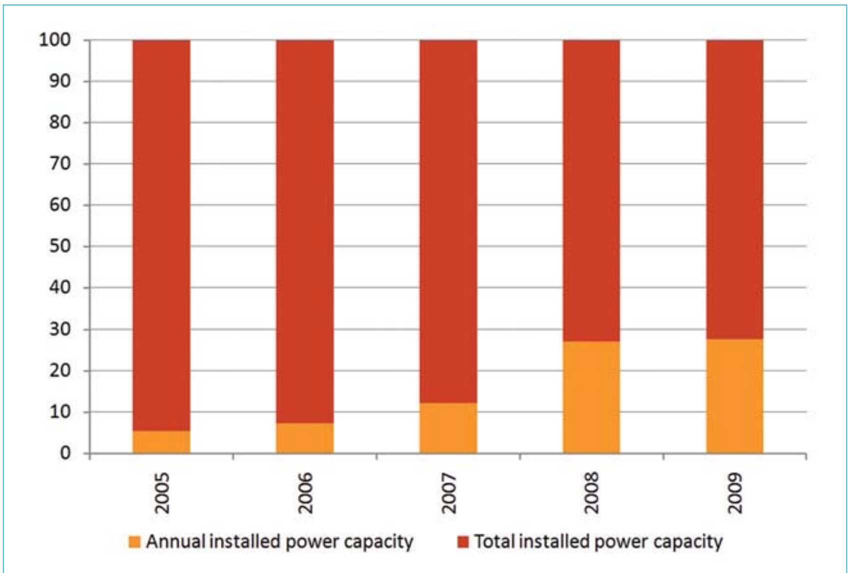


Map courtesy of U.Dewald, H.-J.Ehrig, RWTH Aachen

Figure 2. PV power capacity in MW (>200kW) installed in Europe as at December 2009.



Courtesy of EPIA, pvresources.com

Figure 3. Large-scale PV power capacity as a percentage share of total PV power capacity installed.

capacity in France (including French overseas territories) is estimated to be more than 100MW. Some of these French overseas territories have seen significant development in this vein, with plants like La Roseraye and La Mangassaye on Reunion Island completed this year; Guadeloupe and Mayotte are also broaching the MW range in recent projects. PV market share figures for large-scale PV power plants in France and the French overseas territories are presented in Fig. 4.

Although Europe currently retains the number one region position, other regions and countries such as Canada, China and India have also been showing quite rapid developments. Canada has recently commissioned some very large-scale PV power plants. The 20MW Sarnia project has already undergone expansion, and following completion of the second stage at the end of the year, this particular plant will take pole position on the PV ranking list.

Asia's most important new market is China with some very large-scale power plants under construction, while some MW-range PV power plants were also commissioned in recent months in India and Thailand. From a short- and mid-term perspective, these Asian markets are the most promising markets worldwide; however, short-term opportunities are more plentiful in the European countries of Italy, France, Greece and Bulgaria.

Future challenges

With ongoing discussions in the EU in regard to the use of agricultural land (and similar areas) for PV power plants, the industry needs to always be on the lookout for new suitable locations. Large roofs hold significant potential for roof-mounted PV power plants, in particular the current state of play in Belgium where about 75% of PV power capacity is delivered by roof-mounted PV power plants. California's market share of roof-mounted PV power plants is also quite high. As shown in Fig. 5, Germany's share of roof-mounted PV power plants remains quite low – this is also the case in many other developed countries.

Roof-mounted power plants will undoubtedly have a much higher market share in the future in developed countries, whereas ground-mounted PV power plants will still dominate in desert areas and countries where scope is not an issue.

For ground-mounted PV power plants, sites such as abandoned waste-treatment facilities or waste-water treatment facilities should be used more

	Belgium	France**	Portugal	Bulgaria***	Greece	China*	India*	Thailand ***
Annual installed 2009	49	35	14	3.2	14	70	4	1.1
Cumulative installed	68	55	74	2.0	18.2	75	4.3	8.5

* Very promising new markets for the near future; significant progress expected this year.
** Including overseas territories.
*** Significant progress observed in the first half of 2010, valid also for China and India.

Table 2. Large-scale PV power plants: annual and cumulative power capacity (MW) installed in 2009 for some new markets [3].

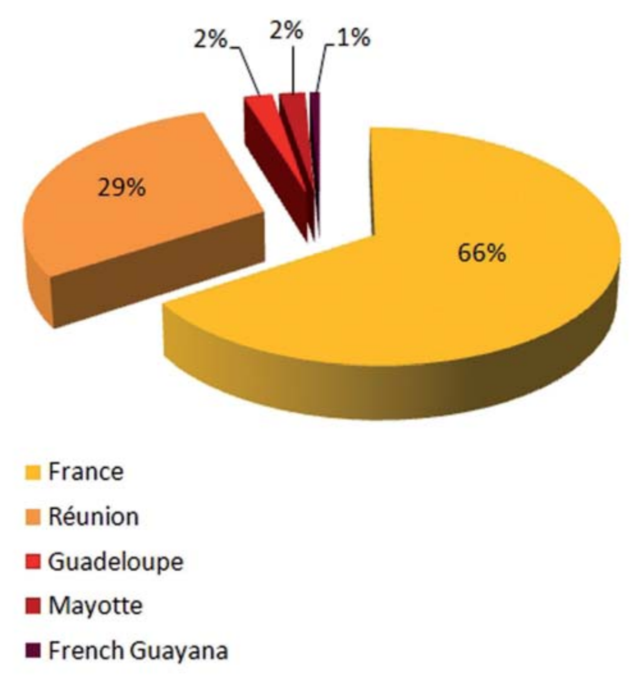


Figure 4. Market shares for France and French overseas territories as at June 2010 (large-scale PV power plants only).

extensively: it is currently estimated that about 1% of the world's large-scale PV power plants is located on such areas [3]. Germany and some other countries have adapted abandoned military areas for the construction of large PV plants, such as Lieberose (53MW), Finsterwalde (42MW) and Brandis (40MW) in Germany, and the

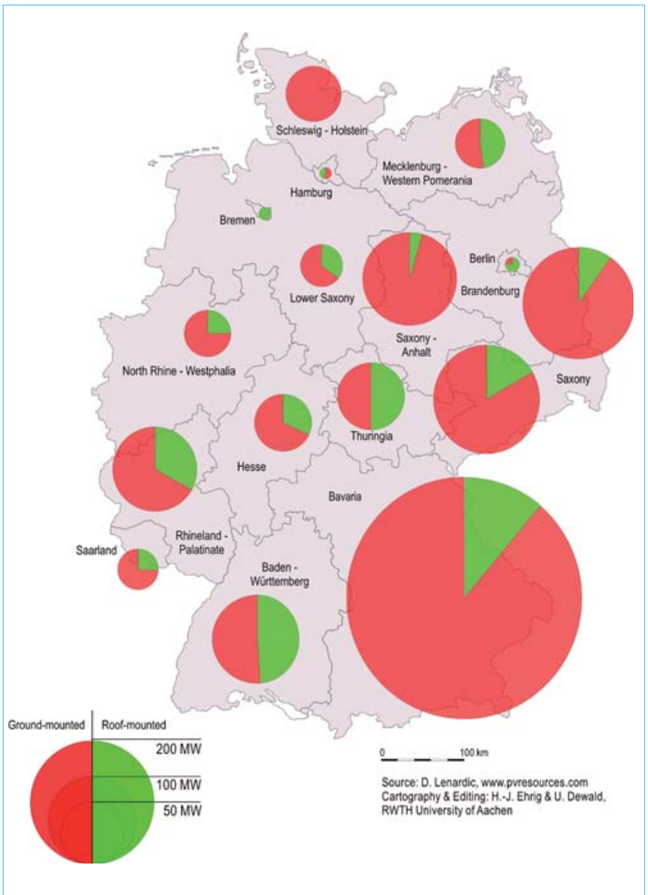


Figure 5. Ground-mounted vs. roof-mounted (large-scale) PV power plants: estimated market share in German states (data correct as of June 2010) [3].

Figure 6. The Stříbro 13.6MW project, built on an abandoned military surface, is the largest Czech power plant put into service in 2009.

1.2MW Sault plant in France and the Czech Republic's 13.6MW Stříbro plant (see Fig. 6).

> "Other very important but often ignored issues are reliable and precise yield prediction and effective power plant monitoring."

Several key issues will play major roles in construction and operation of PV power plants in the coming years. New markets for MW-range plants are completely different from those established European and U.S. markets that claim close to two decades of experience in the construction and operation of PV power plants. The first few large-scale PV plants in Europe commissioned about two decades ago had typical power outputs of 500kW and were usually the result of research projects. Those plants commissioned in new markets – China and India in particular – are very large-scale MW-range facilities that are anticipated to function reliably for at least the next 20 years. New markets require top-of-the-range project planning, financing and construction quality, as failed projects could essentially lead to significant financial losses. In the worst-case scenario, they could also have negative impact on regional renewable energy policies.

Other very important but often ignored issues are reliable and precise yield prediction and effective power plant monitoring. In conjunction with some other activities such as precise maintenance cost estimation, attention to these issues is essential for accurate electricity price calculation. Possible investment price drops may end up lowering feed-in tariffs (or subsidies), and for owners and operators of PV power plants, the electricity price – especially once grid parity has been reached – will be the most important parameter for ensuring an economical plant operation. PV power plants that have implemented more precise monitoring and electricity price calculation measures will be more compatible in the long term with other renewable (and non-renewable) sources of energy.

Acknowledgements

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About the Author

Denis Lenardič holds a degree in electrical engineering from the University of Ljubljana, Slovenia. From 2004 to 2008 he served as chairman of the Slovene national section of the IEC »TC82« Technical Committee. He has been systematically collecting data regarding large-scale photovoltaic power plants for several years. The data that forms the basis of this article is available to the public free of charge at http://www.pvresources.com/en/top50pv.php.

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Pre-construction, engineering and design costs of large-scale residential installations – part 1

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ABSTRACT

PV industry module and component manufacturers have brought down costs significantly over the last four years. This trend is clearly evident as most publicly traded companies continue to increase revenue despite falling module and component prices. However, it is far less clear how downstream system integrators are handling the drop in system prices and contributing to value creation. System prices are generally higher in the U.S. than in Europe, despite lower module prices in the U.S. This disparity often raises questions on the part of European PV professionals where these costs come from, and secondly, what U.S. system integrators have done to reduce costs. This two-part series will shed light on how U.S. system integrators have undertaken tremendous efforts to decrease cost and add value through innovation by focussing on labour-intensive value creation in the downstream segment. Part I will focus on the residential market segment by delving into activity cost savings through innovation in engineering and construction, while Part II will illustrate how changes in sales, rebates, interconnection, and the supply-chain management over the last five years have reduced costs.

Competitive pressures along with falling rebates in the U.S. residential market have forced a focus on cost reduction through the value chain. While the largest cost reductions have been the cost of modules, there have been major improvements in engineering and construction. Both manufacturers and downstream integrators must continue to innovate as system installation volumes grow and subsidies continue to fall. For integrators, the best-known areas for improvement and innovation include system design, installation labour, and BOS components. Each of these areas will be explored in further detail in this paper.

System design

The most important paradigm shift occurring in residential system design today is a move away from the need for custom engineering. Rather than engineered individual projects, residential PV projects are increasingly pre-configured. Five years ago, residential projects were all custom engineered. The PV integration business is finally catching on to techniques and business practices used by other far more complex manufacturing businesses.

Primary areas of improvement in system design have been around site investigation, system layout, single-line drawings, bill of materials and permit-plan set creation. The shift to repeatable configuration requirements in the residential business has led to faster execution and cost savings through simplified skill set requirements for each design, as shown in Table 1.

A comparison of system design labour costs in 2005 versus 2010 shows how residential system integrators are driving toward a far leaner system design process. Labour time has been approximately cut in half. Engineering skills are no longer required for every step of the process, thereby reducing labour cost. Leading system integrators have been able to reduce the $/watt component by 57%, primarily through reduced system design requirements using improved design tools, standards and processes.

All systems start with some form of site investigation to determine the optimum system configuration that meets customer requirements. Significant efficiencies have been gained through the introduction of readily available improved satellite imagery, electronic shade analysis

	2005 hours/kW	$/Watt	2010 hours/kW	$/Watt
Site investigation	1.56	0.05	0.93	0.03
System layout	0.67	0.03	0.39	0.01
Single line drawing	0.40	0.02	0.23	0.01
Bill of materials	1.00	0.05	0.22	0.01
Permit plan creation	1.60	0.06	0.82	0.03
Total	5.22	0.21	2.59	0.09

Table 1. Comparison of system design labour costs – 2005 vs. 2010. Data sourced from REC Solar's analysis of system installation costs of approximately 5,000 residential systems.

Figure 1. Solmetric's SunEye 210 is an integrated shade analysis tool for solar site assessment.

	2005 hours/kW	$/Watt	2010 hours/kW	$/Watt
Warehouse pickup	1.50	0.05	0.50	0.02
Travel	3.00	0.11	3.00	0.11
Layout on site	0.89	0.02	0.44	0.01
Racking installation	6.67	0.17	4.44	0.11
Module installation	4.44	0.11	3.33	0.08
Electrical installation	3.33	0.16	2.22	0.10
Clean-up	0.44	0.01	0.44	0.01
Parts house runs	0.33	0.02	0.33	0.02
Testing of PV system	0.22	0.01	0.22	0.01
Close out Documentation	0.33	0.02	0.33	0.02
Total	21.17	0.67	15.28	0.49

Table 2. Comparison of installation labour costs – 2005 vs. 2010. Data sourced from REC Solar's analysis of system installation costs of approximately 5,000 residential systems.

Figure 3. Specialized module lift mechanism.

tools (see Fig. 1) and online system configuration tools such as the REC Solar Widget, which allows customers to size their own PV system online and see both the layout on a satellite image overlay and the related economic benefits. By understanding site conditions and basic system design parameters prior to performing a physical site visit, all site investigations can be performed in an expeditious manner allowing for focus on key design constraints.

The second critical improvement has been realized by many system integrators in their use of design tools. Templates and standard system designs have resulted in residential systems without custom engineering, while the myriad publicly available design programs and some proprietary solutions allow the designer to input basic system parameters to create an automated code-compliant system design. These tools have not only increased the speed of design but reduced the cost of labour as many integrators use these tools to radically shift their focus from engineering to configuration.

Installation labour and racking

The highest cost component of a residential PV system – besides the modules themselves – is the installation labour. Residential installation is an exceedingly labour-intensive process with very few revolutionizing opportunities to increase efficiency. That being said, there have been many small changes in the construction labour process that have allowed for continuous cost improvements (see Table 2).

Primary drivers in cost reduction include racking systems, tools, management of non-value added tasks, standardized training processes, and a larger workforce of skilled PV installers. The future will likely see further reductions in the areas of electrical installation, system prefabrication and improved technologies.

Racking system design changes over the past five years have had a tremendous impact on the shift toward an overall 'system design' perspective (see example in Fig. 2). The system design perspective views the project as a whole rather than as a series of individual components to be left to an installer for assembly. This shift focuses on identifying and eliminating redundant requirements and inefficiencies, and albeit a low-tech component, racking has been a key driver in increasing installation efficiencies.

For example, many racking systems have moved toward utilizing a single driver for all bolts, eliminating the requirement of having multiple tools. Innovations have been developed in the areas of snap-in components, pre-assembled components, and a general reduction in parts count. What was once a construction process on the roof including drilling and cutting of rails has become an assembly process. Component

Figure 2. The SnapNrack Clamp Assembly, an example of the 'system design perspective.'

assemblies are being established in warehouses by less skilled, lower-cost workers and delivered directly to construction workers for reduced field assembly time and cost. The system design approach and shift towards field or warehouse assembly rather than field fabrication has greatly reduced time spent on the roof.

Newly introduced tools and equipment provide incremental improvements in installation labour efficiencies such as installation trucks and module lifts customized for effective solar installation, such as that shown in Fig. 3. The module lift can prevent installers from transporting modules one at a time up ladders, allowing for more time to be spent on installing rather than transporting.

Customized trucks have greatly improved installation efficiencies. By having a vehicle with all necessary materials, tools and equipment, the installation team spends less time in parts houses picking up material and more time on the project. Less time is also spent loading and unloading the truck when properly sized and configured to accept ladders, pallets, conduit and other equipment.

As volume has increased over the past few years, many integrators have developed internal processes to focus on optimizing installation. Getting installers out of the warehouse and into the field takes an effective back-end support and training function. Using vendor-managed inventory systems helps reduce the possibility of running out of material on site, a situation that has traditionally forced construction crews to waste valuable time driving to and from part supply houses. Standardized approaches to field labour optimization have become an integral part of the residential integrator's success. By shifting crew sizes

between different projects, efficiency can be greatly maximized.

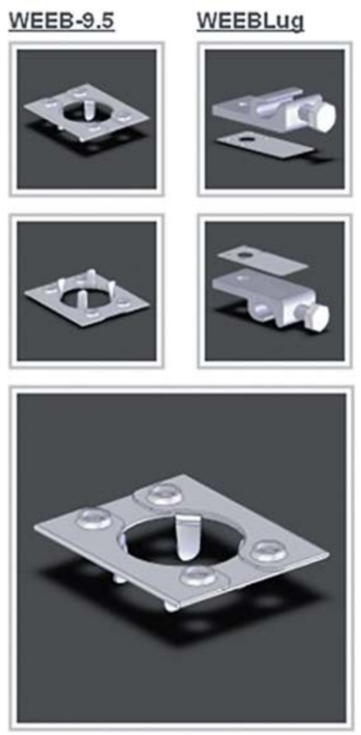
It should also be noted that system integrators have become increasingly aware of safety issues as they have grown. In this light, module lifts have not only increased efficiency but also provided improved safety when it comes to transporting modules to the roof surface, especially for higher structures and steeper roofs. Needless to say, accidents drive up costs significantly in terms of insurance rates and lost time and can lower employee and management morale. Technical and safety training programs are therefore critical to keeping productivity levels up and costs down.

Balance of system components

System component advancement has been another key contributor to recent cost reductions. Aside from improved racking systems, there have been major improvements in system grounding and inverter design. Ground clips are now designed to be assembled into module clamps, electrically grounding modules to rails and thereby reducing labour time running long lengths of bare copper wire. These advancements in acceptable system grounding have brought simplicity to installation and reduced equipment requirements.

Some inverter design changes now include integrated disconnects eliminating the need to install a separate component (see inverter examples in Fig. 4). Many inverters are designed with two sections that are separable; one section contains all the electronic components, while the other contains the system wiring. When in previous years the whole inverter had to be removed and replaced in the event of failure, this was timely because the wiring had to be left in an electrically safe condition. Now, inverters can simply be unplugged and removed for shipment to manufacturers for repair or replacement.

Figure 4. Multi-section inverters with integrated disconnects (left: SMA America; right: Fronius USA).



Source: Wiley

Figure 5. Example WEEB used to bond solar modules to solar mounts.

Module packaging is another important advancement creating considerable savings in material handling time and waste disposal. Several years ago, most module manufactures utilized cardboard boxes as a form of packaging. Cardboard increased the installation time for unpacking modules, materials handling and disposal. New plastic-corner clips allow for negligible material disposal and far lower time spent on handling materials.

Conclusions and outlook

As the PV industry continues to mature in the U.S., there will continue to be opportunities for streamlining the integration business. System costs would not be at the levels they are today and we would not have the thriving residential solar market we do were it not for the laser-focused effort on reducing system costs with respect to engineering, labour and components. From 2005 to today, the total cost for system design and installation has come down by 34% from US$0.88/watt to US$0.58/watt. This has been achieved by making only minimal changes to the module architecture. Improving module design by creating, for example, true plug-and-play solutions for system monitoring independent of specific modules or inverters will have a tremendous impact on total costs. Combined with continued innovation in installation and engineering efficiencies, the total cost reductions required to maintain a healthy residential market in the U.S. should be achievable despite the rapid decline of rebates.

About the Authors

Angiolo Laviziano is the CEO of REC Solar and has over 10 years' experience in the global solar market. He joined REC Solar in 2005, prior to which he was one of the founding members at Conergy AG and worked as CFO and Chief Sales Officer. Before that he worked at an investment bank in Hong Kong and at the Prime Minister's Office of Laos. Angiolo has presented several papers in the PV field, and has a Master's degree in business from the Koblenz School of Corporate Management in Germany and a Ph.D. degree in financial economics from the University of Hong Kong.

As VP of Construction Engineering and Design at REC Solar, **Ethan Miller** oversees the implementation of all solar projects, including branch operations, engineering, installation and service, as well as driving the company's expansion and product development. Since 2001, he has managed the engineering and installation of all REC Solar projects, and has a certification from the North American Board of Certified Energy Practitioners (NABCEP). He has a B.S. in mechanical engineering with a focus in renewable energy from California Polytechnic State University.

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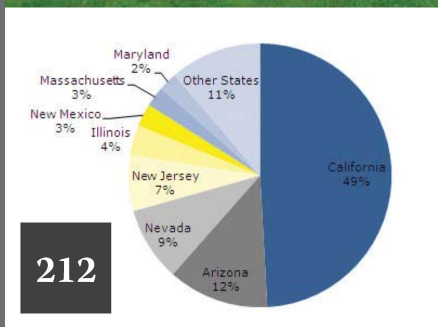
Market Watch

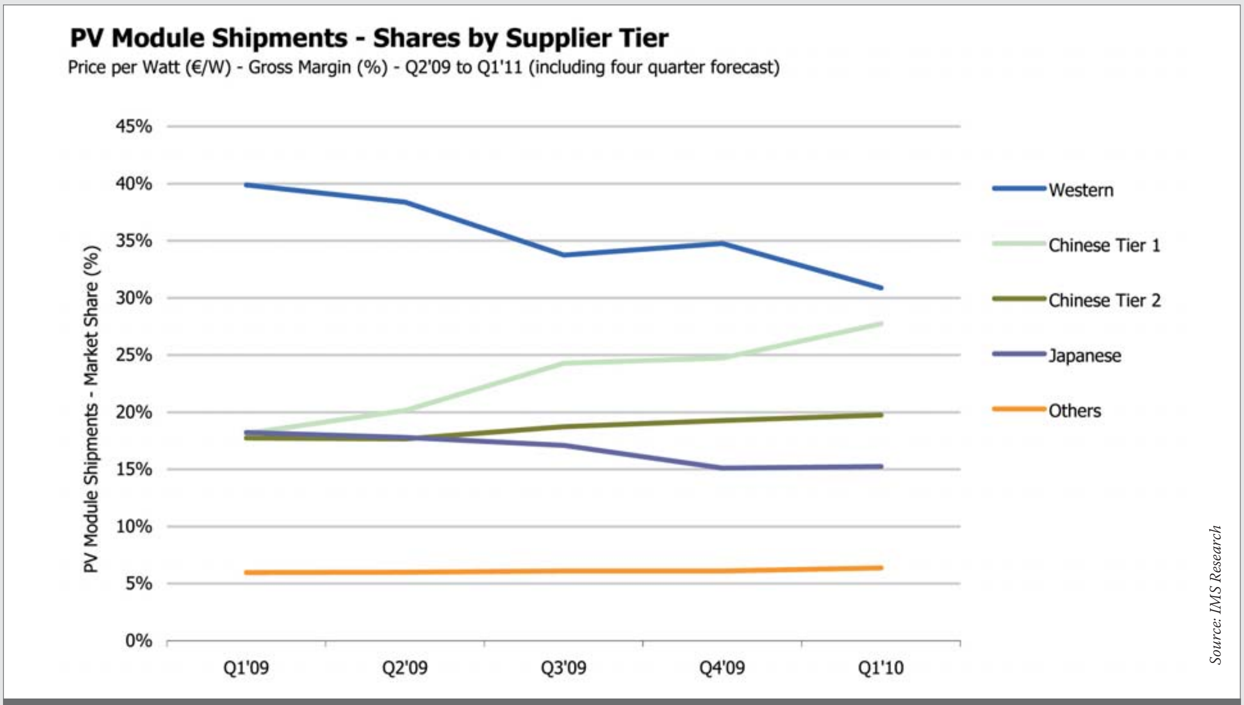


News

Second quarter solar module shipments reach 3.7GW; First Solar losing ground

According to the latest figures from IMS Research, PV module shipments reached 3.7GW in the second quarter and generated US$7.1 billion in revenues. This was the fifth consecutive quarter for increased module shipments. Solar module shipments are expected to increase again in the third quarter, reaching a forecasted 4.3GW. However, IMS Research noted that module shipment share from First Solar decreased for the fifth consecutive quarter and the gap between it and its crystalline competitors closed further due to limited capacity expansion capability until 2011.

IMS Research also noted that the five largest Chinese module manufacturers (Suntech, Trina, Yingli, Canadian Solar and Solarfun), continued to increase their command of the market and their combined share of global shipments reached 28% in the first quarter. Total PV module shipments will grow by 60% in 2010, while First Solar is only expected to increase shipments by 20% this year.



PV module shipments – shares by supplier tier.

Future Market Outlook

Solarbuzz predicts U.S. market could grow tenfold by 2014

Solarbuzz's latest report, "United States PV Market 2010," reveals that the U.S. solar market grew 36% in 2009, responding positively to the economic downfall. These results rank the country's solar photovoltaic market third largest in the world, behind Germany and Italy.

California is still driving the solar power market in the U.S., accounting for 53% of on-grid installations in 2009 and maintaining this position into 2010. While SunPower remained leader for PV installed, Chevron Energy and SPG Solar moved up to the number position in California in 2009. Installers REC Solar, SolarCity and Real Goods Solar led the residential field.

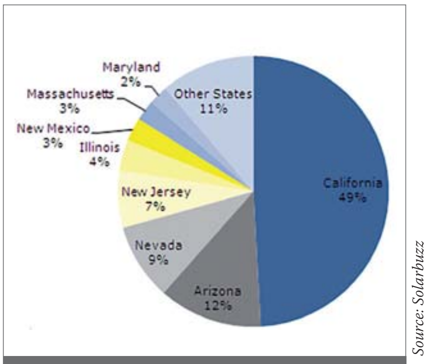
The large number of state policy initiatives has created a fragmented regulations and incentive environment. However, states are doing their job of stimulating local markets. The dispersed funding sources mean the U.S. market does not carry the same level of risk compared to countries driven by a single national policy. Federal incentives are therefore due to play a much larger role in stimulating demand into 2012. Solarbuzz forecasts the market will grow to between 4.5-5.5GW depending on this given scenario, an average annual growth rate of 30% per annum. The U.S. order book for photovoltaic systems currently stands at 12GW.

NYSEIA supports implementation of the New York solar jobs, development act

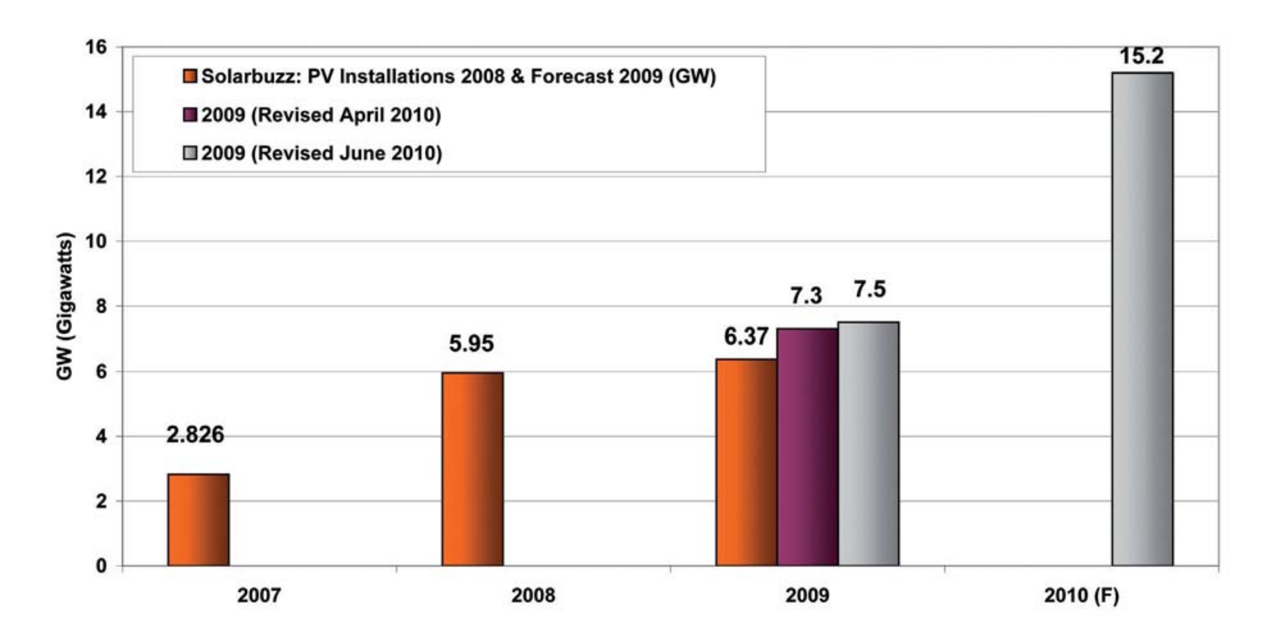
The New York Solar Energy Industries Association (NYSEIA) is pushing state legislators to pass the "New York Solar Jobs and Development Act of 2010," the landmark solar power bill that could create more than 22,000 jobs and US$20 billion in economic output over the next 15 years.

The legislation requires New York to install 5,000MW of solar power by 2025. In order to reach this target, each New York retail electric supplier, the New York Power Authority and the Long Island Power Authority must gradually increase the amount of solar energy produced, until they reach at least 2.5% of their sales over 15 years.

NYSEIA is among a coalition of organizations supporting the bill's passage, including Vote Solar, the Natural Resources Defense Council, the Solar Alliance, the Apollo Alliance and the Alliance for Clean Energy New York. The bill (S.7093a/A.11004) has also recently



U.S. market share divided by state.



Solarbuzz: worldwide PV installations (GW) 2010 forecast (revised June 2010).

received approval from the Assembly Energy Committee.

German PV market remains on top in 2009; set to shift in 2011

According to the latest report from Solarbuzz, Germany remains market leader in the European solar photovoltaic sector, despite feed-in tariff cuts and module pricing adjustments. The German PV market reached 3.87GW in 2009, while Italy came in second place with 770MW and the Czech Republic, France and Belgium combined to add 933MW of newly installed capacity.

Even though Germany came out on top in 2009, with a recorded 109% growth, Solarbuzz reports that this expansion could have been even larger if not for the shortage of inverters that has curbed the market since the September of that year. Growth of the total European market was just 16% in 2009, while growth excluding Spain was 126%. This figure highlights the vulnerability of the overall market to policy review in the larger markets balanced against the growth of emerging markets, claims Solarbuzz.

2010 Market Trends

Nine countries in the mix to exceed 250MW in 2010

Solarbuzz released their recent findings that nine countries, up from six in 2009, are on the path to exceeding 250MW in 2010. Germany leads the global solar market, while Italy, Czech Republic and France harbour the promise of reaching the milestone with their solar growth.

Although the world's economies are in less than perfect order, the potential for growth in countries such as Italy, Czech Republic and France is estimated to be around 3GW in 2010. In addition each of these countries, along with the U.S. and Japan, have the potential to become the third country to ever install 1GW of PV in one year.

China and India add to the significant growth for the PV market with almost 100 planned installations in China adding up to 18.6GW and an Indian pipeline supplying an added 4.8GW. Japanese module manufacturers are continuing the development of their domestic market while distribution channels are growing as well with companies like Yamada Denki and Toshiba.

Solarbuzz forecasts solar market at 15.2GW in 2010: Germany at 8GW

Strong demand for solar installations across multiple markets such as Europe, U.S., Japan and China but especially Germany has forced market research firm Solarbuzz to increase its forecast for the solar industry in 2010. The firm has also made upward adjustments to its 2009 final installation figures to 7.5GW, compared to its previous projection of 7.3GW, issued in April 2010.

Despite the expected feed-in tariff cuts due in markets such as Germany, Solarbuzz believes that continued attractive module pricing will result in 8GW installed in Germany this year. Revenue growth for the industry in the first quarter of 2010 was nearly four times the level of one year earlier, Solarbuzz said. This was a drop of 40% to just over US$12 billion compared with the fourth quarter of 2009. The significant increase in revenue on a year-on-year basis and typically the weakest quarter for demand strongly indicates that significant annual growth can now be expected, barring any macroeconomic events.

Revenue growth is also underlined by price rises at the wafer, cell and module levels due to capacity constraints, which are set to continue at least through the second quarter. Solarbuzz estimates that upstream inventory days will remain flat through the end of the second quarter, whereas downstream days are expected to fall to one-third of their levels seen at the end of the first quarter.

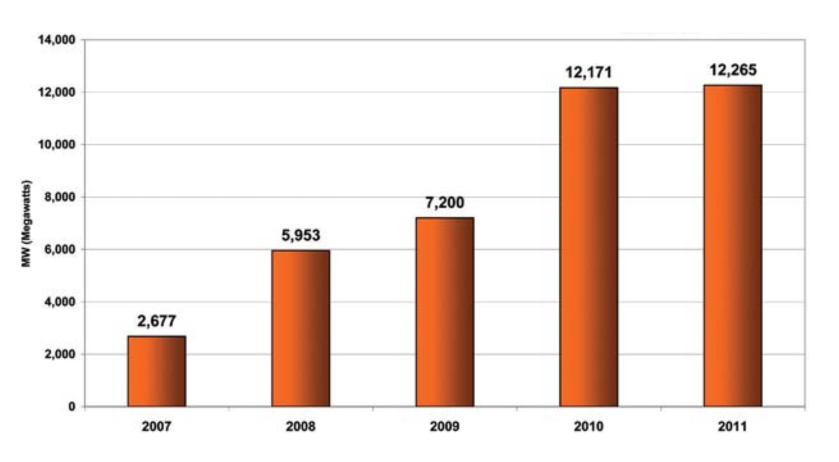
Barclays Capital raises PV market demand forecast to over 12GW in 2010

Strong market demand that is expected to continue through the second half of 2010 is behind a revision of Barclays Capital global PV demand forecast. With Germany, Italy, and the Czech Republic installation figures expected to be significantly higher than the previous year, Barclays Capital now expects 12.2GW installed compared to its previous upbeat forecast of 11GW.

Barclays Capital does not see significant growth in 2011, due in part to the impact of feed-in tariff changes in the hot European markets. However, it has revised upwards its forecast for the U.S. next year. Barclays Capital expects the U.S. market to top 2GW in 2011, up from 1.75GW previously forecasted. The biggest expected decline in 2011 is Spain, with the investment bank forecasting only 72MW being installed, down from its previous forecast of 540MW.

Mercom Capital reports second-quarter results

Mercom Capital has released its second quarter 2010 results for its merger and acquisitions and funding activity for the solar sector of the company along with the result for its smart grid and wind divisions. Total disclosed investments for



Source: Barclays Capital

Barclays Capital: global PV installations (MW) — revised June, 2010.

the solar segment was reported at US$13.8 billion for 34 transactions, the numbers influenced by the US$11.7 million loans issued by Suntech and Trina Solar by the Chinese Development Bank. First quarter investments totalled 30 transactions for US$1.7 billion.

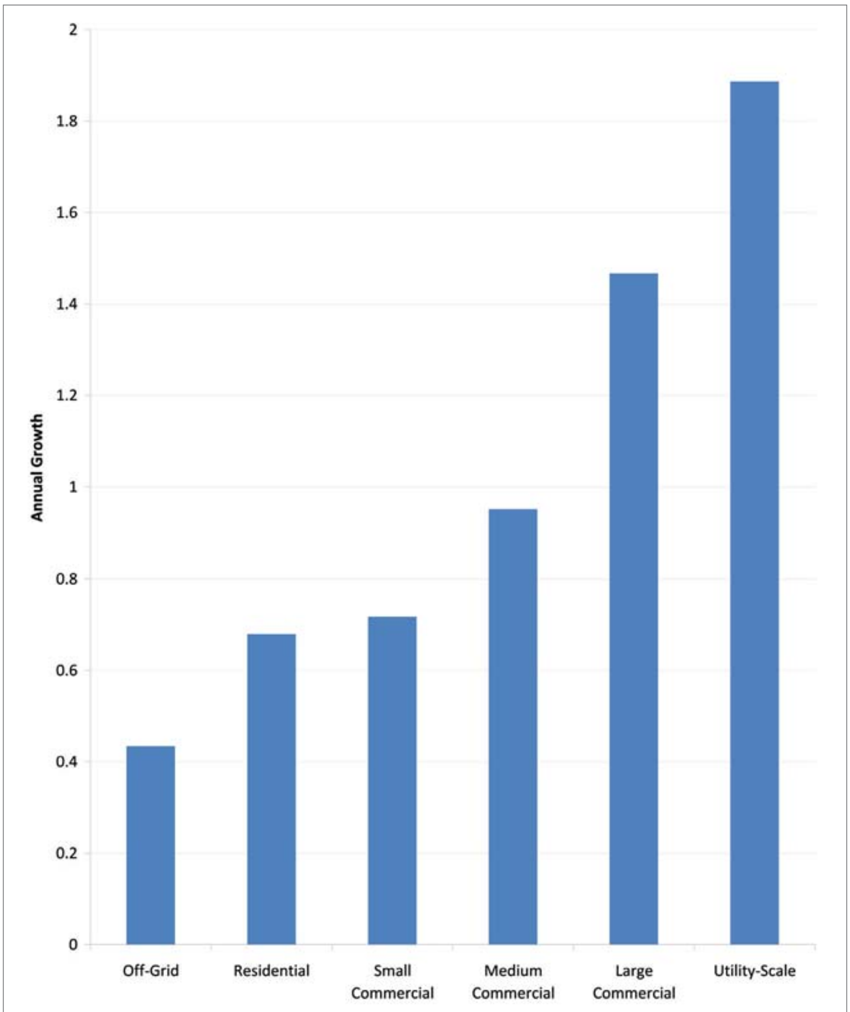
The second quarter also saw Mercom report on a US$175 million private placement received by Solyndra, a Series D raise by BrightSource Energy for US$150 million, Series B raise of US$129.4 million by Amonix and a debt and equity raise by Solar Power Partners for US$115 million. AES Solar also provided project financing of US$128 million and a credit facility was secured by SunPower for US$350 million.

Despite inverter shortages, IMS Research raises 2010 solar market to 14.6GW

Despite only a small improvement in solar inverter component supply expected in the second half of the year, IMS Research has raised its forecast for global photovoltaics system installations. The market research firm expects installs to reach 14.6GW, a 95% increase from 2009 and nearly three times size of the market back in 2008. Increased demand from Germany and other European countries is fuelling demand but growth in other regions such as the U.S. is playing a part.

"Basing our forecast on inverter production is incredibly important this year as it's well documented that inverter supply is limiting the PV market to a massive extent," noted Ash Sharma, PV research director at IMS Research. "Although demand may be higher than this 14.6GW, if customers are not able to secure inverters then installations will not be completed."

According to the analysts, the top three markets in 2010 will be Germany, Italy and Czech Republic, which are predicted to install a combined 9.8GW of new PV capacity. Germany is expected to account for some 47% of new capacity. However, emerging markets in Asia and North America will gain share over Europe, leading to a slight share fall for EMEA countries to 78% of the market. With acute shortages in top-brand inverters, IMS Research noted that double ordering is taking place.



Source: IMS Research

IMS Research: forecast PV growth in 2010 by installation type.

General Market News

Yingli Green signs cooperation agreement with China Development Bank

Yingli Green Energy has entered into a strategic cooperation agreement with the Hebei Branch of China Development Bank (CDB), the government policy bank, which contemplates potential credit facilities in the aggregate maximum amount of RMB36 billion to be granted to Yingli Group and its affiliates, including three PRC subsidiaries.

Under the terms of the agreement, CDB expects to grant, among others, credit facilities with an aggregate maximum amount of RMB36 billion to support Yingli and its affiliates, in particular, Tianwei Yingli, Yingli China and Fine Silicon, in their PV industry-related domestic and overseas investments.

In addition to the internal procedures to be conducted by CDB, detailed terms of the credit facilities and related credit agreements will need to be negotiated before the relevant credit facilities are granted. No assurance can be given that the credit facilities will be eventually granted as currently contemplated in the strategic cooperation agreement, or at all.

From one uncertainty to the next: capped funding overtakes the global financial crisis

Patrick Jonas, EuPD Research, Bonn, Germany

ABSTRACT
The upper and lower houses of the German parliament took their time finding a compromise on the degression of PV tariffs. Cutbacks were finally decided on at the start of July. The German PV market is now headed for another record-breaking year in 2010 despite or maybe even as a result of these reductions. EuPD Research, the market research institute, is making a conservative projection of approximately 5.5GW in newly-installed capacity. Nevertheless, pressure is set to increase, particularly on German solar companies. New marketing strategies have to be developed in the mid-term in order to survive and explore new segments in the long term.

For a long time it was unclear just how high the extraordinary degression of the German solar electricity funding would be. Finding a compromise took months. Both the branch and investors were left in the dark as to the amount and timing of the cutbacks. Finally, at the start of July, the mediation committee tabled a compromise that was acceptable to both the upper and lower houses of parliament. Remuneration is to be reduced in two phases. The first reductions will be retroactively implemented to July 1st, 2010. Rooftop systems will be reduced by 13%, open-space by 12% and areas such as former military or industrial sites by 8%. All tariffs are to be cut by a further 3% in the second phase which comes into effect on October 1st, 2010. As originally intended, farmland will no longer receive financial support from the funding program as of July 1st, 2010.

The suggestion can be seen as a concession to the German federal states, represented by the lower house of parliament. The initial announcement of the government's plans at the beginning of the year was greeted with a chorus of disapproval and protest. A subsequent call for a mediation committee brought the legislative process to a halt. Opposition was led in particular by the federal states in the east, an important PV location, as well as the states of Bavaria and Baden-Württemberg where solar installers and solar wholesale are strongly represented. According to a suggestion made by the federal states, the remuneration for all system sizes should only be reduced by 10%; the withdrawal of the intention to stop all funding for farmland was not planned. The compromise agreed upon means that the cutbacks remain moderate, at least until October.

What impact will these (partially) drastic cuts have on the largest sales market in the world? Unlike the Spanish market of two years ago, it is safe to say that the German market is not about to collapse: the conditions set by the PV funding scheme are stable enough to prevent that. A capping of the market is also not in sight. Despite the extraordinary degression, the rate of return yielded still appeals to several customer groups. The dates, July 1st and October 1st, from which the changes become effective are certain to lead to a surge in demand as well as pull-forward effects, the result of which is likely to be a new record in newly-installed capacity that could top even the previous year. However, the cuts will probably cause a shift in market segments in 2010, and intensify competition especially among German companies. EuPD Research believes that the amendments will lead to a decline in demand in the segments where investors focus most on the returns of a PV system, particularly in commercial open-space systems.

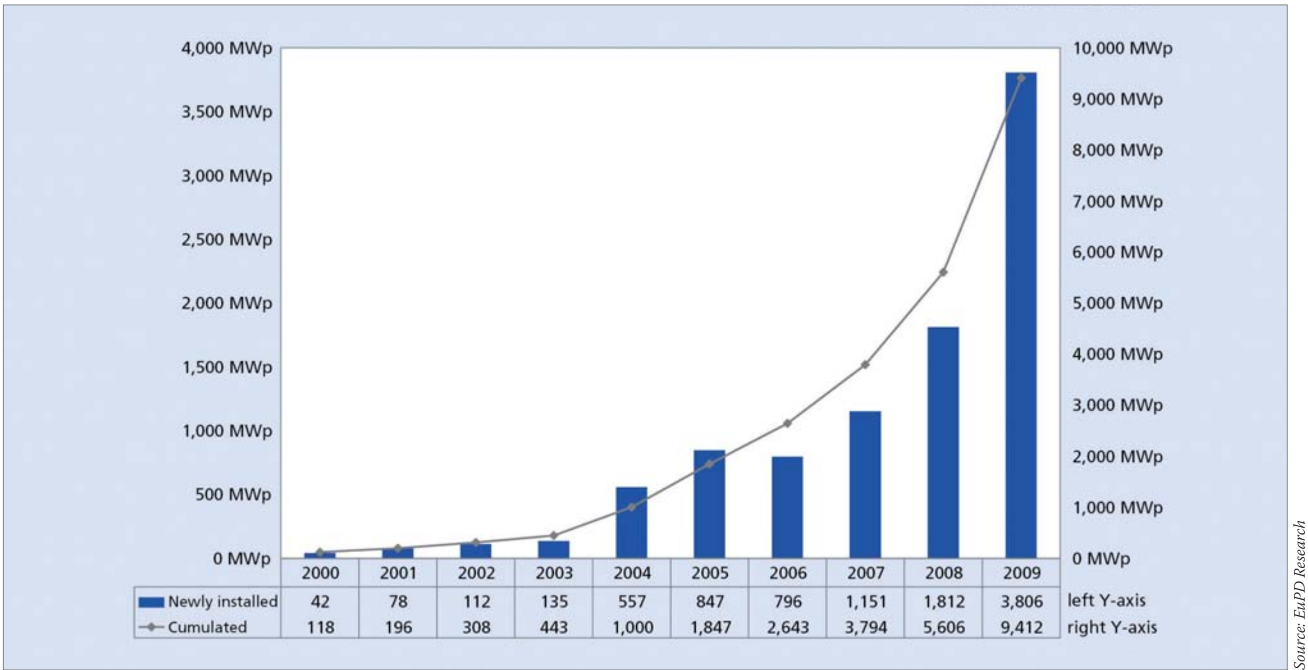
> "The cuts will probably cause a shift in market segments in 2010, and intensify competition especially among German companies."

Following a short-lived run on large-scale systems up to July 1st, the second half of the year is likely to be dominated by smaller rooftop systems. The next date to be watched is October 1st. The sector is bound to enjoy a sizzling third quarter. A first indication of the coming record year was published by the Federal Network Agency, which shows that an impressive 714MW was installed in the first quarter alone. EuPD Research analysts estimate that the second quarter will also profit from the pull-forward effects and show record newly-installed capacity, before the amendment takes effect on July 1st. The figures of approximately 450MW published for the month of April give a first impression of what is to come. A conservative projection for the whole year predicts newly installed capacity at 5.5GW. EuPD Research forecasts modest growth for the following year as a result of the increasing degression, based on newly-installed capacity in 2010 and the changes made to funding in the open-space segment. Nevertheless, the German market will remain one of the most important markets worldwide.

The private customer segment: further expanding market share

In its current study, "The German Photovoltaic Market 2010 – Gigawatt Crisis or Way to Promotion Parity", EuPD Research assumes that the amendment to the German renewable energies law will lead to a shift in market segments. The small system segment will continue to grow in the future and expand on their position as the most significant segment. This trend should become particularly apparent in the second half of 2010 when open-space systems no longer have great appeal to investors and farmland is completely removed from the funding program. In contrast, the expected returns from smaller rooftop systems for private customers have not been affected to the same degree. The remuneration set in the amendment is still of sufficient interest to them. Moreover, the new own-consumption regulation equips this segment with a further growth driver.

The segment with the most growth will be system sizes from 10 to 50kW, a segment that had the largest share of newly-installed capacity in 2009. Little



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	
Newly installed	42	78	112	135	557	847	796	1,151	1,812	3,806	left Y-axis
Cumulated	118	196	308	443	1,000	1,847	2,643	3,794	5,606	9,412	right Y-axis

Figure 1. Development of the German PV market from 2000 to 2009.

will change here in 2010, with EuPD Research predicting newly-installed capacity of almost 2GW. These systems would therefore make up the largest part of newly-installed capacity in the current year, thus increasing their market share further.

No recuperation in sight for installers

With the introduction of the new amendment, the government has put pay to the brief lapse in business some installers may have been looking forward to around the middle of this year, following record growth of 3.8GW in 2009 and a strong first quarter in 2010 (see Fig. 1). The two key dates, July 1st and October 1st, are likely to ensure that installers are in constant demand. The next boom could follow in October when the degression rates for the year 2011 will be announced. Should the German market, as assumed, achieve record growth in the first three quarters, the degression rates for 2011 will be calculated accordingly and the next round of investment will be just a step away.

However, the astonishing amount of newly-installed capacity, pleasing as it might be in the short-term, also harbours danger for market participants. The resulting high rate of degression in the coming year coupled with the extraordinary degression in 2010 could put the German solar branch under enormous price pressure. The amendments adjusted remuneration to the levels of price development and achievable returns of 2008. Should new installations, as assumed, reach a minimum of 5.5GW, this would lead to a degression of 12% at the turn of the year 2010/2011. This would be way beyond cost cuts expected in the second half of 2010. German companies will be affected most by this development. Companies that produce crystalline modules have production costs which are on average 20 to 30% higher than their Asian competitors. American thin-film producer First Solar sets the benchmark for the thin-film PV industry. Considering the expected record amount of newly-installed capacity in 2010, the problems facing the German PV industry in terms of a possible reduction in the degression rate could prove difficult to communicate.

Diversification strategy for German manufacturers

The major issue facing German companies in the coming months will be the question of how best to deal with the ensuing pressure on prices. The fact that they have time to react to these developments as degression in the following year can already be anticipated is to their advantage. While companies concentrated on their pricing policy in the first half of 2010, other factors in the marketing mix are certain to play a greater role in the second half of 2010.

In the short term, EuPD Research assumes that price pressure will increase particularly in the fourth quarter and that companies will be forced to sell their products at a price close to production cost. Against the backdrop of a shift to a buyer's market, manufacturers need to develop marketing strategies to enable their continued success in the long term. This requires the successful addressing of intermediaries between the manufacturers and end customers such as the electro-installers, solar installers and roofers. They are familiar with the requirements of the end customers and recognize trends on the buyers' side in the shift from a supply- to a demand-driven market. Consequently, their significance in the market increases.

> "Against the backdrop of a shift to a buyer's market, manufacturers need to develop marketing strategies to enable their continued success in the long term."

A suitable marketing strategy could be developed under the aspects of product management and positioning whereby the USPs of the company or product in question would play a central role. A distinction can be made between a competitive approach that employs a cost leadership strategy where the price becomes the USP or a strategy of differentiation that focuses on a particular market niche. The latter could use extremely high efficiency modules and inverters, the quality of technology, a well-established brand name or a niche market e.g. building integrated photovoltaics as a USP.

Cost leadership is probably difficult for German companies to implement on the German market. The main reason for this is the aforementioned cost advantages enjoyed by Asian producers in the crystalline segment and by the Americans in the thin-film segment. This applies in particular to the open-space system where the price/performance ratio is of great importance to professional investors and agricultural customers. The returns to be yielded as a result of the cutbacks or rather elimination of funding in July and October

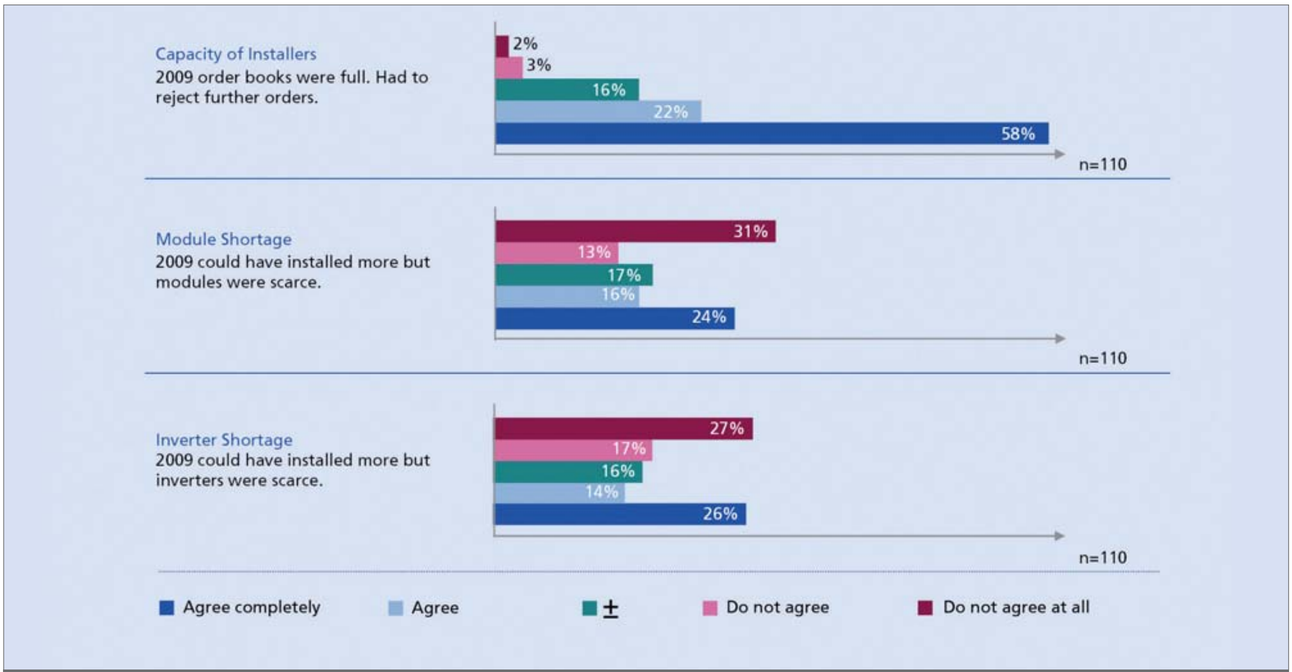


Figure 2. Restrictions on growth as a result of bottlenecks (2009).

are likely to be of interest to professional investors. Producers that can provide modules at lower costs per watt are at an advantage.

EuPD Research estimates that a strategy of differentiation is the best way to guarantee higher margins and a better market position for German companies in the long term, which is particularly of interest to the private system segment and the public sector. The price/performance ratio is not necessarily an essential buying criterion here. The significance of the largest segment which, to date, has been made up of smaller systems sold to private customers and the public sector is set to increase and win market share. Such bolstering is rooted in the extraordinary degression for open-space systems and the elimination of farmland remuneration.

Furthermore, in spite of the degression, the current and future module and system prices still offer sufficient return on investment to both of these customer groups. The private customer segment ranks the origin and brand of a system higher in their purchasing criteria than the price/performance ratio. Ecological components play a major role in the public sector. The portfolio of an installer does not only focus on the best price/performance ratio but also offers products which satisfy alternative preferences such as ecological and brand awareness. Access to the portfolios of installers would be greatly alleviated if companies highlighted the USPs of their products.

Possible bottlenecks in further growth

Two issues could lead to a bottleneck in the German market this year. Where growth was affected particularly by the silicon bottleneck in the past years, this year has seen an artificial restriction resulting from the capacity limitations of installers and inverter producers. In contrast to the production capacities of module producers which were ramped up in previous years, the number of installers – particularly qualified installers – has increased at a much slower pace. The results of a survey among installers carried out in the fourth quarter of 2009 by EuPD Research show how full their order books were. Of those questioned, 60% said they were unable to accept new orders as they were already working at full capacity, as illustrated in Fig. 2. A similar situation was observed for inverters. Although market leaders expanded their capacity, it was too late to absorb demand at its peak in the first half of the year. Moreover, suppliers were not able to supply components at the pace needed for the newly-expanded capacity.

Own-consumption as a new business interest

One of the areas of business that is bound to see substantial growth is the household use of own-generated electricity. This regulation was put in place in 2009, and brings further incentive whereby operators with systems up to 500kW in size receive a bonus for the own use of electricity generated. If more than 30% of the electricity generated is used, the bonus increases accordingly. This new regulation offers solar firms an attractive alternative for differentiation. As is often the case, this new business segment offers both opportunities and challenges. The own-consumption regulation offers scope for a differentiation strategy which could stop turnover shrinking, provide a competitive edge, and foster new business opportunities.

But product development poses a challenge, and intelligent storage and energy solutions have to be developed in combination with solar systems. However, a transfer of technological know-how with regard to storage applications and the grid has to take place in order to develop products which can be quickly integrated into a company's product portfolio. Companies can now take the opportunity to be the suppliers of integrated and systematic energy solutions for the future. Several new ideas were shown at the Intersolar Europe event in Munich earlier this year that combine solar systems with lithium-ionen or lead-gel batteries, so it is clear that at least some companies have already taken hold of this opportunity.

About the Author

Patrick Jonas studied business economics at the University of Applied Science in Koblenz, Germany, and holds a degree in business administration. A particular focus of his degree was on marketing. As part of his thesis he developed a communication strategy for a photovoltaic company on behalf of EuPD Research. Since completing his studies, Patrick has been employed in the communications department of EuPD Research.

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Key characteristics of France's mainland PV market

Melodie de l'Epine, HESPUL, Villeurbanne, France

ABSTRACT

Mainland France's photovoltaics market is substantially different from the situation in the country's overseas Départements (DOM) and Corsica. Feed-in tariffs, tax breaks, financing and market players all differ in these territories. This paper takes a look at France's mainland market, providing a projection for the country's future market and some resources for more information on the DOM and Corsican markets [1].

On the mainland, the most indicative statistics on the PV market are the quarterly grid connection data released by the distribution grid manager, ERDF [2], which covers approximately 95% of all clients. In these high-growth times, long grid-connection delays have resulted in a significant number of installed but not yet connected systems, which are not included in the quarterly figures and thus skew the results slightly. However, when considered over a period of time, this data gives invaluable insight into market growth, with exact figures that are not dependent on manufacturers' or installers' sales estimates.

Several characteristics of the French local market are key to understanding data

- France's feed-in tariff was and is very high – depending on the system and the date at which procedures were completed, between €0.30 and €0.60/kWh. However, to benefit from the highest tariffs, BIPV products must be used on small (<250kWp) systems.
- From July 2006 to January 2010, the feed-in tariff of any project was determined by the date at which the systems requested a feed-in contract; this request could be made up to three years before grid connection and before finalising many aspects of the project.
- In early 2009, the government announced a revision to the feed-in tariffs. Draft changes were available in November 2009 to industry insiders, but the final revision was published and took effect in January 2010, creating a rush of investors (and developers) attempting to secure the known conditions in November and December 2009.
- Since January 2010, the feed-in tariff has been determined by the date of the grid-connection request, which may only be completed when the project material and permission has been finalised.
- Grid connection and administrative procedures require three to 18 months to be completed, resulting in long lead times for projects.

As a result of these characteristics, general growth of the mainland market over the past five years has been dependant on the availability and ability of products to comply with the rules regarding BIPV, and the capacity of market players to accomplish the previously complex, but still very time-consuming grid-connection and administrative procedures.

A small but growing market...

Quarterly figures at the end of March 2010 indicated a combined grid-connected power of 271MW, with 71MW connected in the previous quarter. This represented a growth of 36% in power output, compared to the 42% growth in the previous quarter. Given the long grid-connection delays, these systems were essentially finalised or installed before the feed-in tariff modifications of January and March 2010.

> "The dramatic difference visible in the quarterly figures over the past six months has illustrated the real difficulties faced by project developers and private investors."

At the same time, the power queued for grid connection was a whopping 10 times higher, at over 3.2GW. Whilst it is expected that at least 0.5 to 1GW of projects will be abandoned due to recent legislative changes and financing difficulties, this still represents an enormous change in scale for the local market. Not only is the combined power undergoing sharp growth, but the average power of systems requesting grid connection is also up by a factor of 10. This increase is primarily the result of the development of ground-based multi-MW systems, and the continued strong growth in small domestic PV systems.

The following figures give a clear illustration of the current PV market in France:

- Current connected power: 271MW for 58,000 systems (average power 5kWp)
- Power connected last quarter: 71MW for 16,000 systems (average power 4kWp)
- Power awaiting grid connection: 3.2GW for 66,000 systems (59,000 with average power of 3kWp; 7,500 with average power of 400kWp).

So why is the queue so big and the currently connected power so low? Much of the problem is in the hands of ERDF, who have demonstrated a consistent inability (or unwillingness) to anticipate market growth ever since the first 'official' feed-in tariff in 2002. Whilst the growth over the past six months has been significant, the gap in grid connections and grid-connection requests is not new. The dramatic difference visible in the quarterly figures over the past six months has illustrated the real difficulties faced by project developers and private investors. It will probably take several years for ERDF capacity to catch up with grid requests, leaving increasingly large numbers of future producers unsatisfied.

...driven by 3kWp domestic BIPV systems

The previous – and actual – structure of France's feed-in tariff doubles the tariff for BIPV systems. With extremely attractive tax credits and tax breaks for private citizens, it is not surprising that small domestic systems of 3kWp and under are the driving force behind local market growth. Thanks to the falling system prices that are resulting from the Spanish market slowdown, investors in southern France were, and still are, able to reach payback times as low as five years on a 20-year guaranteed feed-in contract. Over 90% of all systems and approximately half the connected power fall into this category, with the bulk of the remaining power kept on systems small enough to be connected to the distribution manager's low voltage grid (under 250kVA).

The December 2009 'speculative bubble'

Throughout the economic slowdown of the past few years, a booming PV market and increasing demand on the compensation fund that finances the feed-in tariff raised concerns in government that PV would lead to an unacceptably high burden on public funds. How much of this concern is justified remains open to debate in a country that financed a massive nuclear programme in the past.

Although much of the industry dislikes the term 'speculative bubble', it is understandable why the government introduced the term early in 2010. In 2009 the combined power requesting or having signed feed-in tariff contracts saw a steady growth rate of between 15 and 30% per month, but this leaped by a staggering 230% in December. Total requests for feed-in tariff contracts had reached a combined power of 600MW at the end of September 2009, then leaped to 2.8GW in December. Clearly, the domestic PV systems were not at fault, as two thirds of this power was accounted for by systems over 250kW.

The March 2010 legislation that introduced retroactive measures to eliminate 'speculative' projects, combined with modifications to the permitting process for ground-based systems introduced in late 2009, should reduce this 2.8GW significantly.

Much of the industry supports the goals of these changes, recognising the need for an industry clean-up, although the method chosen is not as consensual. Controlled, sustainable growth benefiting the local industry is desired by most industry stakeholders, and much of the speculation concerned systems that were clearly to be installed with low-cost foreign products by a greatly reduced number of companies.

Whilst these changes have a significant impact on the volume of the French market, they will not significantly change the grid-connection queues or the number of systems to be installed, as private domestic systems are not affected.

Long-term pressure on support mechanisms

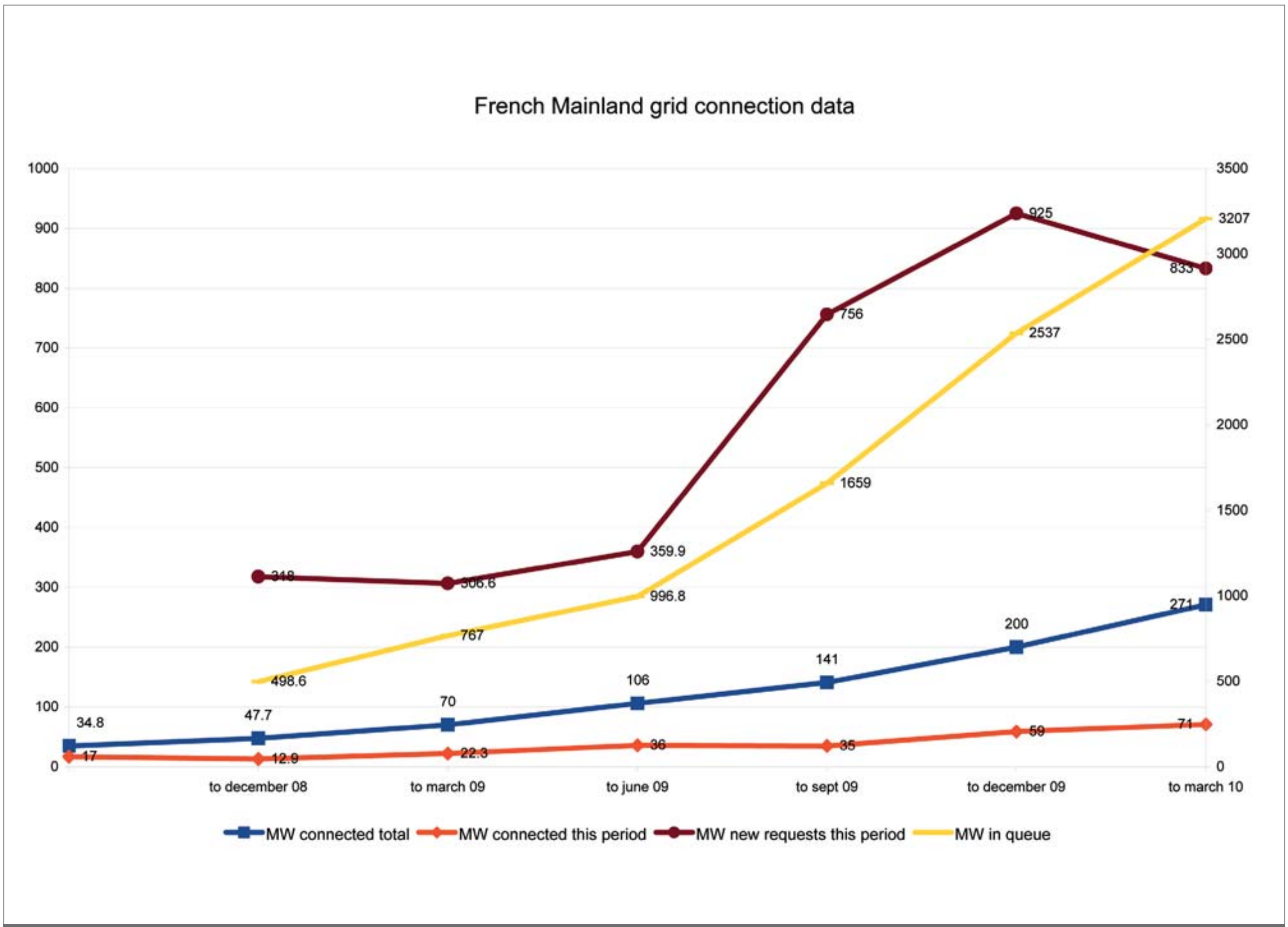
Whilst the impact of spectacular growth in planned projects in late 2009 brought the subject into national media, industry representatives have been concerned about the sustainability of existing support mechanisms for quite some time. Although there is no general agreement on which market sectors should be encouraged, there is a consensus that current support is too high for most sectors, and a further revision is necessary.

The main goal of support mechanisms is to ensure continued growth in the industry until grid parity can be reached, with a very clear desire on the part of government to favour local industry and companies, for example through the creation of BIPV niche markets best covered by local industry.

> "The main goal of support mechanisms is to ensure continued growth in the industry until grid parity can be reached."

In the past few months, several different investigations and working parties have been set up by the government, and most industry representatives have been heard in at least one instance. The pressure on financing mechanisms is clear, as a special task force from the Inspection Générale des Finances prepares to deliver a report that aims to "analyse national PV support mechanisms and their impact on local industry and the benefits they bring to the nation".

France's industry representative SER-SOLER proposes in a recent (June 2010)



Source: Hespul/ERDF data

Figure 1. Evolution of grid connections and grid-connection requests from December 2008 to March 2010 .

Figure 2. Domestic BIPV, such as this Photowatt Wattea system, is driving the market.

Courtesy: Photowatt

paper a 20% cut in feed-in tariffs and an annual ceiling on the power eligible for the feed-in tariff each period [3]. Both Hespul, an independent non-profit organization responsible for much of the early development of grid connected PV in France and editor of the national documentary resource site photovoltaique.info [4] and the French environment agency ADEME believe a cut in tax credits for private citizens is necessary, not only to reduce the impact of PV on the public budget, but also to reduce competition with investments in insulation and solar thermal systems. Enerplan [5], representing installers and consultants, agrees but also believes that whilst modifications are necessary, stability in the legal framework is even more important, a view also held by APESI, the organization that represents professional PV electricity producers [6].

What does the future hold for the local market?

Despite the changes to come, France's mainland market will continue to grow over the next two quarters, as systems that have completed all the administrative procedures are installed and connected to the grid. Whilst a probable drop in tax credits and the feed-in tariff will impact the market for domestic PV systems, the slowdown will probably not be too significant; there is room for a further drop in module prices on the French gross market and systems will still be financially viable for private investors over the 20-year contract – at least in central and southern France.

Multi-MW systems are likely to remain viable, albeit less attractive. The good insolation in southern France and constant reduction in module costs will ensure this. Increasing interest from local councils in 'green' investments means a steady supply of viable sites will remain available.

The sector that will be the most affected by any future drops in the feed-in tariffs will be mid-sized systems on professional and agricultural buildings; whilst roof integration remains a priority for the government and a condition for obtaining 'reasonable' feed-in tariffs, BOS and associated costs (insurance, grid connection, financing) will continue to make this sector fragile. A drop in the feed-in tariff could create real difficulties for this sector, unless the integration criteria are loosened to allow for lower-cost systems.

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About the Author

Melodie de l'Epine has accompanied the growth of France's PV market since before the introduction of the first feed-in tariff in 2002. She has spent the interim working not only on educating installers and the general public about grid-connected photovoltaics, but also local and national decision-makers, financiers and architects, covering the whole spectrum of people involved in creating a functioning solar industry. She takes an active part in national consultative workshops that prepare legislation and policy, as well as administrative procedures. She co-animates the national documentary resources centre on grid-connected photovoltaics at www.photovoltaiques.info.

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CORRECTION: In the eight edition of Photovoltaics International, the paper titled "Examining cost of ownership for front- and back-side metallization of crystalline-silicon solar cells" by Darren Brown and David Jimenez contained some erroneous data provided to the authors about the cost of silver (Ag) paste. While most of the paper's conclusions remain valid, the authors said they want to provide a more realistic view of the absolute cost of the metallization process, so the online version of the paper contains the updated, corrected data and subsequent recalculations.

The paper can be purchased here:
http://www.pv-tech.org/technical_papers/_a/examining_cost_of_ownership_for_front-_and_back-side_metallization_of_c-si_/

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Life on the edge: Wily veteran Sharp Solar keeps on keeping on

Sharp Solar, one of the oldest names in the youthful PV industry, has been on a roll of late. The one-time top-dog PV company regained the lead in the revenue race last year, edging out younger upstarts Suntech and First Solar, with more than US$2.2 billion in sales. It also held its own in production, claiming 792MW of cell/module output. First-quarter 2010 results reinforce the solar division's surge, with sales coming in at ¥57.6 billion (US$667 million), an increase of nearly 66% over the same period last year, and production volume hitting 258MW, up almost 90% year-on-year.

In March, the Japanese electronics giant opened one of the largest solar manufacturing facilities on the planet – the Green Front Sakai plant boasting 870MW (1GW eventually) of multijunction silicon thin-film manufacturing nameplate capacity.

Photo: Tom Cheyney

Thousands of those 128W Si-TF panels coming off the production line are already in service in the United States. More than 50,000 of them have been active since April 30 as part of the 5MW CalRENEW-1 project (engineered/built by Quanta Renewable Energy, owned/operated by Meridian Energy), which sits on 50 acres of long-fallow farmland in Mendota in California's Central Valley. Not only is the array by far the biggest utility-scale deployment of the company's 9.5%-efficient thin-film technology in the States (or of any type of single- or tandem-junction a-Si, for that matter), it's the first largish-scale PV project to achieve California Independent System Operator (CAISO) approval to deliver power directly to the transmission-level grid, its PV-generated electricity doled out wherever it's needed over the utility lines.

Another 9,120 Sharp Si-TF modules powered up in late March in a 1.1MW Schletter-racked, Xantrex-inverted array near Dayton Power and Light's Yankee Substation in Montgomery County, OH. General contractor Ameridian Specialty Services, which partnered with Inovateus Solar, started the project in December, working through the sometimes-harsh Buckeye state winter to get the system online.

Company sources told me that "at least 18MW" of additional TFPV panels were in the pipeline for a major project in Ontario, offering some counterweight to the prevailing opinion that the future of silicon thin-film solar is bleak – at least when it comes to Sharp's technology. A pair of megawatt-scale fields also started flowing electrons to the grid in Germany earlier this year.

But all of those projects pale in scale compared to a deal announced in early July. Sharp has agreed with NED, Mitsubishi's Thailand-based, wholly-owned independent power producer, to build 73MW of a-Si thin-film PV power plants in the southeast Asian country. Construction was scheduled to start by the end of July, with completion projected for sometime in 2011.

While Sharp targets the utility market with TFPV, the company continues to crank out thousands of crystalline-silicon modules every week from its U.S. assembly line in Memphis, TN, for the residential and commercial/industrial/governmental sectors. Earlier this year, the company celebrated the two-millionth panel produced at the 160MW capacity facility (the one-millionth unit came off the line in early 2008), which equates to some 400MW of total output since the plant opened in 2003.

The c-Si modules coming off Sharp's Memphis line have also been deemed good enough for government work, now that the company has won a U.S. General Services Administration "schedule 056" contract. GSA, which establishes "long-term government-wide contracts with manufacturers to provide federal, local and state government agencies purchasing access to commercial suppliers through the GSA 'Advantage!' online shopping and ordering system," offers "government customers the convenience of direct purchase and delivery of products and services at most-favored pricing." (Sharp's Si-TF panels have not yet been afforded the same GSA privileges though.)

The company has also accelerated plans to expand its manufacturing assets in Europe. Sharp's c-Si module factory in Wrexham, Wales, UK, which has been running full-tilt boogie making panels for hot parts of the European market, will soon see its capacity doubled to 500MW. The build-out will begin in December, with the expansion set to be finished by February 2011.

A second European factory will begin operations in the second half of 2011. The thin-film plant, which will inhabit an unused STMicroelectronics semiconductor fab shell in Catania, Sicily, will be the production hub for the Sharp/STMicro/Enel Green Power strategic partnership known as 3Sun. Initial annual capacity is set at 160MW, with an eventual goal of 480MW. Some of those new modules will go to projects around the Mediterranean area developed by ESSE, the independent power producer venture formed by Sharp and Enel.

Sharp sees its growth, in both PV technology food groups, continuing at a healthy clip, holding to a forecast of 2010 solar segment revenues of ¥250 billion (~US$2.9 billion at the current exchange rate) and production output of 1200MW – both prodigious increases over the previous year – as the company continues to deploy what it calls "a local production for local consumption business model."

While BP Solar, Mitsubishi, Sanyo, and some of the other photovoltaic old guard have fallen back in the race, passed in revenues and shipments by the agile Chinese companies and the First Solar juggernaut, wily veteran Sharp just keeps on keeping on.

This column is a revised and updated version of a blog that originally appeared on PV-Tech.org.

Tom Cheyney is North American editor for the *Photovoltaics International* journal and writes blogs and news for PV-tech.org.