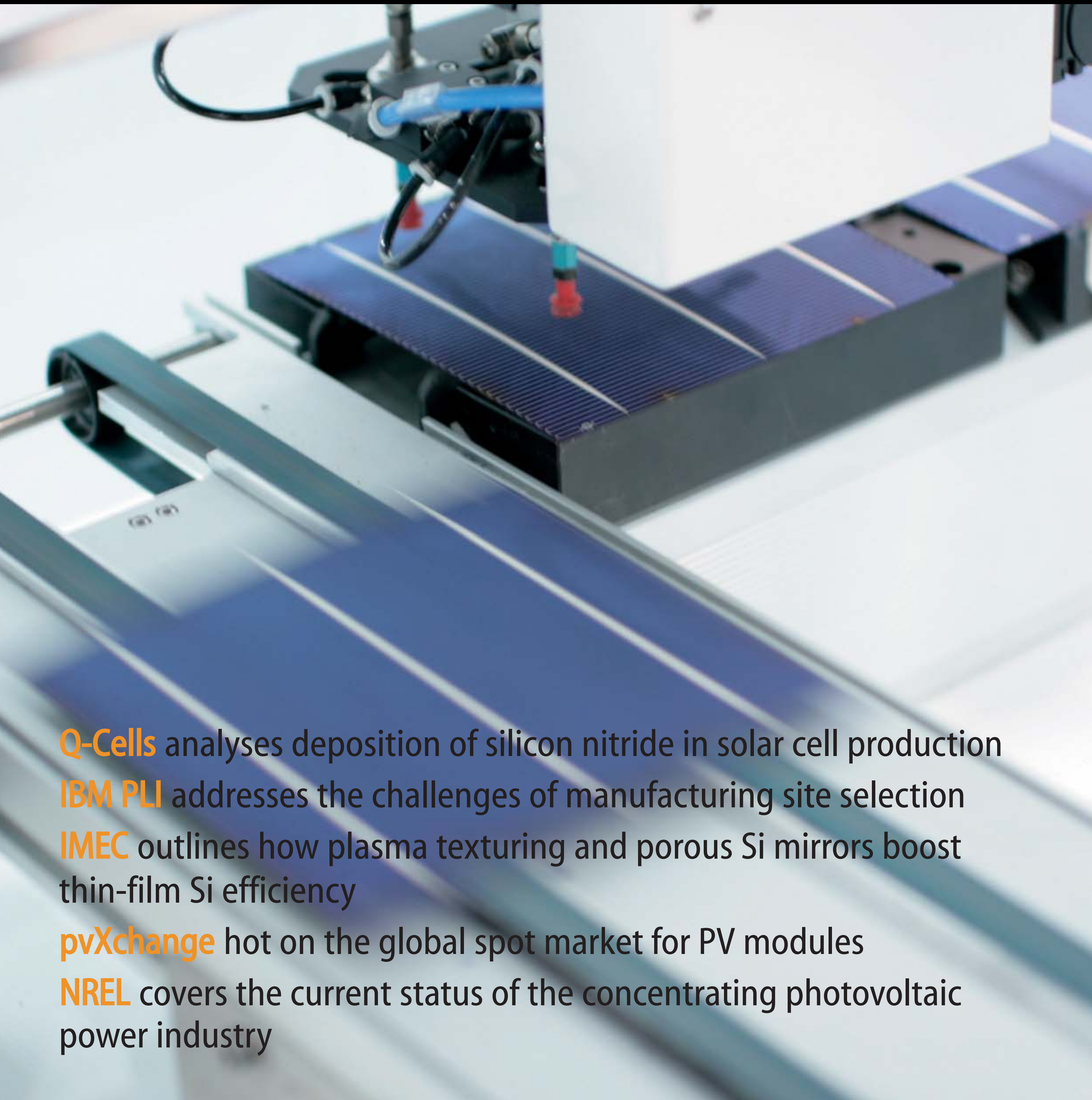
First Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS



Q-Cells analyses deposition of silicon nitride in solar cell production

IBM PLI addresses the challenges of manufacturing site selection

IMEC outlines how plasma texturing and porous Si mirrors boost thin-film Si efficiency

pvXchange hot on the global spot market for PV modules

NREL covers the current status of the concentrating photovoltaic power industry

Third Quarter 2008 www.pv-tech.org

The solar energy revolution is not far away. The spark will come when solar electricity reaches grid parity. With its unique know-how in gases and chemicals, Linde is working with solar cell manufacturers worldwide to increase cell throughput and efficiency and to reduce the cost per watt, helping to bring grid parity and the revolution even closer.

Meet the Linde team at the 23rd European Photovoltaic Solar Energy Conference & Exhibition, 1st-4th September in Valencia.

→ Visit us at booth A13 in Hall 2 and learn more about our unique gas & chemical technology and turnkey capabilities

→ Attend our seminar "Meeting the Challenges of the Gigawatt fab" on Tuesday 2nd September, 13.30PM - 16.45PM. To register email us or visit our booth.

→ See our poster session (3AV.1.37) CVD chamber cleaning with fluorine on Monday 1st September, 13.30PM -15.30PM.

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THE LINDE GROUP

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Publisher's foreword

Now is the time for scale.

Welcome to the inaugural issue of *Photovoltaics International*, the quarterly journal written by and for the PV manufacturing industry. With the help of our highly respected and influential advisory board (see overleaf), we have put together a collection of papers from some of the foremost thinkers currently working in the PV industry. Together as an industry we can share knowledge to help drive solar power to grid parity that much faster.

The social forces are in place to keep public opinion firmly in favour of renewable energies a most households around the globe are faced with higher consumer prices for everything from energy to a loaf of bread. This has been brought about by the ever-increasing price of oil and the knock-on effect for commodity supply chains.

The solar industry is booming! Orders are up and manufacturing companies are rushing to meet the growing demand. Recent announcements on the practical usage of upgraded metallurgical-grade silicon have allayed the fears of many wafer and cell manufacturers. Yes – the days of US$200p/kg polysilicon may be behind us.

Through ongoing process, material, and tool developments, the solar manufacturing industry can achieve the scale of manufacturing that it requires to serve the market in the short term and grow the market in the future.

Divided into core sections, *Photovoltaics International* will bring you valuable information on key technical issues that will drive solar power towards greater efficiencies and a faster approach to grid parity.

You only get one chance to make a first impression and for a manufacturing facility, choosing the correct site can be key to a lasting and profitable manufacturing base. We find out from the experts at IBM's Plant Location International what the standards are for selecting the right site.

Could the ITRS (International Technology Roadmap for Semiconductors) hold the key to unlocking manufacturing standards for PV manufacturing? Bettina Weiss from the PV Group outlines a couple of key standards being driven by tool manufacturers in the industry.

Dr Hubert-Joachim Frenck, currently leading the vacuum division at Q-Cells, shows us how to depose thin-film silicon nitride to increase the cell efficiency of Si solar cells. A contribution from IMEC shows how efficiencies of up to 17.5% can be achieved on screenprinted multicrystalline Si solar cells incorporating a plasma decoupling process.

Tom Cheyney visits the factories of Global Solar and Miasolé in a bid to assess the commercial manufacturing scale of the promising CIGS thin-film technology. Dr. Dirk Ochs from Hüttinger explains how important fast-reacting arc management is to attain high-quality solar cell coatings.

c-Si and thin-film modules are failing more now than in the past ten years. The Arizona State University PV Testing Laboratory (ASU-PTL) tells us why.

Sarah Kurtz, principal scientist at the U.S. National Renewable Energy Laboratory (NREL) writes about significantly reducing cost-per-watt through the use of CPV systems. Also in Power Generation, I manage to catch up with City Solar, installers of large-scale PV power generation projects, to find out what goes in to a new facility and how effective are thin-film modules for large-scale power generation.

There are eighteen papers in this issue and I hope that you will gain some useful insight into photovoltaic manufacturing and keep the journal for later reference in your work. If you have not yet subscribed, I would encourage you to do so using the form at the back of this book.

Be sure to check out **www.pv-tech.org**, your daily dose of PV-related news and opinion, where you can now see and hear the people shaping our industry on Solar Leaders TV.

Looking forward to the halcyon days of solar power.

Sincerely,

David Owen
Photovoltaics International

Photovoltaics International

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Front cover shows cell transport systems at Conergy's fully-automated factory.
Picture courtesy of Conergy AG.

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Photovoltaics International

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

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

Editorial Advisory Board

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

Gerhard Rauter
Chief Operating Officer, Q-Cells AG

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

Takashi Tomita
Senior Executive Fellow, Sharp Solar

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

Rodolfo Archbold,
Vice President of Operations, Evergreen Solar

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

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

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

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

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

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Photovoltaics International

As the CapEx for special machinery in the photovoltaic industry is quite high, subsidies and incentives often play an important role.

The maximum efficiency of light conversion for the Si/SiN/air stack is obtained at n_{633nm}~1.9 at a thickness of d~85nm, assuming zero or negligible absorption.

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Meet the people shaping today's solar industry

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Evergreen Solar CEO

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

Åsmund Fodstad
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Roger Little
Spire CEO

SolarLeaders Television

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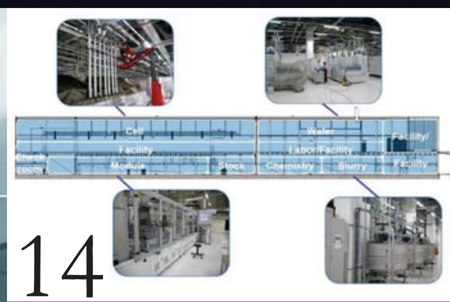


News

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

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

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

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

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

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

Solar Cell News Focus

Suniva selects first PV manufacturing site; plans 100MW ramp

Suniva has selected Gwinnett County, Georgia, USA, as its initial solar cell manufacturing centre with plans to have an initial capacity of 32MW on its first line and plans to ramp to 100MW in the next two years.

"As the solar industry looks to bring down costs and compete with conventional power, Suniva has built the team and the technology to execute on our vision of low-cost, high-efficiency solar energy," said John Baumstark, CEO of Suniva. "We are pleased to be moving into our next phase of growth close to home, and we are interested in working with state and local government to create an ecosystem of clean energy companies in the Atlanta metro area."

Currently headquartered in Atlanta, Suniva expects its new facility to create approximately 100 additional jobs in the region within its first year of operation.

ARISE Technologies fast-tracks production in record time

In one of the fastest constructions and installations in the industry, ARISE Technologies and its engineering firm DHV have constructed and prepared a solar cell plant in six and a half months. The company announced that it has produced its first solar cell at Line 1 of the €50 million, 4,000m^2 Bischofswerda production facility in Germany using a novel layered production technique.

The production line, which, unlike Line 2 at the same location, does not use proprietary technology, will produce 1,500 solar cells per hour. It utilises a dual-layer building principle, which means that all chemical treatment equipment, air conditioning equipment, etc. can be housed on a level below the production level, enabling faster response times and a safer working environment, according to the company.

The line will produce approximately 40MW per annum. ARISE also plans to install 10 additional production lines through 2012, targeting an annual capacity of 560MW. Three of these production lines are expected to begin operation in the next 18 months.

"We've noticed a steadily increasing demand in the market for sustainable solutions and a dramatic growth in the solar-cell market," said Ad Schrijvers, DHV's project manager. "That's why it's essential that solar-cell plants be extremely flexible and prepared for future developments. The ARISE facility is built according to a two-layer principle. This means that the installations are located below and production takes place on the first floor. In this way, plants can be expanded rapidly and respond to increasing demand. More and more other engineering firms are going to make use of the power of the 2-layer principle."

Praxair wins on-site gas supply contract for Pevafersa's 120MW plant

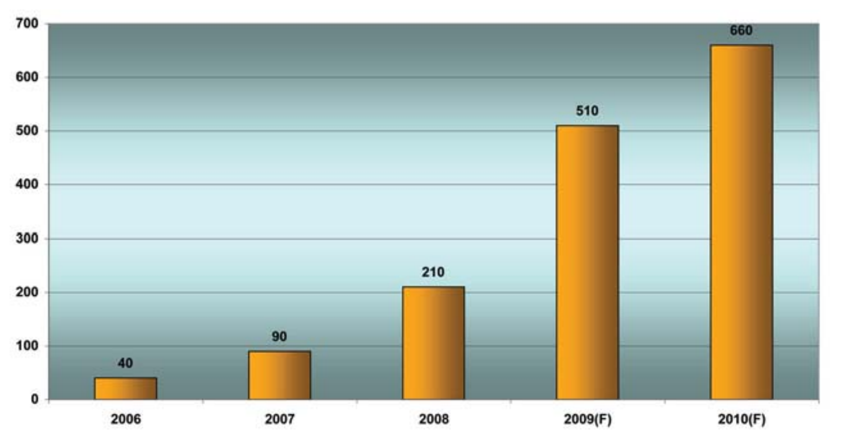
Pevafersa Group has selected Praxair to supply its new 120MW solar cell manufacturing facility in Toro, Spain with on-site gases, gas equipment and gas management services. Initial production is set for early September, 2008.

Fluor's LDK Solar project logs two million incident-free craft hours

Fluor Corporation has announced a major safety milestone in its polysilicon project for LDK Solar in China. At the end of April 2008, the company had logged over two million craft hours without a reported safety incident, attributing the achievement to the implementation of a "Zero Incident" program to educate and train employees in safe work practices in the workplace.

The 15,000MT facility, located in Xinyu City, Jiangxi, China, is near LDK's existing solar wafer manufacturing facilities and headquarters and is expected to be the largest polysilicon production facility of its kind in the world. Construction began in August 2007 and the completion date is scheduled for mid-2009.

Thin Film News Focus



Neo Solar Power: Capacity ramp schedule.

Neo Solar Power updates solar cell and thin-film production plans

Neo Solar Power (NSP) has said that its thin-film task force, which is led by Dr. Sam Hong, President of NSP, expects to commence production of its first thin-film production line in the second half of 2009. The company is targeting between 30 and 60MW initial capacity.

NSP's new silicon solar cell facility, 'FAB 2,' located in HsinChu Science Park, is scheduled to complete four additional production lines in mid-August, 2008, adding 120MW. Total capacity will now be 210MW, a 133 percent increase over its previous production capacity levels.

The company plans to add an additional 300MW of capacity in 2009 with a total capacity of 510MW, which is in line with earlier projections made by the company. To meet capacity ramp goals, NSP has secured a further supply of polysilicon from an unnamed 'top 3' European supplier. The seven-year deal is worth approximately US$43 million with deliveries starting in 2009. NSP did not guide capacity ramp figures for 2010, but had previously stated that its goal was to reach capacity of 660MW in that year.

First Solar officially opens Malaysian plant

First Solar has held an opening ceremony for the first four plants being built at the Kulim Hi Tech Park in Kedah, Malaysia. The four thin-film manufacturing facilities make up an investment of US$680 million by First Solar and will create around 2,000 jobs, the company said. When fully ramped, the four facilities will have a 720MW capacity and are a key aspect of First Solar's plans for 1GW-plus production by the end of 2009.

"Dedicating this plant today represents a major milestone for First Solar. Our expansion into Asia enables us to achieve cost reductions through economies of scale in a high quality manufacturing environment," said Bruce Sohn, President of First Solar. The last of the four plants is expected to be completed at the end of 2008, with ramping beginning in late Q109.

Applied Materials expands 'SunFab' tool manufacturing in Taiwan

Applied Materials is expanding its equipment manufacturing capabilities in Taiwan with the construction of an extension to its Tainan Manufacturing Center at a cost of US$17 million. Demand for its AKT flat panel display equipment and SunFab Thin Film Solar equipment was the reason for the expansion, which should be completed in mid-2009, Applied said. The expansion will add 7,200 square meters of new production area, doubling the existing space and employing 150 people.

Innovalight to deploy Eyelit's MES for development and future manufacturing

Silicon nanocrystalline ink module producer Innovalight has selected Eyelit's Manufacturing Execution System (MES) for both its development and future manufacturing needs. Eyelit's software suite enables Innovalight to track WIP, consumables, inventory and experiments as part of a comprehensive integrated MES approach for full tracking and process traceability. "We reviewed several MES vendors and selected Eyelit because of their product flexibility, speed of implementation, and low cost of entry. We wanted a solution that meets our development needs today and one that we will need as we move to production," said Tu Du, Vice President of Operations for Innovalight.

"Many solar manufacturers are finding with the rapid growth in the solar market, they are quickly outgrowing smaller point or home-grown solutions. Many solar manufacturers are at a crossroad of further investment or the need to reinvest in new, scalable software for high-volume production," commented Dan Estrada, Vice President of Sales and Business Development at Eyelit, Inc. Innovalight is a Silicon Valley-based start-up in pre-production operations.

Thin-film start-up Sencera invests US$36.8 million in 38MW plant

Amorphous and microcrystalline thin-film solar module manufacturing start-up Sencera International Corporation has announced plans to build a 38MW module plant in Charlotte, North Carolina, U.S. Sencera will invest US$36.8 million and plans to use its proprietary 'Viper' plasma-enhanced chemical vapor deposition (PECVD) technology to reach the 38MW capacity by 2011, creating 65 jobs in the process.

"We considered several different states and foreign countries. We're glad we can remain in Charlotte. The Charlotte Chamber was extremely helpful in shepherding us through this process," said Britt Weaver, COO of Sencera, "We're grateful that our state and local public officials recognize the potential of both our company and what the solar industry brings to the city of Charlotte and North Carolina." Sencera will move its current headquarters and R&D operations to the new facility.

Other News

Applied Materials breaks ground at Singapore Operations Center

A groundbreaking ceremony for the new Applied Materials Operations Center at Changi North Industrial Park in Singapore took place in June, 2008, and saw the attendance of several Applied Materials executives, including Mike Splinter, company President and CEO. Chairman of the Singapore Economic Development Board Lim Siong Guan and U.S. Ambassador Patricia Herbold were also present for the ceremony.

The new 32,000 square metre operations facility will be completed in late 2009 and will serve as a hub for the company's activities throughout Asia. The new facility will house operations including global purchasing, sales, manufacturing, engineering and financial groups for both the chip and solar industries. Applied currently has approximately 400 employees in Singapore.

The facility will be designed to meet some of the most stringent green building standards in the world. Applied Materials also announced that it is to sponsor the Environment Education Hub at the local Marsiling Secondary School.

Entegris opens office in India to support PV and microelectronics businesses

Entegris has established a wholly-owned subsidiary in Bangalore, India to provide support of the company's product portfolio for the photovoltaics and microelectronics industries. Entitled Entegris Materials Integrity India Pvt. Ltd., the division will be led by Badarish Appanna, and will incorporate support for activities such as wafer and mask handling and shipping, subsystem and fluid handling products and finished electric products.

MES provider Eyelit partners with integration specialist SYSTEMA

Eyelit has said that SYSTEMA GmbH will now offer consulting services and product sales for Eyelit's manufacturing software suite of products across Europe as the demand for its products has increased in the region. SYSTEMA is already a trained Eyelit solution provider.

"In combining Eyelit's products suite and SYSTEMA's automation solution and integration capability, we believe we can provide the best solution in the industry and deliver real value to our customers," said Manfred Austen, SYSTEMA's CEO.

SYSTEMA provides manufacturing automation solutions and integration services on the levels of Equipment, MES and ERP including data collection and analysis solutions and is well known for implementing and integrating MES systems such as FAB300, Factoryworks, PROMIS MES and Worksteam and ERP systems such as SAP and Oracle EBS.

Product Briefings

Pfeiffer Vacuum

Pfeiffer Vacuum's 'HiPace' turbopump line expanded

Product Briefing Outline: Pfeiffer Vacuum has broadened its line of 'HiPace' turbopumps to include four new sizes. They are characterised by their high pumping speeds for both light (H_2, He) and heavy gases (Ar, CF_4), achieving high throughputs for heavy gases.

Problem: The new, integrated drive electronics reduce the need for cumbersome and costly cabling. Innovative materials have enabled Pfeiffer Vacuum to double the service life of the drive systems. Reduced run-up time for the HiPace pumps means that they are able to go into service faster.

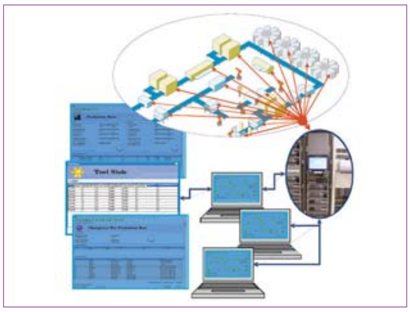
Solution: A variety of drive versions (including Profibus and DeviceNet) are available without any increase in physical size. Remote and sensor functionalities allow analysis of pump data such as temperature. Their functional aluminum housings make these pumps extremely light in weight. A sealing gas connection safeguards the bearings against particulate matter or reactive gases, affording optimum integration capabilities. The mature rotor design and precise sensory technology of the HiPace pumps provide a high level of safety.

Application: In addition to photovoltaics and semiconductor technology, the pumps' broad range of applications also includes coating architectural glass and eyeglass lenses, as well as employment in industrial applications, such as furnace engineering. Protection Class IP 54 and SEMI S2 assure their suitability for industrial applications.

Platform: HiPace stands for a complete line of compact yet powerful turbopumps featuring pumping speeds that range from 10 – 700 litres per second. The proven bearing system affords dependability. The improved rotor design makes for higher pumping speeds, higher backing pump compatibility and higher gas throughputs coupled with very good compression for light gases. Mean time to failure > 200,000 hours.

Availability: September 2008 onwards.

Applied Materials



Applied Materials' 'E3' process control suite targets 20% boost to overall equipment effectiveness

Product Briefing Outline: Applied Materials has introduced the 'Applied E3' advanced equipment and process control solution, intended to be a comprehensive factory automation (FA) software package for improving the productivity and reducing the costs of semiconductor, flat panel display and photovoltaic solar cell manufacturing. The modular packages utilize proprietary algorithms that are claimed to boost process capability by >30 percent, reduce unscheduled downtime, and shorten cycle time to achieve up to a 20 percent increase in overall equipment effectiveness.

Problem: Due to continued migration to higher levels of factory-wide automation that includes both software and hardware implementation, there becomes a need to constantly gain improvements in productivity, throughput and cycle-time to reduce overall manufacturing costs and improve efficiencies. This results in greater automation complexity, higher implementation costs and overall increase in operating/maintenance cost burdens, which is contrary to higher costs, contrary to manufacturing goals.

Solution: Using graphical development environment and pre-configured modules the Applied E3 solution is claimed to be quick to deploy and easy to update and extend, offering a faster and more cost-effective route to raise factory output. Equipment automation, data collection and logic handling simplify the construction, deployment, and maintenance of automated process control (APC) applications.

Applications: Semiconductor, flat panel display and photovoltaic solar cell manufacturing.

Platform: The Applied E3 system is part of a broad portfolio of manufacturing automation solutions and services designed to help companies improve their factories' productivity and reduce costs by managing, controlling and automating all aspects of their factory and tool operations.

Availability: July 2008 onwards.

Eyelit

Eyelit's MES is designed for fast ramp flexibility

Product Briefing Outline: The 'Eyelit Manufacturing' solution delivers a full-featured, technically-advanced manufacturing execution system (MES), asset management, product costing, plant-level connectivity hub, and a broad spectrum of other essential functionality. By giving clear insight into production process efficiency, performance/equipment efficiency, inventory control and resource management along with the ability to automatically react to conditions in any factory system, Eyelit Manufacturing suite enables customers to coordinate, control, and respond to changing demands in production.

Problem: Many solar manufacturers are finding that with rapid growth in the solar market, they are quickly outgrowing smaller point or home-grown manufacturing management solutions and find themselves having to invest further in existing systems or to reinvest in new software to allow scaling from pilot to high-volume production.

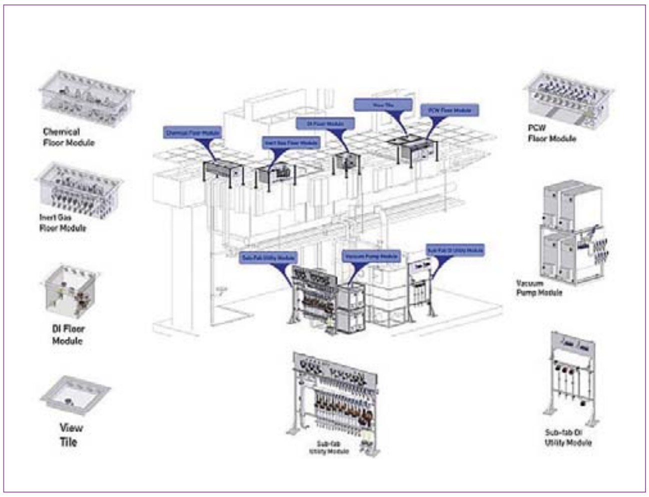
Solution: Eyelit say their solution enables solar start-ups to begin with a low-cost investment, yet provides the needed infrastructure to scale with Eyelit's broad set of functionality and copy-smart capability. Their products cover a broad set of manufacturing solutions, including Manufacturing Execution (MES), Asset Management (Semi E10), Factory Integration (Automation), Supply Chain Execution, Quality Management (CAPA/OCAP/SPC/APC), and Business Process Management. These are designed to allow customers to rapidly and cost-effectively optimize production and company processes.

Applications: Manufacturing management and factory control.

Platform: All Eyelit Manufacturing operations are managed using an advanced interactive interface that sets up in seconds, and allows users to configure logical representations of their production operations and any resources within it.

Availability: July 2008 onwards.

NEHP



NEHP offers solutions for rapid low-cost tool hook-up projects

Product Briefing Outline: NEHP has utilized return-on-investment modeling developed in-house to better assess the cost of installation of major tools using a modular approach versus traditional stick-built methods and the timeline for tool installation from Dock to Signoff. According to NEHP, its 3D or 2D P&ID pre-packaged modules have reduced costs by an estimated 14 – 49% (based on degree of modularity and tool complexity) and schedules by as much as 30 to 35% from start to finish.

Problem: Traditional tool installation methods utilizing onsite labor for orbital welding, fabrication and construction of tool installations is expensive and is difficult to complete prior to tool arrival on the fab floor. OEMs are working on methods for tool installation that allow some utilities to be brought to the tool prior to arrival, but these methods do not necessarily address the need to minimise installation cost per tool.

Solution: NEHP modules are manufactured offsite in a controlled environment and are designed to optimise installation cost by effectively bringing the breakout point of the utilities as close to the tool connection point as possible. In a consistent and repeatable way, these modules can be utilized on single tool installations or can be shared between tools allowing for maximum savings of fab floor and subfab space. Onsite facilities work becomes limited to point-to-point hook-up between the tool and sub-fab modules with existing fit-up utilities being brought to the tool efficiently. This minimizes the need for extensive home runs between laterals and the tool. Cost of labour is lowered by reducing activities normally accomplished onsite in a traditional stick-built method.

Applications: A full lineup of modules for gasses (inerts and toxics), process waters, chemicals and other system utilities are available for Applied Materials, Nikon, Tokyo Electron, Lam Research, Novellus, Hitachi High Tech and other OEM tools of all types for the fab owner. NEHP modules are compatible with all existing OEM facilitization solutions.

Platform: Process-level modules located integral to the floor system and sub-fab modules are prefabricated at NEHP to meet or exceed the demanding purity requirements required by OEMs. The sharing of modular utilities between like adjacent tools is also possible further reducing the cost of tool installation in any fab. Modules can be utilized in time-critical one-off installations and well as a consistent methodology across any new wafer fab.

Availability: June 2008 onwards.

A fully-integrated solar factory – requirements for achieving grid parity

Sylvère Leu, Conergy AG, Frankfurt, Germany

ABSTRACT

Each year, the photovoltaic market has been achieving a two-digit growth rate. The resulting economy-of-scale effects are not enough to achieve grid parity on their own. In order to reduce the production costs to grid parity level, new concepts and ideas must be realised as the basis for a photovoltaic factory. There are four main requirements that must be fulfilled in order to adhere to this cost reduction strategy: a highly integrated factory; automated and stable processes; a production control system (PCS) that provides the statistic data in order to continually optimise the processes; and an optimally-sized aligned production capacity.

Fully-integrated solar module factory

Conergy AG realised an innovative inline concept to produce photovoltaic modules in Frankfurt (Oder), paving the way for new photovoltaic factory concepts. By integrating the three value-creation stages of wafer, cell and module production under one roof, a modern and future-oriented concept as a requirement for grid parity was realised for the first time.

Inline processes enable high productivity. The required handling steps are reduced to a minimum, thus guaranteeing consistent quality and reducing the breakages of the brittle and very thin silicon waters. This is an advantageous feature of the process, given that the trend is towards ever-thinner wafers. While initially the wafers had a thickness of 800µm, now the values are below 200µm. Over the course of time, the format and size of the cells has also changed. The formerly typical 80mm round discs have been replaced by square forms of sizes such as 100x100mm^2, 125x125mm^2 up to 156x156mm^2. Solar cells of dimensions such as 210x210mm^2 are already available on the market.

The installed product lines in Frankfurt (Oder) are state-of-the-art and have a production capacity of between 50 and 65MWp. The individual production lines run parallel enabling a total factory capacity of up to 250MWp per year.

The silicon discs that are sawed in the wafer production are automatically transported to the directly adjacent cell production lines. An integrated transport system supplies the optimal wafer quality to the four cell lines. The finished solar cells then reach the floor below (see Figure 2) where the module production is located, and are allocated to one of the five production lines, according to demand. Inline testing, measuring and sorting units characterise each wafer, each solar cell and each solar module. Adequately dimensioned buffers ensure the constant supply of consistent quality to the production areas. A separate department for quality assurance and

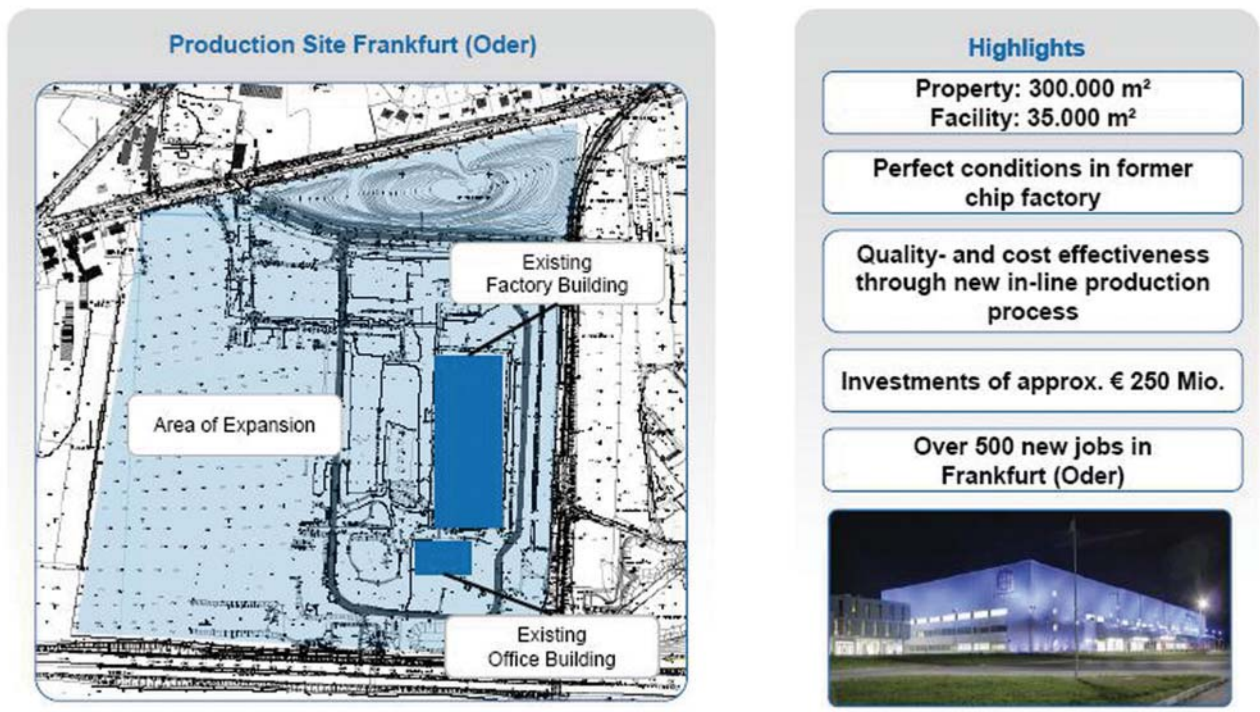


Figure 1. Conergy's Frankfurt (Oder) production site features.

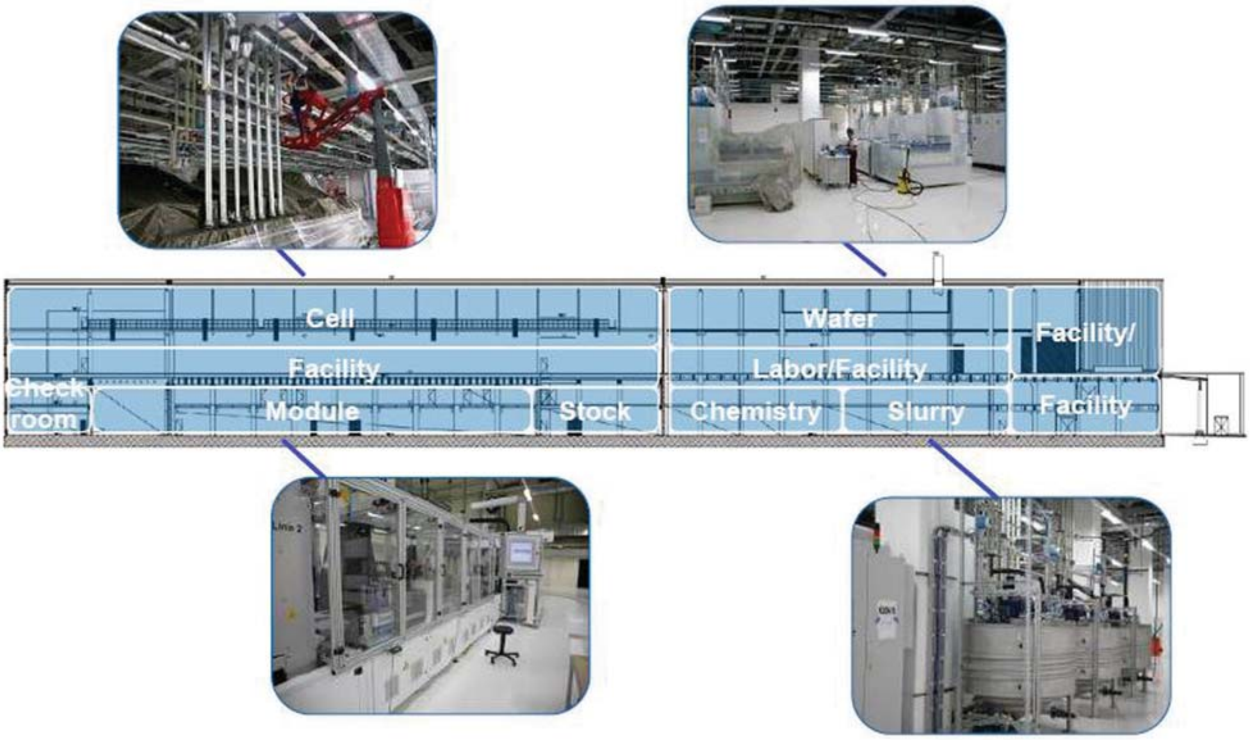


Figure 2. Dual-floor production layout.

analysis, equipped with climate chambers, flasher, cleanroom, electron microscope and further highly technological devices to produce solar cells and solar modules, makes it possible to recognise differences in quality and to advance the research and development directly at the production location.

Location and staff recommendations

On looking into the production areas of the solar module factory, it soon becomes clear that dark production halls with noisy machines are a thing of the past. Large window fronts let adequate light into the production areas, while high rooms give an airy feel to the employees working in the area. The material transport is almost completely automated and well organised. The facilities of central media delivery and removal with unavoidably loud generators, such as vacuum pumps, are located in separate areas or on an intermediate level.

The highly-integrated production of the facility reduces the interfaces along the value-creation chain of solar module production. In comparison to the benchmark, considerable productivity improvements are achievable in terms of logistics, construction volume, quality management expenses, and facility systems. The sorting of the wafers regarding TTV (Total Thickness Variation), sawing damages, thickness, etc. and the associated adaptation of the processes in the four cell production lines geared towards increasing efficiency can only be easily and effectively realised in an integrated factory. Process automation ensures guaranteed and

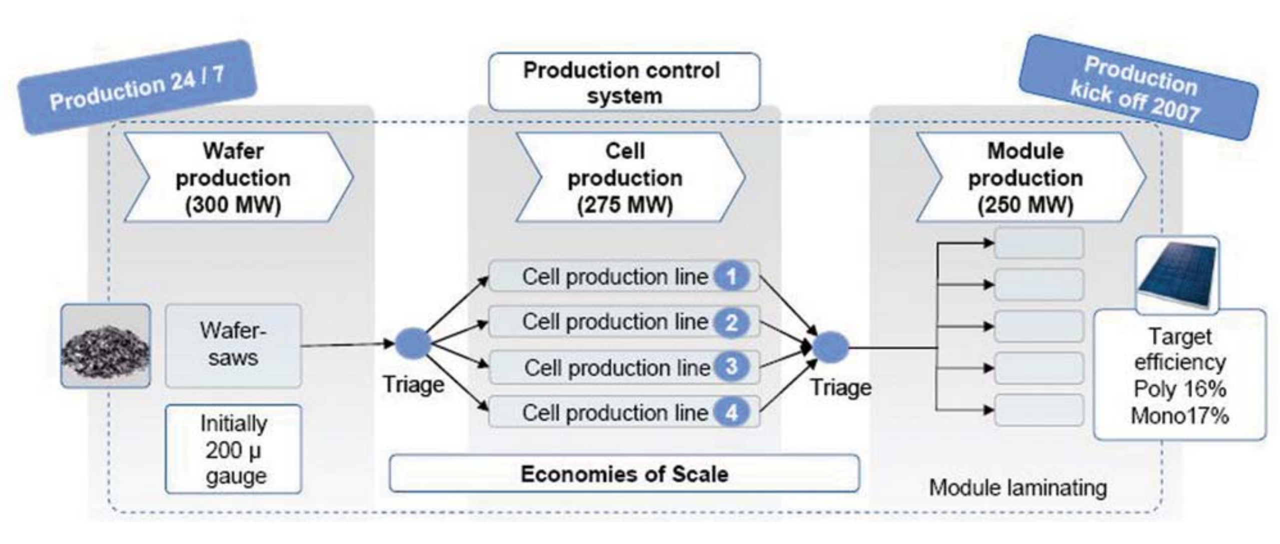


Figure 3. Production and process overview.

A workforce of up to 500 is employed in a four-shift system for the continuous production in Frankfurt (Oder), among them many skilled workers who operate and service the machines. The operators work at the machines in teams. Through in-company training, they can further their qualifications and thus become indispensable all-rounders. The operators are supported by trained technologists, and attend to the detail processes and use their expertise for production optimisation and research.

The high level of process automation drastically reduces the direct staffing costs and also the infrastructure costs per person. In Frankfurt (Oder), 200 employees work in module production. In comparison, in a semi-automated production facility, up to 1200 people are necessary. In addition to the obvious reduction of wage costs, lower staff costs also means a reduction of the indirect costs, e.g. for parking spaces, break rooms, work clothes, etc.

The inline concept

With its module production in Frankfurt (Oder), Conergy is combining an inline concept with a clustering principle. The inline concept guarantees a high flow rate; the integrated clustering principle enables a shift from the individual lines during the process and so creates the necessary flexibility to increase the run-up time. Moreover, sufficient capacity is available in the cell production to install further processes to increase the cell efficiency.

The installed production control system in Frankfurt (Oder) is based on wafer tracking (patent pending). Each ingot is marked so that the process history of the individually sawed wafers can also be recorded, enabling the location of each wafer – even in the finished module. This requirement creates the precondition for a permanent feedback process from the production over the analysis to R&D. This communication flow continually enhances expertise, makes it easier for employees to understand complex contexts and provides the motivation to constantly improve the production processes.

The cycle time of the factory in Frankfurt (Oder) is 20 seconds. Every 20 seconds a 220Wp module is produced, and this volume is such that it needs to be managed logistically. Logistical management of such a process also determines the optimal size of a factory. Extensive studies have shown that the optimal unit size of a wafer-based solar factory is approximately 250MWp. This is precisely what Conergy is realising in Frankfurt (Oder).

About the Author

Sylvère Leu was born and educated in Switzerland, and graduated from ETH Polytechnic in 1975 with a degree in Electronic Engineering. After joining BBC (ABB) in engineering nuclear power plants, he studied industrial design and business administration at the University of St.Gallen (HSG). He managed production processes at Hilti AG Principallity of Liechtenstein, and also worked as an associate lecturer at the University of HSG for several years in the field of industrial production. As a Swiss pioneer, Sylvère Leu started working in photovoltaics 18 years ago. He constructed the first industrial relevant laminator and sun simulator in his own company. In 2001 he sold his company to Conergy. As Managing Director, he was substantially involved in increasing profit and turnover of SunTechnics between 2001 and 2005. At the beginning of 2006 he was charged to build up an integrated 250MWp photovoltaic facility for Conergy AG, including wafer, cell and module manufacturing at Frankfurt (Oder).

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Site selection in the photovoltaic industry

Steffen Weiser, IBM Plant Location International, Belgium

ABSTRACT

Climate change, oil shortage, green energy, energy security – these are some of the global 'mega'-topics currently dominating the agenda in the news, in politics and in private lives. One of the industries that has most profited from the ever-growing consciousness about the need to de-carbonize current energy use is the photovoltaic industry.

With this economic background, the photovoltaic industry has experienced impressive growth rates in the last decade and is expected to grow at 30% per year over at least the next couple of years. Since its upswing, it has become a multi-billion dollar industry and subject to speculation on stock exchanges worldwide. At the beginning of the solar boom there was a shortage of available silicon to produce wafers and cells. One response of the industry was the quest and the use of alternative thin-film materials to produce solar cells. The reaction of the silicon supply industry was (and actually still is) the expansion of silicon production facilities, including specialized solar-grade silicon production facilities. Despite a much more relaxed outlook on the silicon supply-demand ratio, investments in solar silicon production facilities is predicted to amount to more than €4.0 billion by 2010. This is slowly reducing the supply gap, enabling photovoltaic producers to invest heavily in new production capacities.

Introduction

Electricity produced by means of photovoltaic energy devices is still much more expensive than that produced by traditional nuclear or fossil fuels. Hence, it will be vital for producers of photovoltaic devices to decrease the cost per KW of capacity produced. The industry is currently addressing this challenge by leveraging several dimensions of innovation:

1. **Product innovation** – e.g. using thinner wafers, more effective materials, etc.
2. **Process innovation** – e.g. energy consumption, automation, etc.
3. **Enterprise model innovation** – leveraging internal efficiencies, potentials or innovations of the production network and seeking locations with competitive cost advantages.

Site selection in emerging industries lacks any kind of benchmarks or standard procedures and project managers and consultants have been pioneers in this task. This article is meant to highlight the most important factors when doing site selection for PV manufacturing facilities.

As the various elements in the production chain are somewhat different, the article is split into three site selection approaches:

Process feature	SILICON PHOTOVOLTAICS VALUE-ADD STEPS: SILICON to WAFER	WAFER to CELL	CELL to MODULE
General technological level of production process	Medium – High	Medium to High	Low
Level of process automation	High or Medium to High	Medium to High	Low
Involvement of specialized workforce	Medium to High	High	Low
Involvement of manual labour	Low	Medium	High
Sensitivity towards energy cost	High	Medium	Medium – Low

Table 1. Process features and potential for value addition in silicon PV production.

- Wafer production (SILICON to WAFER)
- Cell manufacturing (WAFER to CELL)
- Module manufacturing (CELL to MODULE)

The site selection for each of the above listed steps is focussed on individual location requirements. In order to determine which of the location criteria are important and which are not, it is useful to have a look at the particular process features.

Table 1 clearly shows the two more technology-based steps are SILICON to WAFER and WAFER to CELL. The regional technological level and the availability of specialized workforce are prime factors when choosing the most suitable location. The CELL to MODULE production is clearly less technology-based. Site selection should focus on different criteria in this value-add step.

In cases where all production processes are being consolidated at one particular location each of the individual location requirements have to be taken into account in order to find an appropriate location for the investment.

In order to gain a general understanding of the different steps in site selection for manufacturing projects, the following section of this article illustrates the general site selection roadmap, while the third section focuses on the important criteria for site selection in the different value-add steps of the photovoltaic industry.

General process of site selection

Before selecting the preferred location for an investment, a clear and project-focused strategy is key for success in site selection. The globalization of recent decades has extensively broadened the freedom of choice when it comes to location for production facilities. Trade barriers have been diminished and IT enables knowledge and know-how to circulate around the globe practically without boundaries. This enables companies to become so-called globally integrated enterprises, ones that allocate resources for each different operational unit at its most convenient location.

Site selection in emerging industries lacks any kind of benchmarks or standard procedures and project managers and consultants have been pioneers in this task.

The task of selecting a preferred location can roughly be split into three steps:

1. Long-list identification through de-selection of less attractive locations
2. Selection of preferred location option(s) through assessment of short-listed locations
3. Site search, due diligence and simultaneous start of negotiations with preferred location options.

1. Long-list analysis

This first step is aimed at quickly reducing the initial list of potential location options to a manageable amount. Depending on the nature of the project, site selection processes can even start at a global geographical scope. By identifying and applying the main project drivers, this initial scope quickly narrows. These main project drivers are regularly translated into criteria that define minimum requirements that a location must fulfil in order to make it to the long-list of candidate locations. These criteria may include geography-driven factors like time zones, distances to other locations of the company, or distances to market or customer. Other

THE TROPICS: A NEW FRONTIER IN SOLAR ENERGY

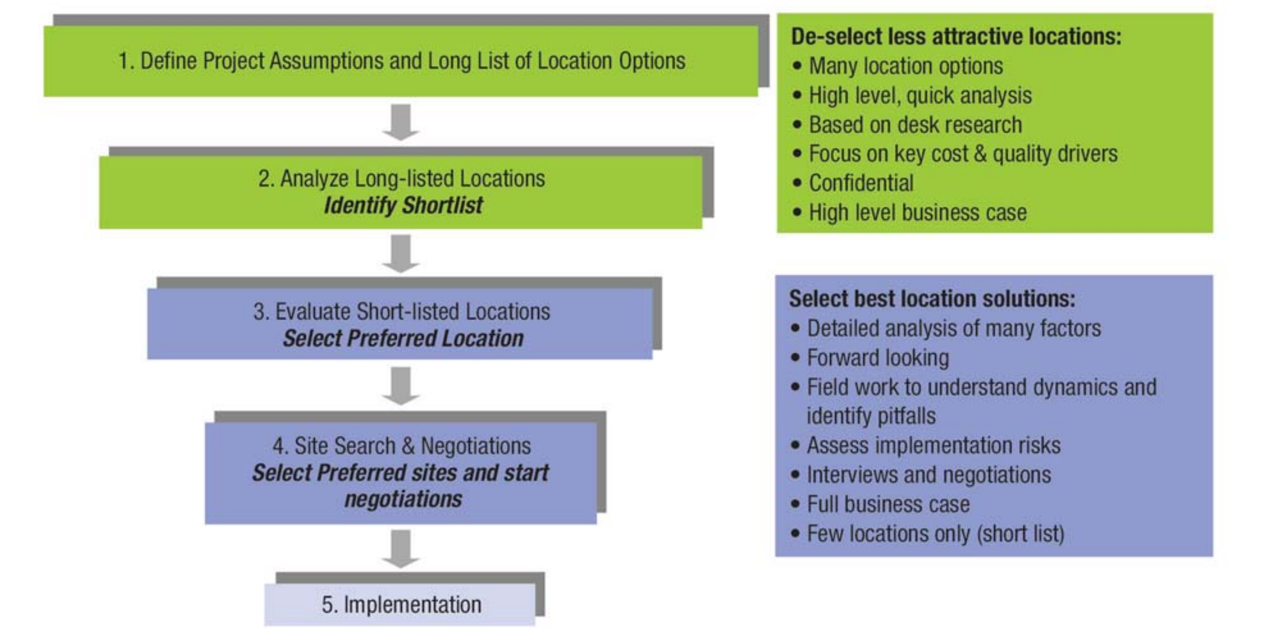
Presently, solar energy systems are mostly optimised for temperate climates. This means there is a critical need to develop and improve solar systems for tropical regions.

To address this need, we would like to invite proposals for solar energy research and development projects to be submitted for funding consideration under the S$50 million Singapore Clean Energy Research Programme (CERP). The topic of this call for proposals is:

Novel roof-mounted solar harvesting devices and systems for the tropical region

Visit www.cepo.sg for more information.
Applications (White Paper Stage) close on 20th October 2008.

An initiative by the Singapore Clean Energy Programme Office (CEPO)
Funded by the National Research Foundation (NRF)



Source: IMD World Competitiveness Yearbook 2008 (based on OECD data)

Figure 1. Stages and important factors involved in site selection.

factors often used to reduce the initial range of possible locations are technology-driven factors, general cost levels of a country/region, and factors describing the competitiveness of a location by assessing its general business environment.

For the photovoltaic industry, such long-listing criteria could include:

- Risk mitigation-driven criteria focusing on the general business environment, technological level of a region, ruling out countries or regions with less promotional business environments or less technological development;
- Purely cost-driven criteria focusing on countries with a general lower cost level; or
- Market-driven criteria focusing on current key or future growth markets (e.g. Germany vs. developing Asia).

The selection of broad elimination criteria is determined by the particular project and the growth strategy of the company.

Once a long-list has been identified, the locations are assessed via:

a **qualitative analysis** assessing all key non-financial factors, each weighted on their importance. Locations are being scored on each location factor and an overall weighted analysis identifies best quality candidate locations.

a **high-level financial analysis**, which focuses on key financial performance drivers showing the different cost levels of the locations assessed.

This analysis is carried out by the use of information provided by official sources from the long-listed locations, as well as information included in industry-specific literature and market studies. The most important financial factors also have to be researched and identified based on strategic, geographical, industry, and corporate context. The combination of the qualitative analysis and the high-level cost analysis are combined in so-called cost/quality-maps to identify locations that best meet the project requirements.

With the help of these kinds of charts, the relative value propositions of locations can quickly be identified and the locations for further in-depth location evaluation can be selected.

2. In-depth assessment of short-listed location options

The subsequent in-depth short-list location assessment is meant to further detail the facts and figures for the remaining options. It aims at the selection of preferred location option(s) and respective back-up options. This process regularly requires on-site meetings with stakeholders of different disciplines. In executing the in-depth field work, critical requirements, many of which are necessary data-points for the input into the business plans, are further evaluated. Usually, these kinds of prospective business plans are made for a fraction or even all of the short-listed cities, allowing comparison of the projected return of investment at the different locations regarded. The result of this phase of the location selection process will be the identification of the preferred location options.

3. Start of negotiations and implementation

Before the final location decision is done, many site selection project managers start negotiations simultaneously with several potential final location candidates. The main topics in these negotiations are subsidies and incentives, as well as other investment costs that can be influenced on the local level (e.g. land cost, waste water discharge cost, etc.).

Site selection for the value-add steps in silicon PV production

Solar wafer manufacturing

Using silicon as the prime input, solar wafer manufacturing is the first step in photovoltaic manufacturing. Solar-grade silicon is thermo-treated and transformed into ingots, and cut and sliced into thin wafers.

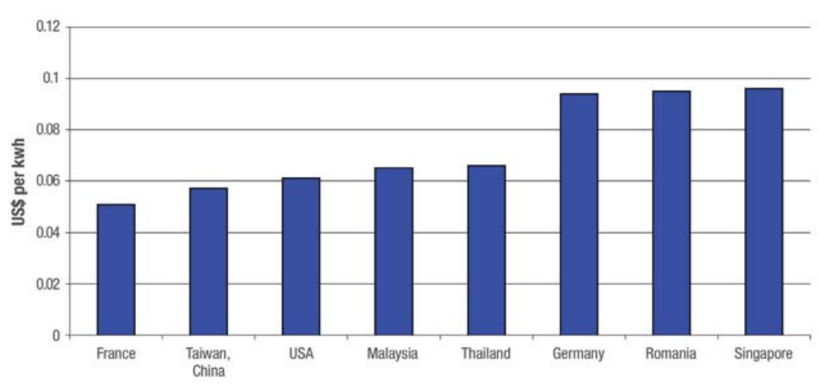


Figure 2. Sample of energy costs for industrial clients (generalised data from 2007).

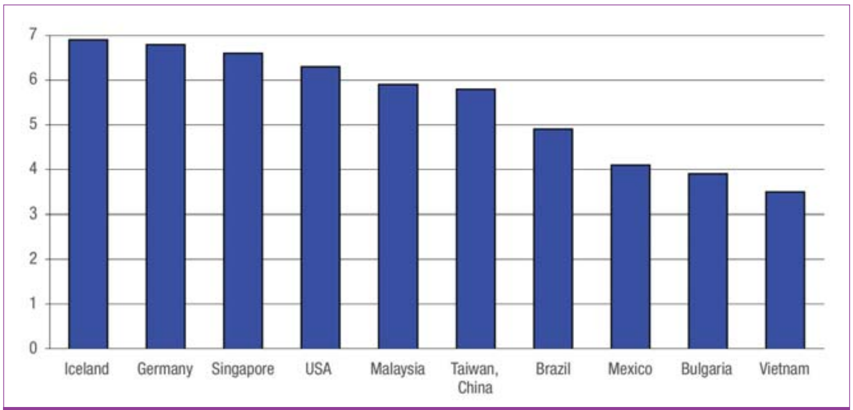


Figure 3. Geographical breakdown of quality of electricity supply indicating lack of interruptions and voltage fluctuations (from 1 to 7, where 7 indicates best quality of electricity supply).

Looking at the key human resources needed to operate and maintain this production step, the dependency on qualified technician and engineering skills becomes obvious. As this process includes thermal treatment as well as sawing and slicing using specialized machines, different engineering skills are needed. Process, mechanical, electrical, and chemical engineers as well as qualified maintenance technicians are needed to operate and maintain the highly specialized machinery. The recruitment of such experienced skills is usually much easier in highly developed countries and in countries where the industry is already present. In countries where photovoltaic technology is still not common, the key engineering staff must be brought in until local labour has been educated and trained to meet the industry's specific needs. Depending on the technological level and the focus of education institutions of the destination location, this state of play can last as long as several years. Also depending on the destination location, the levels of expatriate involvement can vary from operations management to the temporary employment of the whole engineering team until local labour is available. The availability of specialized key engineering skills has to be determined beforehand. A wrong assessment of the availability can have huge impacts on payroll, because expatriate involvement has considerable impact on payroll costs.

Handling of the ingots and wafers is a task that can either be manually controlled or can utilise automated handling and packaging processes. In general, manual and low-skilled labour is not crucial for this step in the value-add chain.

The majority of the processes used for silicon wafer production are still fairly energy-intensive, with the majority of plants requiring huge amounts of energy. In fact, energy makes up the bulk of annual operating expenses. Thus, local power costs play a key role for site selection in this value-add step. Publications that list prices in relation to power cost often tend to generalize or are geared towards a specific profile of industrial user. As Figure 2 shows, general levels of energy cost can vary substantially between countries. However, there are some aspects that can prove problematic when selecting a specific plot of land:

- Energy prices often vary considerably by region within a country (e.g. United States)
- Large industrial customers are often charged individual additional taxes, capacity fees, infrastructure and network fees that considerably change the basic rates per kW/h (e.g. Germany and several Asian countries).

Availability of specialized technician and engineering staff
Energy cost
Quality and reliability of technical infrastructure
Incentives
Vicinity of support industry (technical)

Table 2. Important criteria for site selection in solar wafer manufacturing (silicon to wafer).

Although the illustrations on energy prices in Figure 2 are generalized, they can be used to determine if electrical energy is comparably cheap or costly in a particular country and can therefore be used in the phase of long-list location assessment. A more detailed calculation of the energy bill – including all additional fees, taxes etc. – has to be created during the in-depth assessment of the short-listed location options.

As the CapEx for special machinery in the photovoltaic industry is quite high, subsidies and incentives often play an important role in lowering the investment cost.

As the CapEx for special machinery in the photovoltaic industry is quite high, subsidies and incentives often play an important role in lowering the investment cost. Many European governments are actually using cash grants to attract these kinds of projects, cash grants that can be as high as 50% of the eligible investment expenditures. In fact, these levels are only reached in the least developed regions of Europe, but levels of between 20 and 40% are still being reached by numerous regions in Eastern Europe and in the eastern part of Germany. In Asian countries subsidies in form of cash grants are rather unknown. Therefore, the practice of giving tax holidays up to a certain percentage of CapEx is widespread to attract such investments. Preferential depreciation terms are another instrument of investment stimulation, which is being applied in many Asian countries.

Due to the high dependency of the production process on specialized furnace, sawing and slicing machinery, having key support companies within easy reach is a further factor to be considered in the location of such investments.

The quality and reliability of electrical power supply is a valuable indicator of the general suitability of the energy infrastructure of a country. In countries where the risk of power interruptions is too high, soundly maintaining the production process can become a hard and costly task. Countries that show increased risk for power outages are therefore often sorted out using this indicator; however, when looking at the example of China with a huge amount of different regional economic compounds, the viability of this kind of indicator can be limited.

The limits of informative value of this indicator can be illustrated by taking the case of booming Shanghai. Albeit a region with power shortages, foreign companies in Shanghai are rarely subject to power shutdowns.

As previously stated, electricity cost is an important location factor for photovoltaic fabs as the energy bill can make up as much as 75% of the operating expenditures. Therefore, some regions are using electricity cost as an incentive. Heavily-reduced electricity rates are exclusively being offered to photovoltaic companies in order to attract investments in the sector.

Solar cell manufacturing

Site selection for a solar cell manufacturing facility has to balance cost effectiveness and a high level of technological capability, even more so than in the site selection for wafer manufacturing. Site selection for solar cell manufacturing has to find the right balance between cost, human resources availability and technical infrastructure reliability.

The engineering team required of this kind of facility consists of a broad bandwidth of disciplines (e.g. specialized process, chemical, electrical or quality engineers), and so the labour market has to be comprised accordingly. In many cases, when these facilities are located in less developed labour markets, engineers and technicians that have the right basic education and experience get hired and then receive extensive training focussed on the particular technology and tooling of the fab. In contrast to the on-the-job training engineers and technicians receive in developed countries, which tends to be relatively brief, this training can take more than a year in less developed countries. The cost of this training combined with traditionally higher turnover rates in the first years of a facility's existence have to be carefully considered in the business plan. Hiring of expatriate resources for key positions is a strategy that is often followed by investors investing in Asian countries. The bulk of Asian countries have tailored their immigration laws accordingly and the workforce is highly mobile. In most cases, the local Investment Promotion Agencies (IPAs) offer special guidance through the visa application processes.

Site selection for solar cell manufacturing has to find the right balance between cost, human resources availability and technical infrastructure reliability.

Depending on the production technology used, water and electricity are key inputs in this step of the photovoltaic value-add chain. Water has to be available in the right quantity and the right quality, as many processes require a certain level of water purity. This is especially relevant to countries and regions with weaknesses in their technical infrastructure. In regions with temporary or ongoing droughts, steady availability of sufficient water has to be assessed carefully. Parts of the production process (e.g. doping) require thermal treatment and are therefore sensitive to energy cost. As the transformation of wafers into solar cells includes treatment with several speciality chemicals, stringent and complex environmental laws often cause complicated, time-consuming and costly permitting procedures. A compatibility assessment of the specific production process with national and local environmental regulations can save the project from unnecessary delay or even cancellation. Local agencies prepared to help and facilitate investors through the procedure for environmental applications can be very helpful. Investment promotion

Technological level of local technician and engineering staff
Energy cost
Incentives
Level of complexity of environmental regulations
Dedicated science and university programmes
Vicinity of support industry (technical)

Table 3. Important criteria for site selection in solar wafer manufacturing (wafer to cell).

Availability of cheap manual labour
Market vicinity
Transport Infrastructure

Table 4. Important criteria for site selection in solar wafer manufacturing (cell to panel).

agencies, regional development agencies and local governments that have specialists dedicated to promoting the PV industry in their territory can therefore be seen as important assets in the implementation of a project.

Solar panel manufacturing

Solar panel manufacturing, as the last step in silicon PV manufacturing, is also the least technologically intensive. Most companies still assemble the cells manually to form panels using tailor-made frames and profiles that they receive through specialized suppliers. The lower technological level of this production step is one of the reasons why the first facilities that are aiming to supply markets in Germany and Spain have started to locate to low-cost locations in Eastern Europe. An example of such a scenario would be a big Japanese PV company investing in a panel production facility in the northwest of the Czech Republic, receiving cells from Japan, and supplying markets in western and southern Europe. The Czech Republic's EU membership (for taxation reasons – import of unfinished goods and finishing within the EU), low wage cost and the direct market vicinity to Germany would make the Czech Republic a location of choice in this instance.

The involvement of manual labour and the low technology level of this production step make the availability of cheap labour an important criterion in location selection for PV panel production. However, cost is not everything. Depending on the size and output of the facility, sound and stable logistics are becoming more important, guaranteeing stable supply and delivery of each of the production steps.

It is vital for the PV industry to further decrease the cost of the manufactured devices; choosing a location that offers the right trade-off between cost and quality is crucial.

It is vital for the PV industry to further decrease the cost of the manufactured devices; choosing a location that offers the right trade-off between cost and quality is crucial. Site selection in the PV industry, therefore, has to consider the different value propositions of developed and less developed regions. The big question in site selection for the PV industry is how to decrease cost through choice of location, while still being able to maintain technological standards. Each of the production steps has its own requirements and its own sensitivities. In order to avoid the many pitfalls in site selection, specialized knowledge is needed to evaluate cost, human resources, infrastructure, incentives and local IPA support. Thus, a company must be assured that the project team and its advisors have in-depth experience in locating these kinds of facilities.

About the Author

Steffen Weiser is senior strategy consultant with PLI Global Location Strategies, a global service offering within IBM Global Business Services, exclusively specialised in global location strategies. He has expertise in location selection, business and economic development projects and advises corporate clients in multiple technology sectors as well as economic development authorities worldwide for the development of corporate location and economic development strategies. Steffen Weiser received his diploma in economic geography from the University of Stuttgart, Germany.

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International Standards: a critical step towards reducing PV manufacturing cost

Bettina Weiss, PV Group (North America), SEMI, USA

ABSTRACT

Many readers will equate SEMI with the SEMICON trade shows around the world, business and technical conferences, EHS and advocacy initiatives and, most of all, industry standards. Currently, SEMI has close to 2,000 member companies, about 20% of which are active in the photovoltaic sector. These companies form a community called PV Group.

The mission of the PV Group is to serve the photovoltaic market with events, standards and services. Working with other industry groups throughout the world, SEMI is dedicated to advancing the growth and profitability of its members, and to achieve overall cost reduction to enable PV energy adoption worldwide.

We listen closely to our constituents' needs and are committed to developing unique approaches to unique problems. Connecting markets and industries that benefit from dialogue has been our mission for 38 years. Between former semiconductor professionals moving into PV, pure PV manufacturers and a startling number of start-ups, there is fertile ground for collective discussions in all regions of the world that are necessary to propel us forward.

SEMI International Standards Program

The SEMI International Standards Program, established in 1974, is celebrating its 35th anniversary this year. 35 years of continued growth in technology breadth, geography and people have led to close to 800 SEMI Standards and Safety Guidelines collectively developed by volunteer experts around the world for the continued improvement of equipment, materials and processes for a variety of industries.

What started with the historic agreement on a universal wafer diameter in semiconductor processing evolved over the years into a global, all-encompassing volunteer program of currently 1,800 individuals. The program has embraced new and emerging technologies in all corners of the planet, along with the people who populate the technical committees and task forces. The Standards Program has been the foundation and launching pad for the innovative spirits needed to tackle new manufacturing challenges and new business opportunities. It is vital to a sustainable global supply-chain and market community.

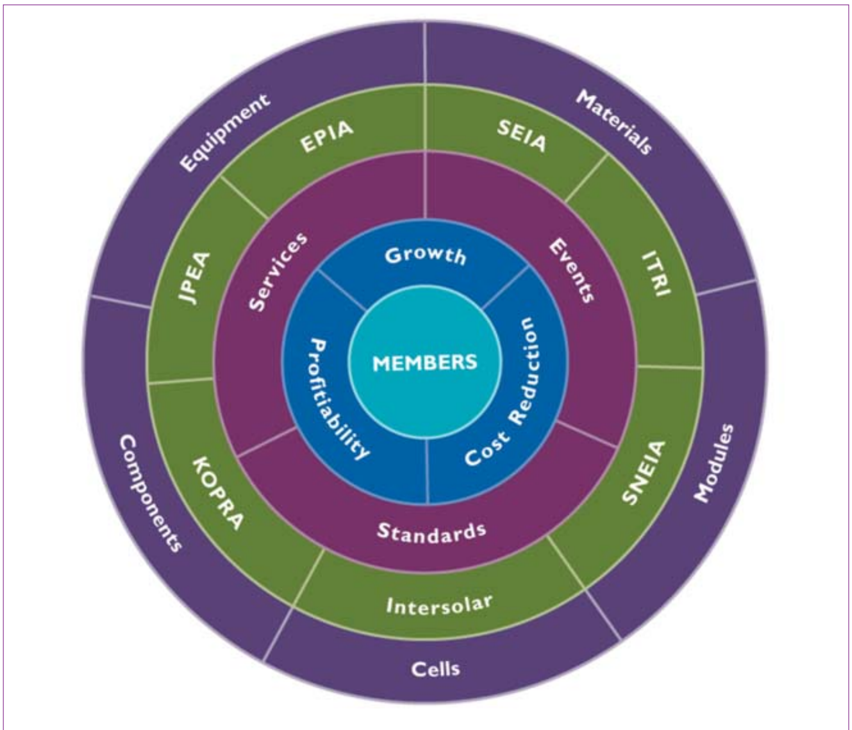

Figure 1. SEMI's PV Group constituent parts, members, focus and aims.

Determining where standards can strengthen weak links, open borders and create a global understanding and acceptance of PV manufacturing challenges is difficult but possible if stakeholders work together.

Why PV standards?

PV standards are urgently needed in the industry. Representatives of our member companies – as well as their customers – have remarked on the fact that they experience a lack of agreement on basic parameters, that materials specifications and test methods vary and that industry stakeholders are worried about giving up their intellectual property for the collective good with no gain for themselves. The long answer to the question of why PV standards are so urgently required is more complex. For starters, it is not entirely obvious where consensus standards are needed, and when. Pain points, such as cost, waste, time-to-market and environmental concerns, could clearly be addressed by standardized approaches but lack the collective industry voice to move forward. Secondly, several standards-developing organizations (SDOs) are active and could, potentially, create more confusion and delays. And thirdly, there are the complexities that come with a global market and a global supply chain. Determining where standards can strengthen weak links, open borders and create a global understanding and acceptance of PV manufacturing challenges is difficult but possible if stakeholders work together with common objectives, determination and a collaborative spirit.

PV standards efforts in SEMI

As soon as SEMI member companies began expanding into the photovoltaic space, and SEMI began developing supporting products and services to ease the transition, 'Standards' was the first key word that entered the equation. At the first informal Photovoltaic Standards meeting in September 2006, executives from the PV industry discussed where SEMI could most positively influence and contribute to the growth of the PV industry. Standards at the manufacturing equipment and materials level were identified as both missing and absolutely critical in order to lower trade barriers and reduce cost of ownership for cell and module manufacturers.

Within a year (2007), both Europe (with support and endorsement from EPIA, the European Photovoltaic Industry Association) and North America established formal PV Standards Committees and jointly produced the following global committee charter:

> Explore, evaluate, discuss, and create consensus-based standard measurement methods, specifications, guidelines, and practices that, through voluntary compliance, will promote mutual understanding and improved communication between users and suppliers of photovoltaic manufacturing equipment, materials and services to enhance the manufacturing efficiency and capability so as to reduce manufacturing cost of the photovoltaic (PV) industry.

While there is agreement on the overall scope (and limitations) of work to be done, Europe and North America started their efforts in different areas. In the spirit of developing standards 'by the industry, for the industry,' the first working group to be established under the North American PV Standards Committee was the Analytical Test Methods Task Force, led by Evans Analytical Group. This task force has developed a draft document titled *Test Method for the Measurement of Elemental Impurity Concentrations in PV Silicon Feedstock by Glow Discharge Mass Spectrometry*.

Ongoing standardization work is a step towards the future, but it may not beat the speed of innovation and growth we currently see.

The ballot failed technical review and will be re-balloted with revisions based on the feedback received, which will naturally make it a better standard in the end. This is one of the biggest benefits of a global Standards development process, as even if a company does not participate actively in a task force or committee, it will have the opportunity to review and comment on the drafts prior to approval and publication, ensuring that additional perspectives and obstacles are being addressed that may have been missed during the first round. And with seven ballot cycles per year, the volunteer experts in the SEMI Standards Program do not have to sacrifice quality for speed.

The second North American PV Standards Task Force, led by Mark Frederick of Entegris, is currently drafting a *Specification on 150mm, 156mm, and 200mm wafer and cell transfer carriers for use in PV manufacturing*, which will be distributed as a technical ballot later in the year.

The results of a third ballot, *Revision to SEMI M6-0707 Specification for Silicon Wafers for Use as Photovoltaic Solar Cells,* were reviewed at the North American PV Standards Committee meeting, where the document was approved for publication. This particular document now includes the 156mm x 156mm wafer specification, which is widely used in the PV industry.

In Europe, on the other hand, an at times heated debate over equipment interfaces appears to have just been resolved. The PV Equipment Interface Specification Task Force (PV- EIS TF), chaired by SolarWorld and Manz Automation, worked through a challenging time of discussions around the issue of whether or not SECS/GEM will be the present and future interface in PV manufacturing, and the answer is a resounding 'yes', especially since major cell manufacturers have supported this choice, which in turn should come as a relief to equipment vendors. The task force issued a draft of its *Guide for PC Equipment Communication Interfaces* as an information ballot during PVSEC in Valencia, Spain in early September. This document referenced existing semiconductor standards that are applicable to PV manufacturing with only minor modifications.

Other regions are coming up to speed very quickly. Taiwan, for example, assembled a SEMI PV Standards Working Group within a very short period of time, with the aim of becoming a formal regional committee in the near future. Chaired jointly by Chroma, Delsolar, PVTC/ITRI and UL Taiwan, the working group aims at investigating standards opportunities in the following areas, and has already established subgroups on all of these issues:

- Si feedstock
- Cell performance
- System performance
- Module performance
- Equipment interfaces (liaison with EU PV-EIS TF).

SEMI Global PV Standards Roadmap

Ongoing standardization work is a step towards the future, but it may not beat the speed of innovation and growth we currently see. In order to provide both a truly global platform for solar standardization as well as an outlook of future requirements that will impact today's design, manufacturing processes and end products, SEMI is spearheading a Global PV Standards Roadmap project. A core team of equipment and materials suppliers, cell and module makers, academia and other interests was established in May 2009. After two teleconferences, core team members met at SEMICON West 2008 to begin development of a Roadmap Project Plan which will define the purpose and scope of the Roadmap, the timeline it will cover, and of course the individual elements it will address, such as materials, process equipment, environmental, health and safety considerations, facilities aspects, critical cell and module issues and drill down into areas where a standardized approach will help mitigate risks, reduce costs, improve time-to-market and cost of ownership. Completion of the Project Plan is tentatively scheduled for December 2008.

The photovoltaics industry is supported by a global supply chain, which will benefit by and prosper through the availability of collectively-developed, globally-applicable and accepted standards and guidelines, which is critical for its continued growth and vitality.

Phase 2 of the Roadmap project is designed to be a broad, global industry effort to develop substantive, consensus-driven content to the individual Roadmap elements. Supported by a strong SEMI marketing and communications plan, SEMI and the core team will disseminate regular updates about Roadmap development, recruit experts to aid in the effort and communicate the results to a broad audience on a regular basis. Phase 2 is currently projected to be concluded by the end of 2009, or earlier if possible. Core team members agree that this document has to be made available to the industry as soon as possible and is working with a sense of urgency and speed to make it happen.

Phase 3, the actual development of Standards to address the needs and requirements identified in the Roadmap, is envisioned to overlap with Phase 2, and we expect many volunteer experts to be active in defining the requirements as well as aiding in the document development process.

Partnerships and strategic alliances

While these activities and initial results are very encouraging, we realize that no organization can do all the work that needs to be done single-handedly. For several decades, SEMI has partnered with other Standards Developing Organizations (SDOs), institutes and associations to engage not only SEMI member companies and their customers, but also any community that is impacted by the results a published standard offers.

This is not only true for standardization, but for many other related areas as well, such as EH&S, sustainability and environmental stewardship activities, which will require close collaboration among participating countries, in particular with respect to new regulatory and compliance legislation. This will likely impact the development of related PV Safety Guidelines to address unique challenges in the areas of hazardous materials, waste management, raw material supply, etc.

The photovoltaics industry is supported by a global supply chain, which will benefit by and prosper through the availability of collectively-developed, globally-applicable and accepted standards and guidelines, which is critical for its continued growth and vitality.

About the Author

Bettina Weiss has been working with SEMI for 12 years. She joined the SEMI Europe office in Brussels, Belgium in 1996 as Standards Coordinator and transferred to SEMI Headquarters in spring of 1997 where she worked in several Standards-related positions. From November 2003 to March 2008, she served as Director, International Standards as chief staff of the SEMI International Standards Program.

Since April 1, 2008, she has held responsibility for all initiatives and activities in SEMI's photovoltaic segment in North America, with continued global responsibility for PV standardization efforts as well as successful execution of the PV Standards Roadmap project. Prior to joining SEMI, Bettina worked in marketing and sales positions at Metron Technology and Varian Semiconductors in Munich, Germany.

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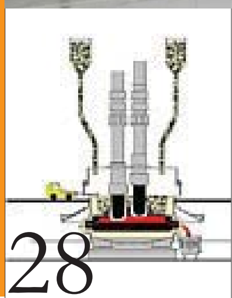

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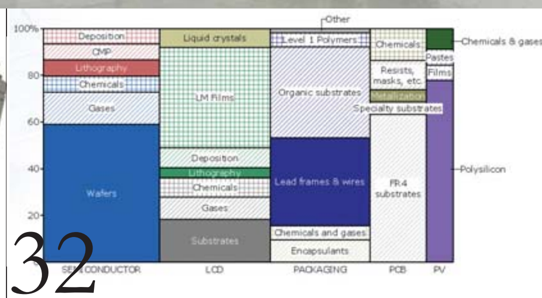

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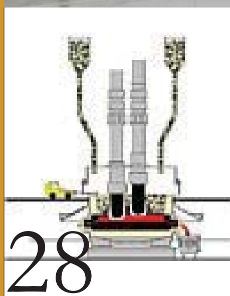

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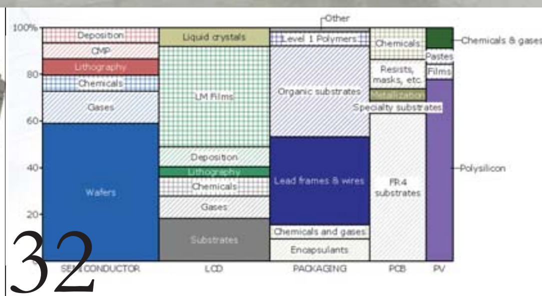

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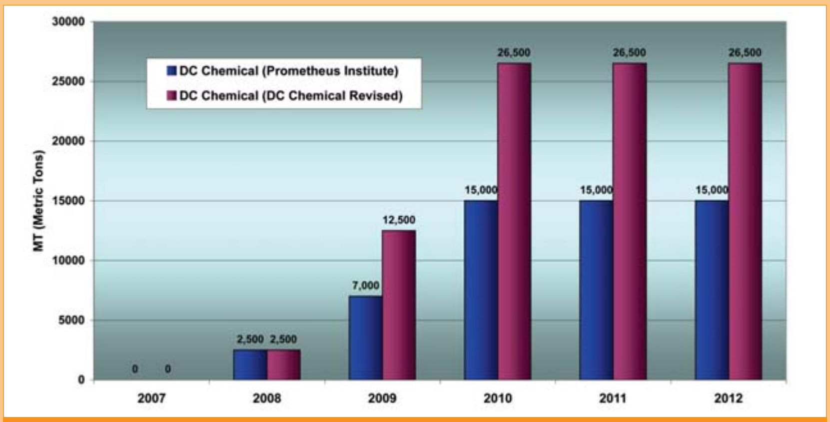
DC Chemical to expand polysilicon production by 11,500MT

DC Chemical's Board of Directors has approved plans to expand the company's polysilicon manufacturing facilities. The move will see the expansion of the existing No. 1 and No. 2 facilities at an estimated cost of 260 billion South Korean won (just under US$250 million), and the construction of a new 10,000MT plant at its Gunsan site at an estimated cost of 880 billion won (approximately US$840 million).

With this expansion, DC Chemical would move up the ranks to become the world's second largest polysilicon producer, with an annual polysilicon output of 26,500MT per annum by 2010. The company has also said that it is currently discussing further long-term arrangements for the capacity of the No. 3 plant. Construction on the new 10,000MT site (No. 3) was due to begin in July 2008, with an expected completion date of December 2009.



DC Chemical polysilicon production ramp.

Polysilicon News Focus

Centrotherm photovoltaics wins new polysilicon reactor order

A Ukrainian company has placed an order with centrotherm photovoltaics AG for the supply of multiple reactors and converters for the production of around 2,500 tonnes of polysilicon. The deal also encompasses engineering services for the construction of the polysilicon plant that will also include centrotherm photovoltaics' new vent gas recovery system. The new polysilicon plant will be constructed in the southeast of the Ukraine with the equipment expected to be delivered in the autumn of 2009.

Start-up plans polysilicon plant in Italy

An Italian start-up, Estelux, has given a contract to Jacobs Engineering Group, Inc. to oversee the construction of its first polysilicon production facility to be built on an existing petrochemical site in Ferrara, Italy. SOLON Group was said to be an owner of shares in Estelux.

The plant is expected to cost approximately €360 million and produce 4,000 tonnes of polysilion per year with full capacity expected to be reached in 2010. The polysilicon plant will use the 'Siemens process' and have two production buildings employing a closed loop process.

Photon Consulting starts solar grade silicon price index

In an effort to provide greater transparency to the photovoltaics manufacturing industry, PHOTON Consulting has launched a paid subscription-based service, tracking high-purity silicon prices, both spot and contract, dubbed the PHOTON Consulting Silicon Price Index (PCSPI).

"Rising prices, increasing price spreads and quality variation, rapid volume growth and new sales dynamics have created significant uncertainty for companies selling silicon, users purchasing silicon and investors in silicon production," noted PHOTON Consulting Head of Silicon Research, Hilary Flynn. "We wanted to create a mechanism – a trustworthy reference service – to address this market need. The PCSPI represents a critical first step to real-time spot and contract pricing in the future and we are thrilled to be an agent for change by helping to increase pricing visibility in the silicon producer/consumer/investor universe."

Prime Solar starts design of 5,000MT polysilicon plant in Leipzig, Germany

Polysilicon and multicrystalline wafer manufacturing start-up, Prime Solar, headquartered in Perth, Australia has selected CDI Corp to undertake detailed engineering design work for the construction of a polysilicon manufacturing facility near Leipzig, Germany. The contract was signed with CDI Engineering Solutions, a division of CDI Corp.

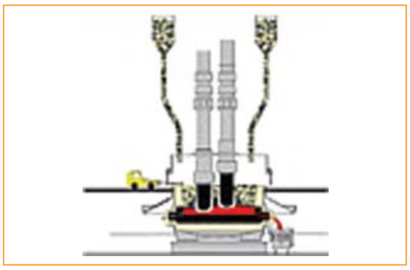
The initial plan is for a polysilicon plant with a capacity of 5,000 metric tonnes per year that will feed Prime Solar's second business unit producing 600MW of multicrystalline wafers, from the second quarter of 2010. Phase II is planned to boost polysilicon supply to 10,000 metric tonnes per annum in 2011-2012.

UMG Silicon News Focus

Q-Cells confirms BSI/Timminco UMG silicon supply extension

Q-Cells has confirmed that it has extended the solar grade silicon supply deal with Bécancour Silicon, Inc. (BSI), a wholly-owned subsidiary of Timminco, which was originally signed in March 2008.

The extension means that Q-Cells will receive 6,000 metric tonnes of silicon per year between 2010 and 2013. The original deal was for 410 metric tonnes in 2008 and 3,000 metric tonnes in 2009 at fixed prices.



CaliSolar signs 1,700MT UMG Si purchase agreement with Bécancour Silicon

Silicon Valley start-up CaliSolar, which has an exclusive patent and several pending on the purification of Upgraded Metallurgical Silicon (UMG Si), has signed a purchase agreement with Bécancour Silicon, Inc. for 1,700 metric tonnes (MT) through December 2012, with initial shipments starting in the third quarter of 2008. CaliSolar will use unblended UMG to produce multicrystalline ingots and solar cells.

CaliSolar has an exclusive patent license from UC Berkeley and eight patent applications related to improvements in ingot yields and overall UMG material quality improvements.

Wafer News Focus

MEMC signs US$3 billion solar wafer supply agreement with Tainergy

MEMC Electronic Materials, Inc. has announced the signing of an agreement for the supply of solar wafers to the value of over $3 billion to Tainergy Tech Co., Ltd., a Taiwan-based solar cell manufacturer. The agreement, which will see MEMC provide Tainergy with solar wafers for the next 10 years, will commence in the third quarter of 2008.

LDK targets 3.2GW solar wafer production in 2010

LDK Solar has signed a major exclusive contract with China-based JYT Corporation for its 800KG capacity multicrystalline ingot furnaces, which is expected to enable LDK to reach a capacity of 3.2GW of wafer production in 2010.

After an extensive evaluation of JYT's large capacity furnaces, LDK said that the furnaces would contribute to a reduction in energy consumption and capital expenditures that will see an overall reduction in operating costs. Furnace deliveries are expected to start in 2008 and run through 2010. LDK said that it has an exclusive deal for JYT's 800KG furnaces through 2010.

PV Crystalox Solar to supply Suntech with 260MW of silicon wafers

PV Crystalox Solar is to supply Suntech with 260MW of silicon wafers from 2008 to 2013 at predetermined prices and volumes. This is the first supply deal Suntech has made with PV Crystalox. PV Crystalox is currently building a new 1,800MT solar grade polysilicon production facility in Germany.

LDK Solar signs 10-year 400MW wafer supply contract with Photovoltech

LDK Solar Co., Ltd. has signed a 400MW multicrystalline solar wafer supply contract with Photovoltech. The 10-year agreement, which will commence in 2009, will see Photovoltech pay a down payment of the undisclosed cost of the contract value to LDK Solar.

Canadian Solar signs 10-year 800MW wafer supply contract with LDK Solar

LDK Solar has signed an agreement with Canadian Solar, Inc. (CSI) to supply the solar module manufacturer with 800MW of solar wafers over a 10-year period. The agreement is in addition to the three-year wafer supply contract signed between the two companies in late 2007.

Delivery of the first batch of wafers is expected to begin in July 2009 with a shipment of 40MW, and an annual shipment of 80MW thereafter until 2018. The agreement will bring Canadian Solar closer to securing its total materials supply for its planned 500-550MW module output for 2009. Combining both agreements between the two companies, LDK will provide CSI with 120MW of wafers in 2009 and 170MW in 2010.

Silane News Focus

Linde and Schmid to collaborate on silane production at new Dresden plant

In an attempt to meet the increasing demand for high-purity silane gas in the PV industry, the Linde Group and Schmid Silicon Pilot Production have decided to collaborate on silane production via the joint ownership of a new facility in Dresden, Germany. The silane produced at this facility will contribute towards the current capacity for Linde's customers and will be based on the new Schmid Monosilane Technology process.

"Demand for high purity silane gas for electronics industry applications is growing rapidly, especially for the new thin-film photovoltaic (PV) market," said Graham Hodgson, Director of Linde's Silane Program.

News

The plant, which is currently under construction in Schwarze Pumpe near Dresden, will be owned and operated by Schmid for a capacity of up to 540 tonnes per year, while Linde will then take over ownership and operation for production of an initial capacity of 300 tonnes.

REC ASA enters several silane supply deals worth close to US$1 billion

REC ASA has entered into several long-term supply contracts with major gas distributors worth a total of NOK 5 billion (~$984 million). The contracts will see REC deliver the monosilane gas through 2014 under a pre-determined pricing agreement. REC has said that these most recent deals will account for the majority of its silane production for 2009, and a smaller but significant proportion of its capacity from 2010-2014. The companies involved in the contracts were not named.

Linde enters long-term silane supply agreement with Sodiff

Linde has signed a long-term contract with Sodiff Advanced Materials for the supply of electronic-grade silane. The agreement, the duration and cost of which were not specified in the announcement, will see the delivery of the silane from Sodiff's facility at Youngju, Korea, which comes on line in the second half of 2009. This contract will account for a large proportion of Sodiff's 2,000-tonne silane production output.

Other News

Morgan Technical Ceramics to supply Oerlikon Solar with ceramic bars

Morgan Technical Ceramics (MTC) has been selected by Oerlikon Solar to provide high-purity alumina ceramic bars for use in solar panel thin-film deposition processes. The bars, which will be used for lifting and stacking glass panels in Oerlikon's thin-film deposition machines, are ideal for the process as they can withstand the high temperatures necessary to the procedure.

The use of high-grade alumina in the semiconductor industry has proven its suitability to application to the thin-film PV deposition process, in that it is inert, and as a result does not react with other gases involved in the manufacturing process, and it is thermally stable, capable of withstanding the high temperatures involved in the process.

"The manufacturing challenge is to produce a consistent flatness and parallelism over the 1.2m length of the bar," said Yannick Galais, Commercial Manager, MTC Rugby. "We have the capability to achieve flatness of less than 0.01mm and parallelism of less than 0.05mm, with a mirror polish finish."

Voltaix to supply germane gas for XsunX's thin-film lines

Voltaix, LLC, a specialty high-purity gas supplier, has been selected by XsunX to supply manufacturing quantities of its germane gas, used in XsunX's tandem solar cells. XsunX is currently refurbishing an existing 90,000 sq. ft. building in Oregon to start volume production of its thin-film solar modules.

"The use of germane allows XsunX to improve the efficiencies of our tandem solar cell design and we are very pleased to be working with Voltaix, a recognized leader in the production of germane gases," stated Mr. Tom Djokovich, CEO for XsunX. "As with the balance of our preferred vendors for various components and materials necessary for our TFPV manufacturing system we've found Voltaix's experience and knowledge very helpful as we progress with the build-out of our thin film photovoltaic solar manufacturing facility," concluded Djokovich.

Valspar introduces its enhanced solar reflective paint

The Valspar Corporation has launched Flurospar, its range of enhanced solar reflective paint for aluminum extrusion and wall panels. The coating, which is designed to lower room temperatures of solar facilities, decreases the amount of energy required to cool components, thus cutting costs for facility operators.

Solar-reflective pigments are used in the coating, which, it is claimed, keep building components cooler than do bare or anodized aluminium. Free from cadmium or lead-based pigments, the Flurospar coatings can be sprayed on and require minimal touching-up, according to Valspar.

"The new Flurospar SR coatings line is an example of Valspar's ongoing commitment to manufacture energy saving, environmentally friendly paint coatings and the role that technology can play in meeting the needs of the green building market," said Mary Ann Johnson, Marketing Manager for the Valspar Coil and Extrusion Coatings Group.

BioSolar partners with Rowland Technologies for 'BioBacksheet' production

BioSolar has said that Connecticut-based Rowland Technologies, a manufacturer of plastic film and sheet, has been selected to be BioSolar's production partner for its bio-based materials from renewable plant sources.

"After an exhaustive selection process it was evident that Rowland Technologies was uniquely positioned to meet our requirements," said Dr. David Lee, BioSolar's CEO. "Specifically, Rowland Technologies' expertise in sophisticated extrusion manufacturing and their highly-regarded custom manufacturing capabilities, coupled with our shared commitment to being both environmentally aware and yet economically feasible, allowed us to achieve the common goal of delivering the highest quality product to our customers."

BioSolar is expecting production volumes to begin in the second half of 2008. Samples of its backsheet material are already available.

DuPont to double PV thick-film metallization paste production

With plans to boost its sales into the photovoltaic market to over US$1 billion in sales in the next five years from approximately US$300 million currently, DuPont has said that it will more than double its production capacity of thick-film metallization pastes at its Electronic Materials DuPont Dongguan Ltd. (EMDD) facility in China.

"The PV industry is in the midst of a substantial surge globally, and demand for solar as a renewable energy source will continue to increase," said Timothy P. McCann, Vice President and General Manager, DuPont Electronic Technologies. "We are expanding Solamet production to support increased demand. Through future development, we will accelerate our ability to deliver innovations that will further drive down PV system costs and improve the lifetime and performance of solar modules. As a leading global materials supplier to the photovoltaic industry, we are using our science to make the use of renewable energy easier for everyone."

DuPont's 'Solamet' product range of thick-film metallization pastes are used for front- and back-side metallization of solar cells.

Umicore to double germanium substrate production

Umicore is to double the production of germanium substrates used for high-efficiency solar cells with the construction of a new manufacturing facility in Quapaw, Oklahoma, U.S.A. Construction is expected to start in July 2008, and to be completed in the spring of 2010, allowing Umicore to achieve a company total wafer run rate of 900,000 per annum when fully ramped.

Umicore said that the doubling in capacity was required due to the expected rapid growth of the terrestrial concentrator photovoltaic market, especially in North America. The company cited a concentrator market projection of 6GW demand by 2020 that would require approximately 10 million germanium wafers.

Product Briefings

MTI Instruments

MTI Instruments launches its PV1000 thickness measurement system

Product Briefing Outline: MTI Instruments has introduced the PV1000, a thickness measurement system for the solar cell production industry. PV1000 can be incorporated into solar cell production lines to help them quickly determine quality control issues, saving manufacturers time and money.

Problem: PV1000 addresses a critical need for solar cell manufacturers around the world who are now experiencing significant growth and need to manufacture higher quantities of solar cells for mass consumption.

Solution: Using MTII's exclusive Push/Pull capacitance probe technology, each PV-1000 module provides up to three pairs of probes for measurement of maximum, minimum and average thickness, as well as total thickness variation (TTV) and wafer bow. For applications requiring additional thickness channels, multiple PV-1000 modules can be chained together for unlimited line scans on the wafer. Wafer saw mark detection and classification is accomplished by adding optional laser sensors to the PV-1000 module. Utilizing up to two of MTII's Microtrak – SA standalone laser heads, saw marks can be classified for orientation and depth simultaneously with wafer thickness scanning making the PV-1000 ideal for incoming wafer characterization and sorting.

Applications: Wafer type: mono- or poly-crystalline silicon. Surfaces: as-cut, lapped, etched, SiN layer.

Platform: Each PV-1000 module comes with a complete software package for easy integration into an existing production line. Their Windows-based interface package allows for quick set-up, calibration and data monitoring at the module or across the Ethernet network. Multiple PV-1000 modules can be monitored from a single location using standard TCP/IP protocols.

Availability: July 2008 onwards.

HORIBA Jobin Yvon

HORIBA Jobin Yvon extends low cost ellipsometry tool capabilities

Product Briefing Outline: HORIBA Jobin Yvon has extended the capability of the UVISEL with a new independent Reflectometry Module (RM) that can be mounted on the UVISEL goniometer. The UVISEL+ RM is designed as a low-cost system which is available either as an option or as an upgrade for all current models of the VISible and NIR UVISEL Spectroscopic Ellipsometers as the module is simply connected to the Xenon lamp and monochromator of the UVISEL via two optical fibres.

Problem: Ellipsometry is a very versatile technology that has applications in many different fields. This very sensitive measurement technique provides unequalled low-cost capabilities for thin-film metrology, and has the advantage that it is non-destructive as it uses polarized light to probe the dielectric properties of a sample.

Solution: The RM allows Reflectance measurements at normal incidence over the wavelength range 210nm – 2100nm with a 200µm measurement spot. Via the integration of ellipsometry and reflectometry, the UVISEL+ RM enables flexible and accurate measurements of thickness of single and multiple layer films ranging from 1Å to 30µm; optical properties (n, k, α) of materials; direct spectroscopic measurement of sample reflectance; and precise description of thin-film stacks for interfaces, roughness, inhomogeneities. The UVISEL+ RM is simple to operate using the DeltaPsi2 acquisition system and benefits from the large materials database and powerful analysis features of the software. For difficult applications it is possible to bind both ellipsometry and reflectometry measurement for the analysis of a sample.

Applications: Wafer thickness measurements ranging from a few angstroms to tens of microns for single layers or complex multilayer stacks.

Platform: The XY motorized stage provides automated stage movement for sample mapping.

Availability: July 2008 onwards.

Sputtering Materials

Sputtering Materials offers higher material utilization in thin film deposition

Product Briefing Outline: Sputtering Materials, Inc. is now offering high-density casted CIG (CuInGa) targets for thin-film deposition in rotatable and planar form factors for thin-film solar production. The casted targets offer high density (99%+) material that enable technicians greater control and better material utilization in thin-film deposition, physical vapour deposition and sputtering system processing.

Problem: Thin-film deposition with low density material, such as powder-based metallurgy and cold spray, create low-density target material that is prone to arcing and contamination in process. Casting the ternary alloy CuInGa has proven very difficult because of its unique properties and complicated phase transitions. Normal casting techniques yield segregated material prone to contamination by cast forms and other casting equipment.

Solution: Sputtering Materials has invested over three years of research and development in creating a process for casting CIG and CIGS onto planar and rotatable backplates. Casted targets enable a high level of total material utilization; because of the increased density, target life and control are extended and can be reclaimed and reused to make new targets. There is a significant difference between powder metallurgy targets and casted CIGS targets; casted target processes can reuse the spent material by machining clean material off spent targets and re-casting it to make new targets.

Applications: This new innovative casting technology also works with high-purity materials such as In, InSn, Sn, Zn, Al, SAC, and others. The nature of high-density and high-purity material lends itself to be cleanly reclaimed and re-casted into new targets.

Platform: Materials can be casted to rotatable targets up to 50" in length.

Availability: November 2007 onwards.

Opportunities for advanced chemicals and materials in solar cells and modules

Mike Corbett & **Mark Thirsk**, Linx Consulting LLC, USA

ABSTRACT

The rapid growth of the solar energy industry owes its success to the development and production of mono- and multi-crystalline solar cells. This growth has been limited in recent years due to the lack of available supply of polysilicon, the key raw material for making the wafers that serve as the basis of the solar cell. As a result of this limitation, the price of polysilicon has increased dramatically and this has led to significant new and planned capacity expansions. These new capacity expansion announcements have been highly publicised, with little additional outside focus on other chemicals and materials.

This paper will examine technical and business aspects of the materials business as it relates to the flat plate solar industry, including the current situation on materials for crystalline silicon cells as well as other key chemicals and materials used in the production of various thin-film solar cells. In addition, we will discuss the types of chemicals and materials consumed and the business opportunities for electronic chemicals and materials suppliers.

Introduction

The foundation of the solar industry is based upon the phenomenon of the photoelectric effect. Many different semiconducting materials can be utilized to obtain this effect, and optimization of the efficiencies and better matching of band gaps through process and materials choice are being pursued every day. Early photovoltaic products relied on higher efficiency compound semiconductors, and were primarily for military and aerospace applications, where higher costs were acceptable. The majority of today's commercial cells are silicon-based, and cost reduction efforts, as well as economies of scale, promise to bring PV power generation into competition with grid power. However, silicon remains an expensive commodity, and focused attempts to develop next-generation solar cells include such thin-film technologies as tandem cell silicon or replacement semiconductor materials such as CdTe (cadmium telluride), or CIS/CIGS (copper indium selenide/copper indium gallium selenide) materials. These thin-film products are all typically built on a glass, steel or plastic substrate. This paper's primary focus will be a review of the chemical and material requirements for silicon and thin-film solar cells and modules.

Crystalline silicon solar cell manufacturing

Crystalline cells still account for over 90% of solar cell production. The production of crystalline solar cells has parallels to the production of silicon semiconductor devices such as bipolar and analog ICs. Both start with a silicon substrate which is then doped to produce a diode upon which electrical contacts are provided, similar to the interconnect structure in a chip. Integrated cell producers will typically source PV-grade polysilicon, which is then either grown into single crystal boules or polycrystalline ingots. The boules or ingots are cut into wafers which pass onto the cell manufacturing process. Producers trade off the lower cost of polysilicon wafers with their lower conversion efficiency.

Until recently, the dominant demand for high-purity silicon came from IC manufacturing, but industry dynamics resulted in a significant overcapacity in manufacturing, resulting in price competition and excess supply. This low pricing made reinvestment in capacity unattractive but helped early growth in the solar cell industry. Skyrocketing demand for crystalline silicon PV modules has reversed this situation, driving demand for huge increases in polysilicon capacity.

However, the scale of reinvestment over the last few years is massive, with existing leaders such as Hemlock Semiconductor, Wacker, REC, Tokuyama, and MEMC investing to maintain share, as well as new companies such as LDK and DC Chemical entering the market. Overall, we feel the impact of this capacity build will lead to a large polysilicon oversupply situation starting in 2009 or 2010, as illustrated Figure 1 (silicon capacity has been converted to megawatt equivalent).

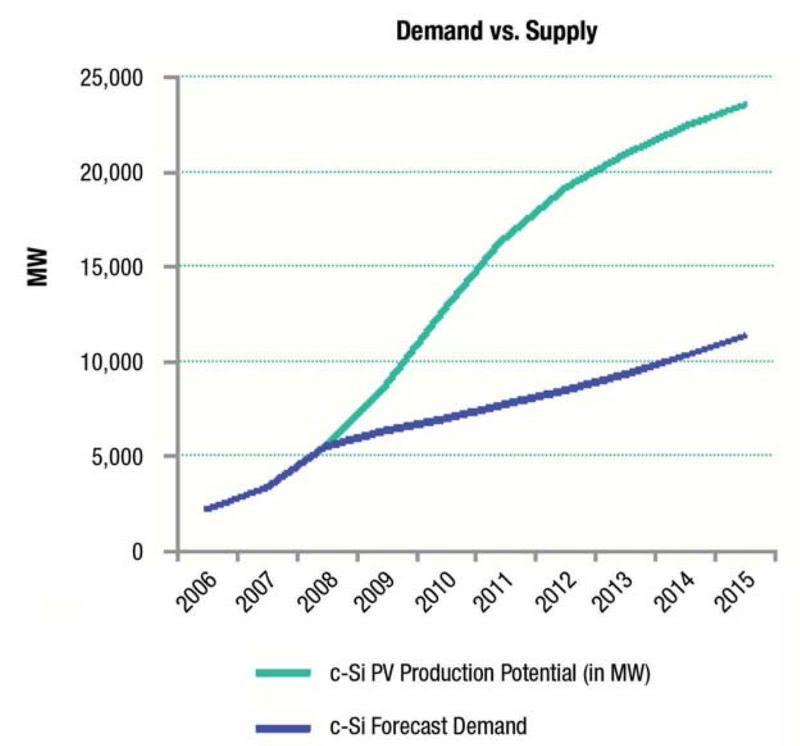


Figure 1. Polysilicon supply and demand balance for Si solar cells.

Other key steps and materials used to produce crystalline silicon cells include the following:

Wafer sawing. A major cost factor in all large wafer manufacturing (except ribbon growth) is the kerf loss in sawing the wafers. Even as wafer thicknesses are reduced, kerf loss remains between 40% and 50% of the starting silicon weight. Sawing consumables of silicon carbide abrasive and polyethylene glycols are largely recycled.

Wafer texturizing. To increase cell efficiency, the wafer surface is roughened by one of several processes, which are dependent on the crystal type of the wafer being texturized. Polycrystalline wafers use HF and HNO_3 etches for texturization, sometimes followed by NaOH rinses. Solutions are generally electronic-grade acid mixes of 25% to 40% concentration. Monocrystalline wafers use NaOH and KOH etches, which take advantage of the crystallographic anisotropic etch rates in silicon, and leave a pyramidal structure on the surface.

Junction diffusion and doping. The most common process for doping is gaseous diffusion of electronic grade $POCl_3$ delivered in a tube or belt furnace at about 900-950°C with nitrogen carrier gas. $POCl_3$ is commonly delivered in quartz bubblers in volumes of 1000ml to 1500ml, and are connected to the furnace gas feed. In advanced processes, selective doping technology is used to form emitter and base regions, and to improve contact resistances to improve cell efficiency. Currently, most monolithic cells are manufactured without selective doping, but tests have shown improvements of 0.2% to 0.4% of absolute efficiency through the use of selective emitters. Screen-printed materials are being employed, but tests with ink-jetted materials are under development. Printed dopants are usually dried in infrared belt ovens, followed by an 850-950°C firing for 3-5 minutes in a tube furnace or belt oven.

Anti-reflective coating (ARC) deposition. To capture as much incident radiation as possible in the final cell, an anti-reflection layer is added to the front side of the cells over the texturized surface. In the vast majority of cell lines, this is a PECVD-deposited Si_3N_4 layer of a thickness chosen to incouple the incident light.

Metal grid deposition. Screen-printed Ag and Ag/Al pastes are used for contacting silicon solar cells passivated with Si_3N_4 coatings. Inks are deposited with high-speed screen-printing systems through emulsion screens. Inks are formulated with glass frits that aid reaction with the nitride and oxide on the surface of the silicon. During the firing process, the glasses and additives contained in the inks react with silicon nitride to form a low-resistance contact while providing good adhesion to the wafer and good solderability.

Back-surface field metallization. Back surface field (BSF) metal is coated across the back of the cell. BSF metallization films are normally printed with pure aluminum inks and can be formulated to be compatible with the back-side grid ink, and, although dried separately, can be co-fired.

Moduling. To seal the silicon cells from the environment, a combination of glass and polymer films are laminated around the cells. Key moduling components are based on advanced polymers and include an EVA encapsulant material and a protective backsheet. The backsheet is usually laminated to combine film properties to control UV damage and moisture ingress, dependent on ultimate application. Critical materials in the laminate include PVF Films, PVDF films and PET films.

However, due to the inherent expense of polysilicon, limits to wafer thickness, cell efficiencies, kerf loss and other factors, many companies are aggressively pursuing thin-film solar cells.

Thin-film solar cells

Thin-film cells offer a route to low-cost power by reducing the amount of high-cost materials, and by automating manufacture. Strategies include developing cells from thin films of silicon or other semiconducting materials such as CdTe, or CIS/CIGS.

The 'hottest' silicon thin-film manufacturing technology combines the overlapping band gaps of amorphous and microcrystalline silicon deposited by CVD. Equipment manufacturers are drawing on technology similar to that used in thin-film display manufacture.

In fact, the production of tandem cell thin-film solar cells is more similar to the production of TFT LCD in that the starting substrate may be a sheet of glass (equivalent to generation 8 TFT LCD glass in the case of Applied Materials' production tools) or a steel of flexible substrate. Materials supply for these manufacturing lines consist primarily of specialty gases and PVD targets sandwiched between float glass. Projected economies of scale have prompted several companies to plan 1GW-size manufacturing lines, requiring significant supply infrastructure.

Tandem cell or micromorph technology is being promoted by complete turnkey manufacturing lines offered by suppliers such as Applied Materials, Oerlikon and Ulvac. This technology is reliant upon PECVD for the absorber layers, and as a result, there is a large specialty and process gas requirement, including silane, ammonia and chamber cleaning gases such as NF_3 or F_2. The Oerlikon process also uses PECVD for the back contact layer, whereas Applied uses PVD deposition. The cell is enclosed with another layer of glass that has a polymeric coating of PVB (polyvinylbutyral) for adhesion and moisture protection.

Non-silicon thin films

Other thin-film solar technologies, including CdTe and CIS/CIGS, have had to overcome multiple obstacles to develop commercial sales. Firstly, cell developers have had to develop the technology, but additionally, manufacturers suffer from the lack of standardized manufacturing equipment. To date, CdTe manufacturers, such as First Solar, have been the most successful in developing viable manufacturing infrastructure. The variation of absorber deposition options for CIS/CIGS has remained a significant obstacle for these technologies.

Thin-film materials are typically deposited on a glass substrate. Some cell producers are also investigating steel and flexible polymeric-based substrates. Key materials used in these applications fall into the category of specialty metals and include the following: Mo, Cu, In, Ga, Se, CdTe, and CdS. As there is little commercial background in widespread mass-production processes involving some of these films, a variety of processes are used to deposit the complex thin-film materials for these cells including sputtering, chemical bath deposition, sublimation, vapor-transport deposition, electrochemical deposition and chemical vapor deposition. In addition, transparent conductive oxides will be used and some processes will utilize SnO, ZnO and possibly ITO.

Opportunities for electronic chemicals and materials suppliers

The major areas of chemicals and materials opportunities can be found in the following segments:

- Polysilicon and upgraded metallurgical grade silicon (UMG)
- Bulk and specialty gases
- Acids and inorganics
- Deposition precursors
- Metal pastes
- Polymeric films for encapsulation, packaging and protection
- Specialty metals for CIS/CIGS

As the industry continues to grow, most of the leading chemicals and materials suppliers will continue to jostle for position or enter the space because they cannot afford to be locked out of an emerging global market, as it would impact perceptions in the financial markets. At the same time, the solar industry is benefiting from a massive influx of talent from other thin-film processing industries including semiconductors – especially in the U.S. and Europe – and TFT LCD. Examples of companies that have crossed the line from one segment to another include Cypress (SunPower), Sharp, and Qimonda. Factory sizes are being increased from tens of MW, labor-intensive operations to GW-scale plants with high degrees of automation and very sophisticated chemicals, materials and logistics capabilities.

The solar industry has material multiple challenges, including:

Raw material availability. From polysilicon for crystalline cells, and pastes

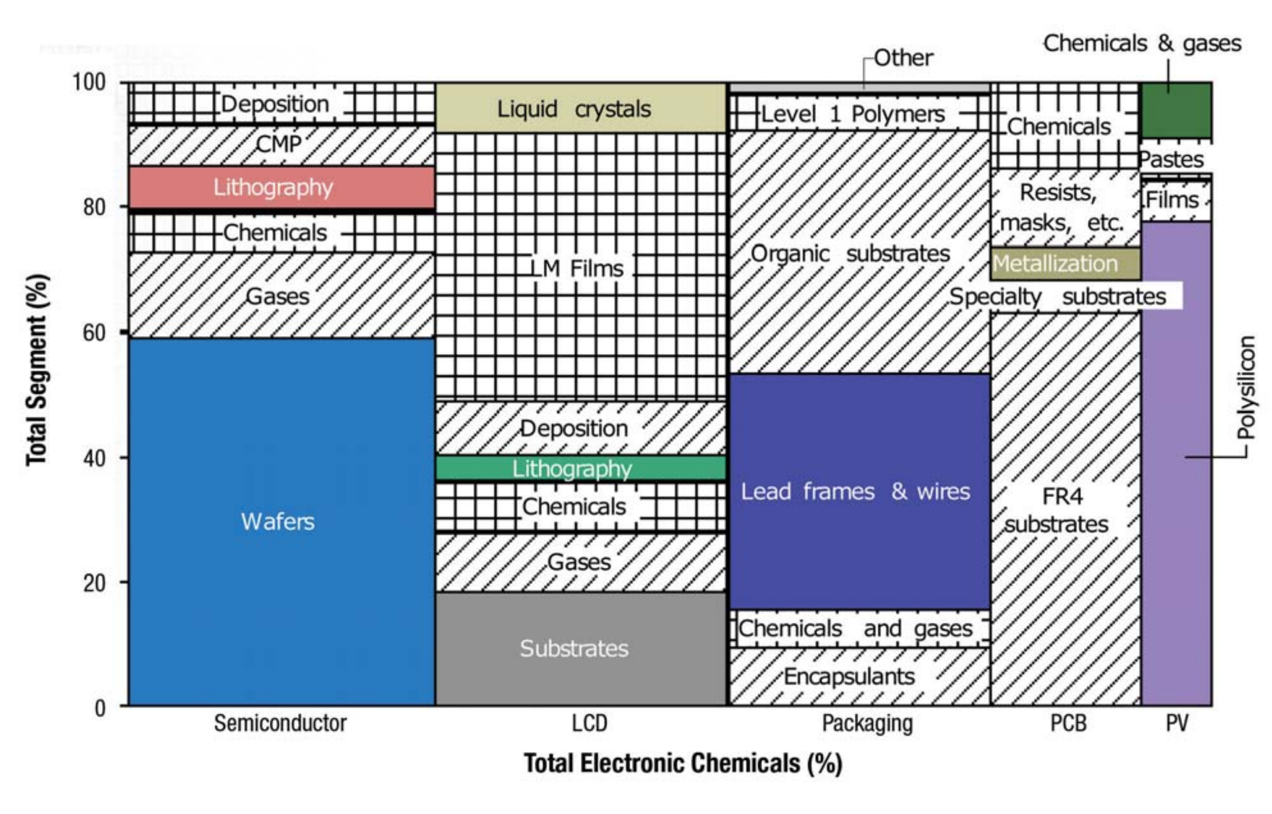


Figure 2. Electronic Chemicals and Materials Landscape in 2007. The electronic chemicals and materials market is estimated at US$72 billion in 2007.

for gridding to the limited global supply of In and Te, ensuring viable supply chains at competitive costs is key. This concern currently seems more severe for In than Te because of competing uses. The primary challenge will be to reduce absorber thicknesses (film or wafer), while maintaining state-of-the-art performance.

Need for high-throughput, low-cost processes. All successful wafer and thin-film companies have devoted resources and effort to developing production processes and tools to enable their technology. This appears to be inefficient, and will inhibit propagation of advanced manufacturing technologies. AMAT and Oerlikon will likely enable high-volume processes in tandem thin-film technologies, but adopting learning from other industries such as IC manufacturing will enable key cost reduction. Fortunately, the chemicals and materials suppliers in the electronics industry have been exposed to these types of challenges in the past in the semiconductor industry and TFT LCD industry. The materials requirements for solar cells and modules are rapidly emerging and represent another segment of the electronic chemicals and materials market as shown in Figure 2.

Most of the chemicals and materials that come in direct contact with the cell are 'electronic grade,' with consequent purity requirements and demonstrated supplier reliability. Many of the leading suppliers to the solar cell and modules industry have a long history of serving the electronics industry; however, new entrants do not have this experience and this new industry represents a novel challenge for them.

As manufacturing scale increases, the volume demands of the PV industry will become significant, and those suppliers that can meet expectations can expect to participate in a strong growth industry.

While there are limited opportunities for novel materials in today's solar industry, the dual requirements of low-cost manufacture, coupled with the need for electronic-grade purity and supply chain reliability, will be a balancing act that could challenge suppliers. As manufacturing scale increases, the volume demands of the PV industry will become significant, and those suppliers that can meet expectations can expect to participate in a strong growth industry. Critical success factors in the solar industry include applying synergies (shared infrastructure, materials technologies, etc.) and learning other electronic segments (semiconductors, TFT LCDs, advanced packaging, etc.).

Lastly, of course, the development in cell technology continues. Materials innovation, process innovation, and applying creativity in materials use, recycling and choice are likely to be vital in aiding novel cell technologies to market, and in offering opportunities to suppliers engaged in these segments.

Reference

The insights and perspectives for this article were derived from Linx Consulting's annual report on chemicals and materials in the solar industry – *Advanced Chemicals and Materials for Photovoltaic Cells and Modules.*

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Challenges of the gigawatt fab

Michael Kostwald, Turner & Townsend GmbH, Germany; **Hans Mahrenholtz**, Linde Gas, Linde AG, Germany; & **Anish Tolia**, Linde Electronics, U.S.A.

ABSTRACT

Thin-film solar cell manufacturing is poised to make a giant leap in scale with the birth of the gigawatt fab. Commercial thin-film plants are typically sized based on the capacity of the production line from the chosen equipment supplier. In most cases, initial investments have been for a single line, typically with an output capacity of no more than 60MWp. This period of initial development has allowed the industry to prove the robustness of the technology and capabilities of the equipment, as well as to understand the significance for the cost-per-watt of key cost drivers such as materials reduction, cell efficiency increases, and productivity. While large-scale manufacturing will positively impact costs, it presents a unique set of challenges for equipment and material suppliers, as well as the engineering and contracting companies tasked with designing, building, equipping and running a facility on this scale. In this paper, we present the insights of two specialty companies in the solar industry. Turner and Townsend, a design and project management consultancy, and Linde, glass manufacturer and gas and chemical company – share their views of the challenges of the gigawatt fab in three dedicated sections.

Methods and considerations in designing and building a gigawatt fab – Turner & Townsend GmbH

As project sizes increase, and time-to-market demands fast-track construction, careful consideration must be given to the project management model that will successfully deliver gigawatt fabs on time, without compromising cost targets or technical performance.

Frequently, traditional project management methods fail when carrying out these fast-track projects, which contain high risks with regards to function, quality, cost and schedule. Traditional execution is characterised by a sequence of mostly individually-developed, separate planning steps. After defining the program, the owner starts to select architects and engineers based on their qualifications. The architects and engineers develop the preliminary and detailed designs and prepare the procurement procedure for selecting a General Contractor or Work Package Contractor. On being awarded the contract, the General Contractor or Work Package Contractor step into the project with no prior knowledge of – and little subsequent control over – the basic objectives. This precludes the possibility of providing valuable input to optimise the design, cost structure or time schedules.

The other extreme, i.e. the development of the entire planning and design by a management contractor, will generate a solution that is optimal for the contractor but will not adequately match the need of the project sponsor.

Better suited to the demands of the task is an Integrated Project Design & Management (IPDM) model (see Figure 1), already proven in the semiconductor industry. Adopting such an integrated approach, and forming a core team of experts to design, co-ordinate and manage all efforts from the very start of the project to the final delivery of the completed facility, brings significant benefits and sees the client form a key component of the team.

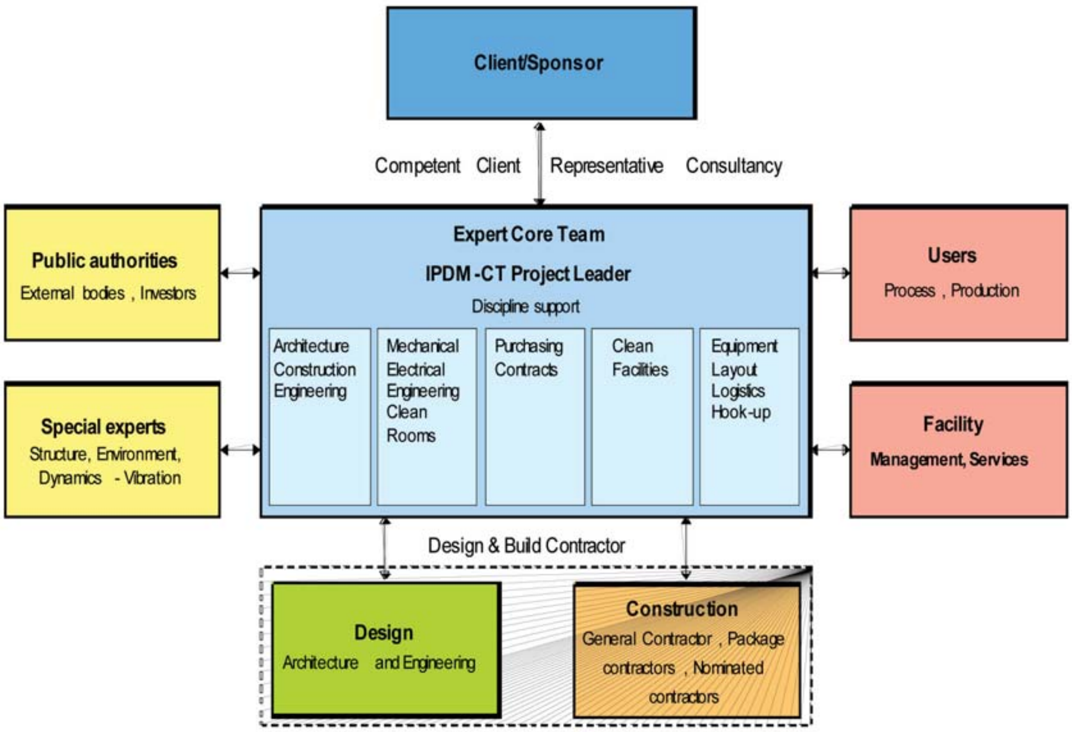

Figure 1. Integrated Project Design & Management (IPDM) model.

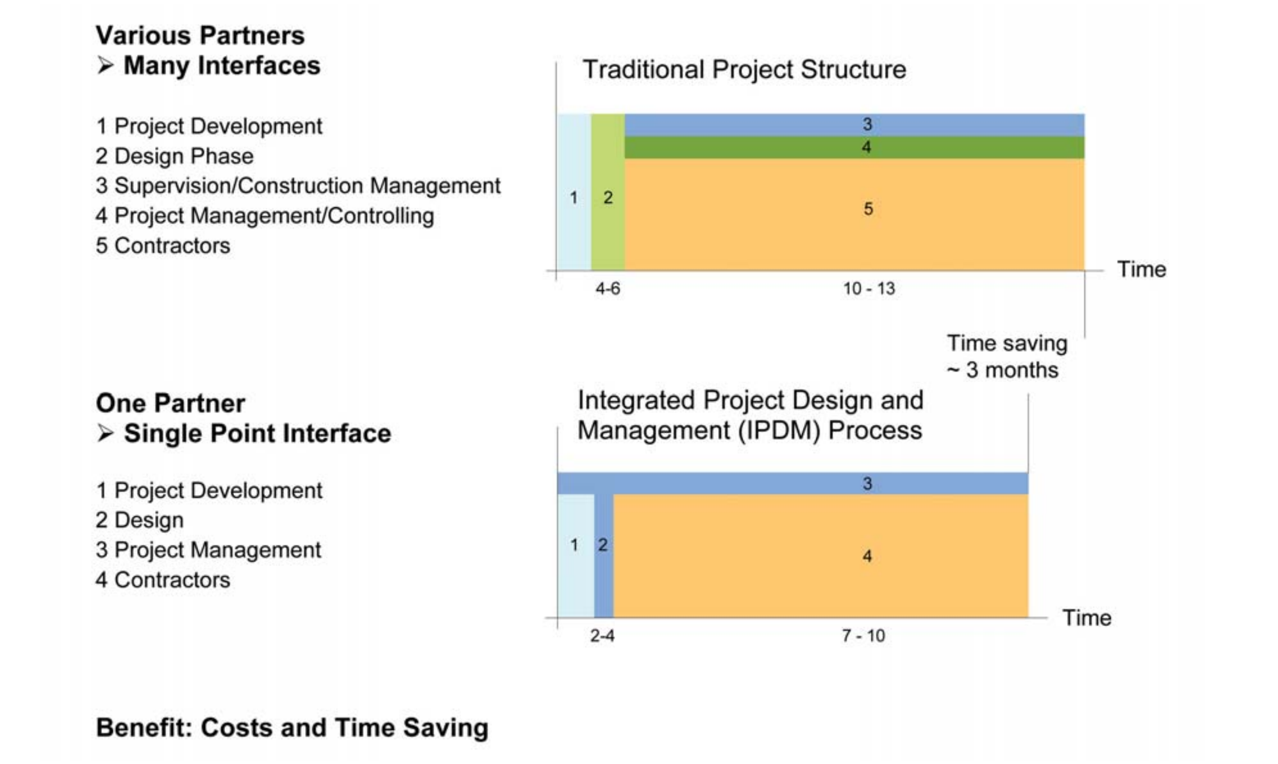

Figure 2. Comparison between traditional Project Structure vs. Integrated Process.

The core team begins to work in the project definition phase. Many key decisions are made during this early phase and cost-saving potential is at its highest. Changing key decisions very often affects costs, schedule or quality. The project is developed in close co-operation with the client/project sponsor, reflecting in detail the objectives and needs of the sponsor. In the next step those needs are transformed into a "Conceptual Design" which acts as a robust tender document to find a Design and Build Contractor in a competitive procedure. The Design and Build Contractor is then controlled and monitored by the core team throughout the entire project.

The risk for the client is reduced and the strict and optimised planning phase saves valuable time through:

- integration of all experts in an interdisciplinary mode from the start
- strong focus on an intensive programming phase to define the needs and objectives
- sequential but integrative progression leading to parallel work
- controlled change order procedures

and reduces project costs through:

- improved competition for detailed design and execution
- innovative concepts by early expert integration, less changes due to the strict and optimized planning phase.

Design challenges

Often, for warranty reasons, the facility planners will not work with "true" design parameters but with "worst-case" design parameters, which frequently result in higher-than-necessary costs.

The question of how the building and facility requirements are impacted by the scale-up will be answered in the IPDM Programming Phase. An intensive workshop, lead-managed by the core team, is held with the owner, equipment vendors, user and representatives of all technical disciplines with the main target to set up qualified requirements for the entire building and infrastructure scope. To ensure the design is state-of-the-art, the core team's role is to verify the redundancies, spare capacities, standards, specifications, qualities and quantities for each system with the help of "best practice" – reference data and benchmark figures, which reflect real design and operational experience. Compared to semiconductor manufacturing, purity specifications for process materials for PV manufacture such as ultra pure water (UPW) and nitrogen (N_2) may be less stringent, but the facility systems will be just as complex, and uptime requirements just as rigorous. System risk assessments and HAZOPs (hazardous operations) are equally as critical, and in some cases are dealing with significantly larger quantities of hazardous materials.

For example, wafer-based PV manufacturers will potentially require a high consumption hydrofluoric acid supply and discharge system, which therefore requires an engineering task force. The n+1 redundancy of cooling machines depends on the system capacity and on the diversity factor. Consideration of modular concept of production area, facility and infrastructure may not have any impact on the production but have to take into account a well-balanced ratio between operational cost and investment, with the target to reduce the overall production cost. Separation of central heating, cooling, gases and power station on site has to be considered to change to alternative business models in the future (e.g. lease-back).

> Utility consumption values for sub-100MW production facilities cannot simply be scaled up to gigawatt facility capacities.

PV manufacturers have not yet gained operational experience at industrial scale over long periods; hence utility consumption values for sub-100MW production facilities cannot simply be scaled up to gigawatt facility capacities. Additionally, facility requirements from equipment vendors are still under evaluation due to:

- Process technology optimization
- Production equipment layout optimization
- Efficiency improvements
- New thin-film clean gas technology under development
- Critical thin-film gas impurities not yet understood

In the programming phase, equipment vendor data are challenged to achieve qualified requirements, and these

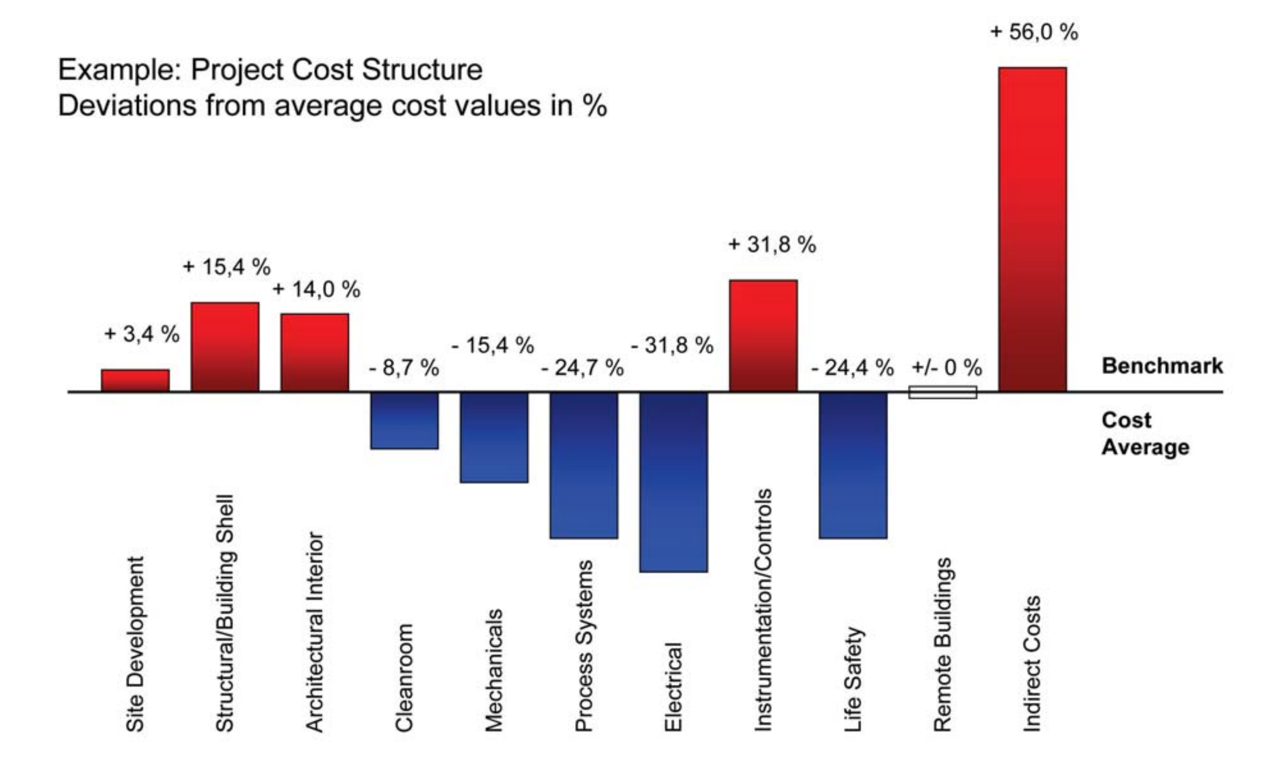

Figure 3. Example benchmark exercise for target costing.

requirements are monitored on an ongoing basis to ensure planning accuracy.

Energy and carbon challenges

With increasing energy supply costs and carbon tariffs, low CO_2 power generation will become more important. From a rational point of view, PV manufacturers should focus on the production optimization and minimization of the energy demand, e.g. by preferring equipment with lower specific consumption figures. Cooling demand should be investigated very carefully. All actions to reduce energy demand should be taken, as well as determining measures of utilisation of waste heat.

Due to the very complex and sensitive cost structure of co-generation plants, power supply should be left to the professionals. At that time, the development of the whole energy price scenery is not convenient for high investment into any power generation system – this is not the core business of a PV manufacturer. The evaluation of the energy and carbon issue is part of the programming phase.

Target costing

Target costing is the basis to achieve savings by evaluating the individual cost targets of scaling factors such as equipment, material, utilities, personnel and building as well as other factors such as area, process complexity and productivity. Using benchmarking and value engineering, the proposed technical solutions can be optimized. The process should start top-down – a critical input for this exercise is the revenue forecast for the product, which should be net of any government subsidies. It is recommended that any such subsidies be treated as additional benefit.

> Due to the very complex and sensitive cost structure of co-generation plants, power supply should be left to the professionals.

As an example, Figure 3 illustrates the deviations per work package from client's budget based on average costs from benchmark data. The analysis shows that the client's overall cost budget was approximately 4.6% (€11million) higher than a budget based on average values.

However, the detailed comparison revealed significant cost differences for nearly all items. Considering the client's cutting-edge technology and future requirements, the costs for the process infrastructure were strongly underestimated, and budgets could be re-allocated accordingly to critical quality-related work packages in order to avoid major changes and claims after contract award.

Glass for PV applications – Hans Mahrenholtz, Linde AG

In the move towards gigawatt-scale manufacturing, greater understanding of the materials used – such as glass substrates – will be required. Key areas of concern include cost, transportation and dedicated supply, especially when photovoltaic production is expanded into regions with fewer glass manufacturing facilities.

Consideration of greater quality control and lower emissions in glass production while controlling costs is also vital in dealing with such a scale of production. Importantly, the number of glass plants will eventually need to be increased, plants that are high in capital expenditure and long in construction.

Currently, both patterned (rolled) and float glass (see Table 1) are used for all types of photovoltaic cells - crystalline silicon and thin-film, as well as in other solar energy systems such as concentrator modules and solar thermal. However, while crystalline cells require only a single sheet in the form of the transparent protective cover, thin-film modules require an additional glass sheet as the substrate. In the case of thin-film, where glass quality requirements are the highest, float glass is the most widely-

Solar Technology	Preferred Glass type	Application
Crystalline silicon PV	Patterned glass	Front cover
Thin-film silicon PV	Float glass	Front cover & substrate

Table 1. Preferred glass types for different solar cell types and applications.

used type. This increased use of glass for thin-film modules means that about 24% of the overall manufacturing BOM is related to glass and TCO coating.

The current annual demand for glass by the solar industry is approximately 37 million m^2. In global terms, this represents less than 0.5% of the current available capacity for high-quality float glass, with most of the output from a typical float glass plant destined for architectural and automotive applications. As you would therefore expect, glass industry expansion is largely aligned with the growth of those large industries.

Given that solar glass is currently such a small share of global float glass output, the demand is largely met by existing glass plants on a batch basis. Notwithstanding the predicted PV industry growth, there are inherent issues with this approach:

- Consistency in key parameters between batches are hard to achieve, leading to varying cell performance
- Inefficiencies due to set-up times when switching from regular float to solar specific sizes and thicknesses add plant downtime and hence unwanted cost
- In many cases the geographical location of PV manufacturing facilities leads to high logistical costs to ship the product from the nearest available source
- "Fresh", recently manufactured glass is preferred to ensure high quality solar cells, so building stock on a batch basis is not necessarily the solution.

Based on projections for PV industry growth of 35% pa, the overall requirement for PV glass by 2011 will be about 84 million m^2, or the output from 22 typical pattern and float glass plants. Table 2 shows the projected development in demand for glass to 2020.

Based on historical investments within the industry, it is unlikely that the top four glass manufacturers alone will cope with the required expansion, especially with the current trend toward gigawatt-scale fab construction activity. Thus, a glass feedstock shortage similar to that of crystalline silicon is a real possibility if additional investment, potentially from new manufacturers, is not forthcoming. It is also worth noting that a new float glass plant can take up to two years to complete, and can cost up to €150M.

Currently, there are no float glass plants in the world specifically designed for, or dedicated to, thin-film PV glass. For optimum glass properties, PV float glass plants require specific designs for the batch plant to prevent contamination by iron particles, and in areas such as the furnace due to the increase of melt temperatures and the tin bath and the lehr due to an increased cooling effect. The plant output must also be tuned to meet the specific thickness, dimensions and properties demanded for PV applications. Table 3 gives key parameters for float and pattern glass plants.

Environmental challenges

Glass production (and PV float glass in particular) is an energy-intensive process and consideration should be given to optimizing the manufacturing to as great an extent as possible. One area of development is through the use of oxygen instead of air within the melting process. Fuel consumption and CO_2 emissions can be reduced by about 25%. Additionally, the NOx emissions can be reduced by up to 70%.

Depending on a large number of parameters, there are many advantages associated with the use of oxygen in glass melting furnaces and in the glass melts:

- Reduced CO_2, low NOx and particulate emissions
- Improved heat transfer with enhanced glass quality
- Lower capital costs, no air preheating necessary, reduced filtration and furnace requirements
- Increased productivity
- Better control over operations, reduced variation
- Energy savings.

	2006		2011		2020	
	GWp	Million m^2	GWp	Million m^2	GWp	Million m^2
cSI modules	2	14	4	26	50	300
Patterned glass lines (@250t/day)	2		10		35	
TF cells	0.3		7		50	
Front glass		0.5		84		550
Back glass		0.5		78		528
Front glass float lines (@400t/day)			6		40	
Back glass float lines (@400t/day)			6		38	
Total glass lines needed to support PV development	2		22		113	

Table 2. Glass lines needed to support PV developments until 2020.

Parameter	Float line	Pattern line
Typical capacity	400 to 800 tpd	240 tpd (2 x 120 tpd)
	~40,000 to 80,000m^2, 3.2mm	
Land requirements	200 x 600m	100 x 150m
CAPEX	€80 to 150 million	€30 to 45 million
Energy requirements	1,500 kcal/kg of glass	1,000 kcal/kg of glass
	1,125 kcal/kg of glass – oxygen melting	900 kcal/kg of glass – oxygen melting
	70,000 to 140,000 Nm^3/d of natural gas	28,000 Nm^3/d of natural gas
	52,000 to 100,000 Nm^3/d – oxygen	25,000 Nm^3/d – oxygen
Operation	365 days a year, continuous	
	10 to 18 years	8 to 12 years
Time from order to start-up	20 to 24 months	15 to 18 months
Manpower	~ 250 persons	
Major applications	BIPV, TF substrate and cover	transparent protective cover

Table 3. Key parameters for different glass lines.

Gas Technology	$/Watt Impact	$/Year per 65MW line (based on > 500MW scale)
Replace NF_3 by fluorine (material savings only)	$0.03/Watt	$2,000,000
Silane cost reduction	$0.015/Watt	$1,000,000
Optimized hydrogen and nitrogen on-site production	$0.03/Watt	$2,000,000
Dopant blending	$0.001/Watt	$50,000
Helium recycle or removal from process	$0.007/Watt	$450,000
Total	$0.087/Watt	$5,500,000
Potential throughput advantage of F_2 clean	$0.05/Watt	$3,250,000

Table 4. Gas consumption cost reduction approaches.

Performance optimization

There are several known projects where newcomers are planning to build PV solar glass plants and overcome the issues identified by incorporating the following features:

- Production of high-quality ultra-bright float glass for solar applications (3.2mm/4mm) only
- Manufacturing process is optimized for one type of glass to ensure consistency and high quality
- Located close to the PV manufacturer to minimise transport costs and risks
- Provide a feedstock of fresh glass, do not build for stock
- Use latest technologies to reduce costs and emissions

Further development is needed to optimize key glass properties such as optical transmission, mechanical strength, and chemical and environmental resistance to minimise performance degradation over an expected 25 years' lifetime, while ensuring economic manufacturing costs.

Some performance improvements may be achieved through the adoption of on-line functional coatings. Aside from TCO, other coatings such as self-cleaning and anti-reflective are likely to increase the cell performance.

While the major glass manufacturers will no doubt figure highly in the growth of the PV glass market, new manufacturers will emerge, including PV manufacturers, either directly or through co-investment.

Thin-film materials for gigawatt fabs – an insight by Anish Tolia, Linde Electronics

Thin-film silicon-based solar cells have attracted a great deal of attention and investment in the last year. Several companies have recently embarked on large-scale projects ranging from 500MW to 1000MW production capacity.

Reaching this aggressive target for fabs of gigawatt scale depends in large part on reducing the associated direct materials costs associated with the process. Direct material costs in the thin-film silicon

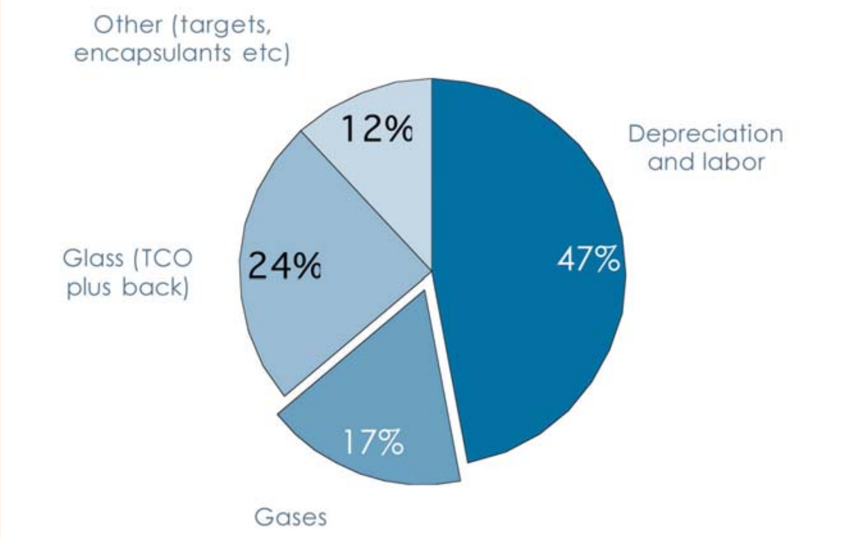

Figure 4. Thin-film cost considerations.

process, particularly tandem junction, can represent over 50% of the cost of production of the module (see Figure 4). Among the direct materials, gases can account for nearly 20% of the cost of module production. Therefore, reducing cost of these critical materials is essential for the success of this technology.

Large-scale manufacturing of solar cells, thin-film silicon in particular, requires very large quantities of gases and chemicals. Figure 5 shows typical consumption of key gases used in a gigawatt-scale fab. While bulk gases have historically been supplied via on-site plants or pipelines from ASU for large industrial users, specialty gases such as silane and NF_3 have never before been used in such large quantities. Gas companies must therefore invest in logistics solutions to supply large quantities of specialty gases. Additionally, large-scale adoption of solar cell production will severely tax the global production capacity of critical gases such as silane. Gas companies must also be willing to invest in additional capacity to meet the growing demand.

In order to successfully impact the cost per watt, gas companies must move from a traditional "supplier" model to becoming an integral part of the solar industry. They must think in terms of overall cost-per-watt reduction and use innovative technologies to lower overall cost per watt.

The critical process step in all thin-film silicon technologies is deposition of doped silicon film from a silane (SiH_4) precursor in a Chemical Vapor Deposition (CVD) system. The result is a thin film of silicon on the glass. Typically, hydrogen (H_2) is also introduced at high flow rates to control the kinetics of the film growth. Dopants are incorporated through precursors such as Trimethyl Boron (TMB), Diborane (B_2H_6) and Phoshphine (PH_3).

This process also results in amorphous silicon deposition on other surfaces in the process chamber, such as the showerhead and chamber walls, which must be periodically cleaned. A fluorine-based etch process using NF_3, SF_6 or F_2 is usually used for this purpose. Finally, nitrogen (N_2) must be used to dilute the pump lines.

Another critical step is the deposition of a transparent conductive oxide (TCO) film on the top glass. This is typically tin oxide or zinc oxide deposited via sputtering or

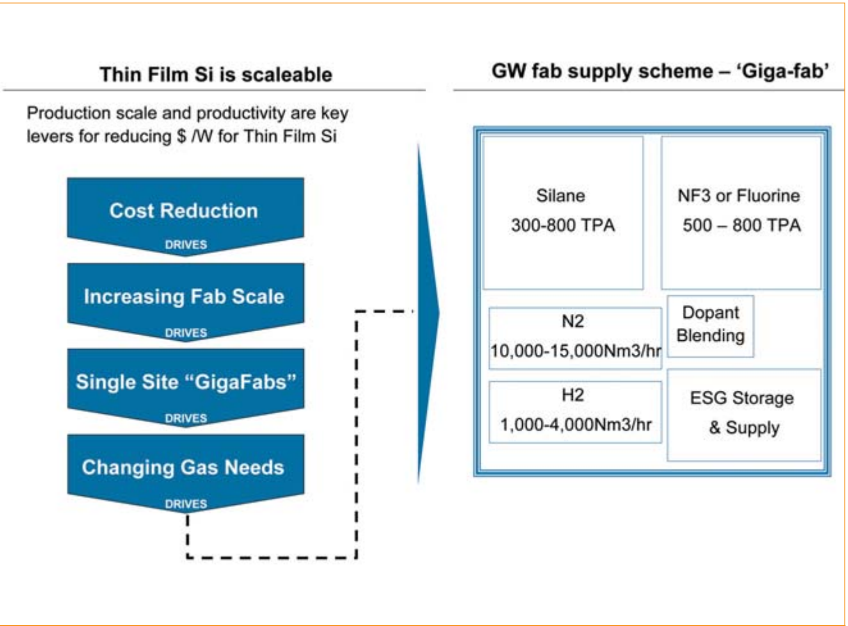

Figure 5. Availability, supply logistics and cost challenges

using an organometallic precursor such as Diethyl Zinc (DEZ).

Figure 6 shows relative consumption of the various gases used for three of the most common types of thin-film manufacturing equipment. Reducing the cost of gases can be achieved in various ways.

On-site generation of bulk gases

Due to the large scale of gigawatt fabs, the economics favour on-site generation of major bulk gases such as hydrogen and nitrogen. This eliminates the transportation and delivery cost and enhances security of supply. Hydrogen is provided through Steam Methane Reformers or electrolytic cells. On-site hydrogen is the preferred delivery method for flows exceeding 150Nm^3/hr.

Nitrogen can also be generated on-site via packaged N_2-generators such as the one shown in Figure 7. Minimum consumption of 1500 Nm^3/hr makes this a cost-effective solution.

Lowering cleaning costs

Approximately 70% of the capital cost and over 40% of the direct materials cost are related to the CVD process that deposits the active silicon layers. The CVD chambers require frequent cleaning of silicon residue. Replacing current methods (NF_3 or SF_6) by using fluorine (F_2) can cut cleaning costs by up to 40%. Fluorine can be generated on-site using packaged fluorine generators such as those shown in Figure 8. The cost benefit breakdown is illustrated in Figure 9.

Increasing throughput

By utilizing F_2-based cleaning, the throughput of the CVD process may be increased by up to 6% at no additional cost. Additionally, additives in the silane gas may increase deposition rates and thereby increase throughput as well.

Improving cell efficiency

The cell efficiency is strongly affected by the composition of the active p-i-n layers in the amorphous and microcrystalline steps. Cell efficiency may be improved by controlling critical impurities or through additives such as disilane.

Silane cost reduction

Silane is the largest contributor to the cost of gases and one in potentially short supply. Silane cost reduction can be achieved through recycling, reducing film thickness and improving film quality and device efficiency by the control of critical impurities. Since these changes impact critical process steps, the impact must be evaluated and the benefits weighed against potential risks.

Dopant management

While dopants (PH_3 and TMB) are used in relatively small quantities, they are very expensive and are typically shipped as 0.5% mixtures in H_2. Since on-site H_2 generators are part of the gas supply solution, costs may be reduced by shipping pure dopants and making the blends on site.

The net effect of all of these programs can result in a significant cost-per-watt reduction. Table 4 shows quantitative cost reductions that can be achieved through this strategic approach to gas use. The cumulative impact of these cost reduction initiatives is illustrated in Figure 10.

Conclusion

While there are many opportunities to drive down cost of production for fabs of large scale, realization of the cost savings will require coordination and partnerships between gas suppliers, equipment suppliers and module manufacturers. Such partnerships must form the new business model in the supply chain if thin-film silicon solar technology is to reach its potential.

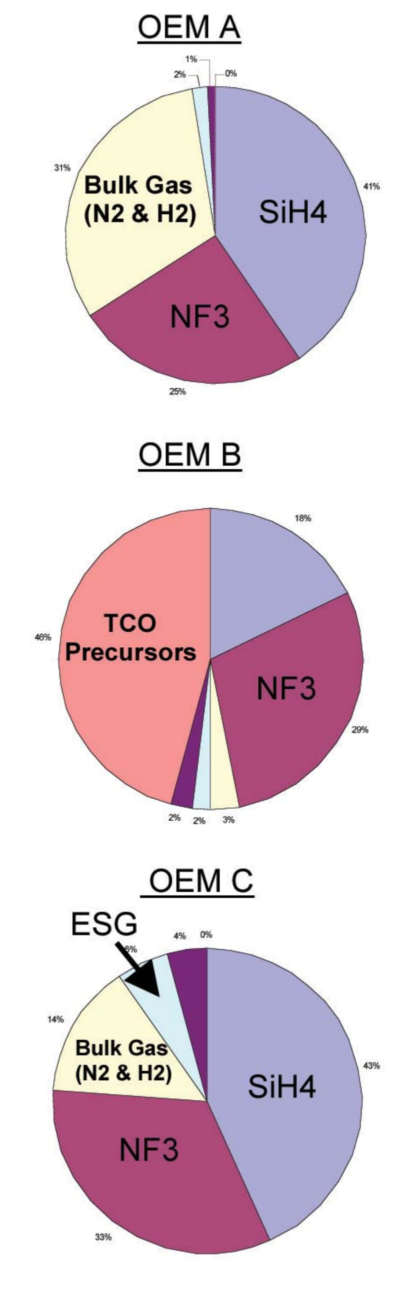

Figure 6. Commonly-used gases for thin-film manufacturing equipment.

Figure 7. On-site nitrogen generation (courtesy of Conergy AG).

Figure 8. On-site fluorine generation.

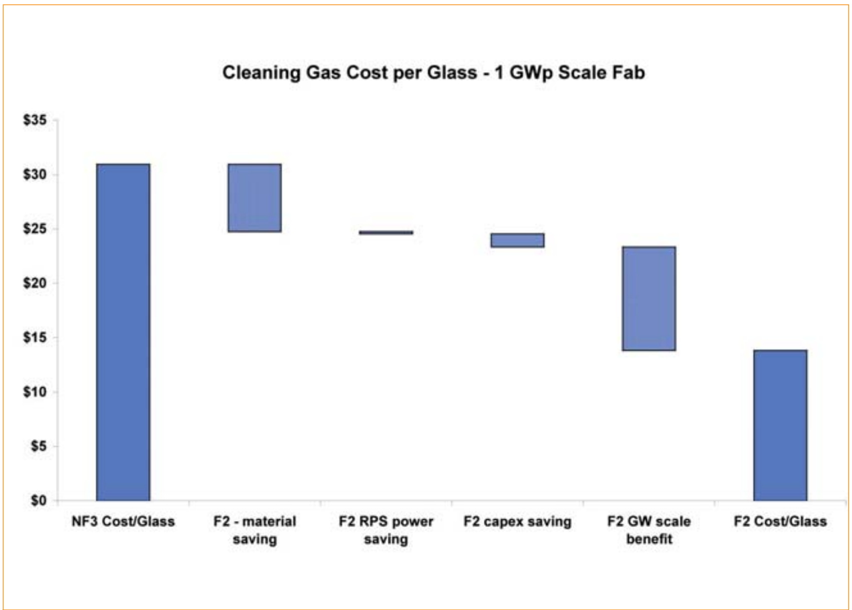

Figure 9. Cleaning gas cost per glass at 1GWp-scale fab.

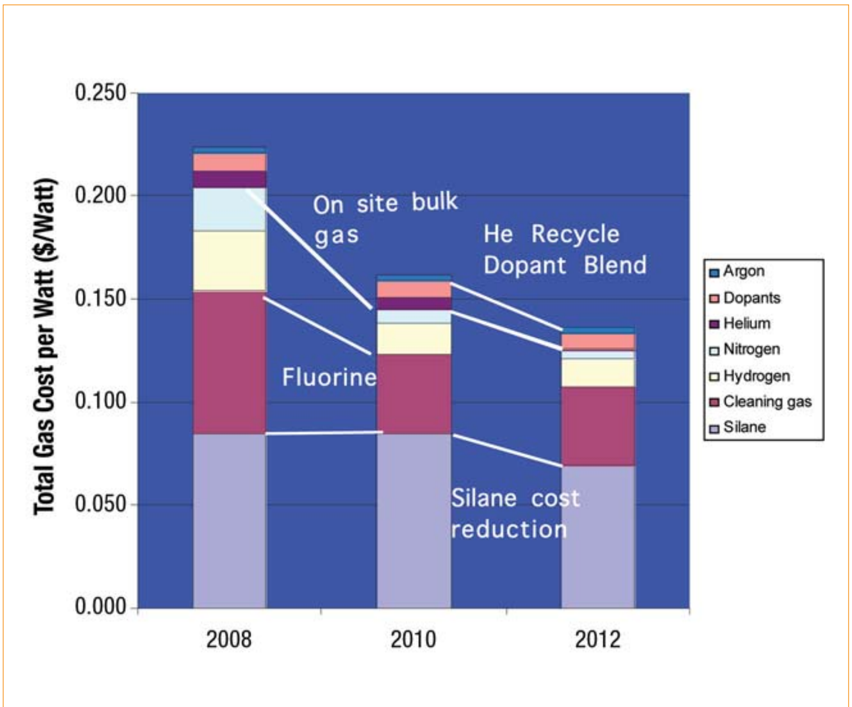

Figure 10. Cumulative cost reduction strategy impact.

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Anish Tolia is market development manager for the solar industry for Linde Electronics. He is responsible for strategic marketing, planning, forecasting and business development in the U.S. Prior to joining Linde in early 2008, Tolia spent several years with Applied Materials in technical development. He also served as senior product manager for Photon Dynamics, a market leading inspection and test OEM for the TFT-LCD industry. Tolia has a doctorate in chemical engineering from Purdue University, Indiana, and holds numerous patents that have been published widely in technical journals and presented at conferences.

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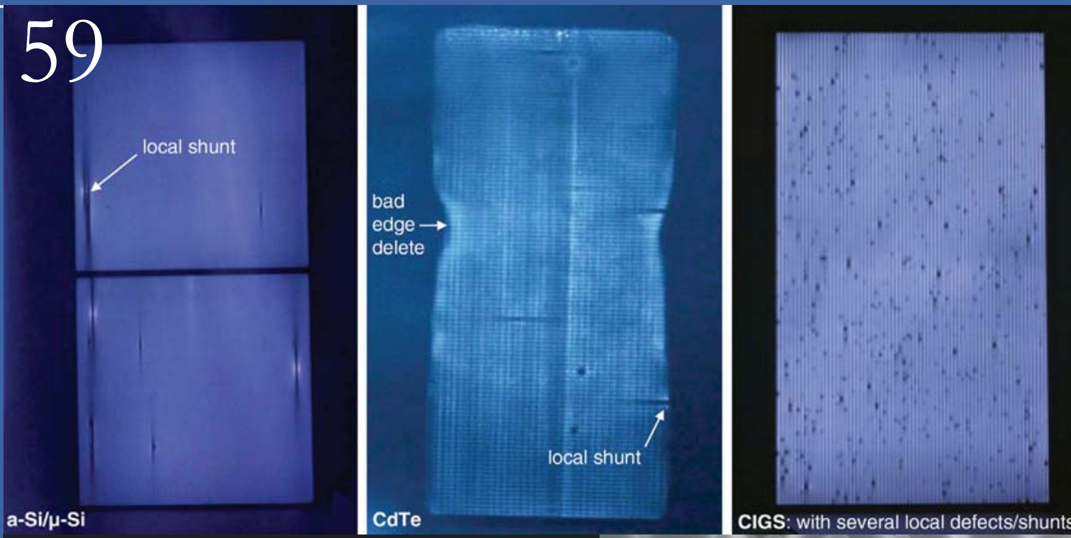
Cell Processing



"The maximum efficiency of light conversion for the Si/SiN/air stack is obtained at n_{633nm} ~1.9 at a thickness of d~85nm, assuming zero or negligible absorption"

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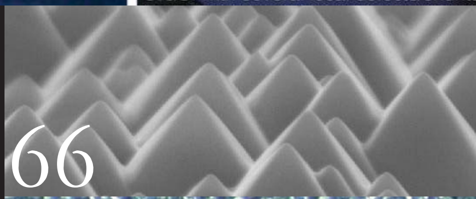

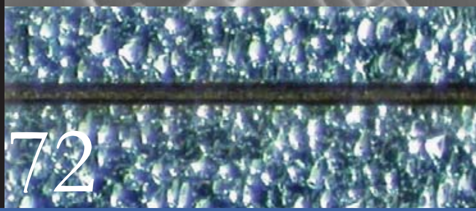

News

Irish company researches "spray-on" solar cells

Science and Technology Research Partners (Strep), a Dublin-based company, is currently developing "spray-on" solar cells that can be painted onto a roof and integrated electronically to generate energy. The company, headed by University College Dublin and Cambridge University graduate Dr. Mazhar Bari, is researching the technology based on titanium dioxide, among other materials, and has recently moved the development from a wet-state chemistry to a solid-state application.

Currently, the dye-sensitised spray-on cells are operating at an efficiency rate of 40% of regular silicon-based cells, but the ease and relatively lower cost of production of the flexible thin-film cells could potentially render the technology a runner in the industry. The aim is to reach a 10 per cent conversion rate at 10 per cent of the production cost of traditional solar cells.

"The technology in its current stage is a wet state. What I am doing is working on the solid state version. It is wet chemistry basically but I have found a way to make it solid state," said Dr. Bari. "Right now, it is more screen printing but it will develop at some stage into a sprayable technology. It will be applied very much like paint."

Research and Development News Focus

Fraunhofer Institute to use AIXTRON's CRIUS epitaxy reactor for III-V-Si PV cell development

The Fraunhofer Institut für Solare Energiesysteme (Fraunhofer ISE) has placed an order with AIXTRON for its 300mm Close Coupled Showerhead CRIUS epitaxy reactor that will be used for the research and development of GaAs-based multi-junction solar cells on silicon.

"Within the scope of the BMBF project 'III-V-Si' we will receive AIXTRON's Close Coupled Showerhead system," said Dr. Frank Dimroth, head of the III-V-Epitaxy and Solar Cells group. "Fraunhofer ISE operates an AIX 2600G3 Planetary Reactor for more than 10 years and has achieved excellent results on this tool. Now we would like to start a second development pathway focussing on single large wafer processes on Si. We have been working with AIXTRON and closely monitored the evolution of growth technology for the preparation of compound semiconductor thin films on silicon wafers. This is a challenging task but we are confident that the CRIUS tool will meet our requirements of low memory effect, high uniformity and throughput with the requisite economics for solar cell production."

SVTC Technologies attracts JA Solar to new Photovoltaic Development Center

SVTC Technologies has officially launched its Silicon Valley Photovoltaic Development Center, with the aim of becoming a leading RD&E center for the global photovoltaics industry. The new centre is located in an 87,000 square foot facility in south San Jose, California, and cost between $20 and $30 million. The facility will also house a 5MW turnkey solar manufacturing line from Roth & Rau.

"SVTC Technologies has seen a surge in demand for a facility devoted exclusively to the solar industry, which is why we have established the Silicon Valley Photovoltaic Development Center," said Kurt Laetz, SVTC Solar Program Manager. "We want to serve the solar manufacturers already here and attract new ones, helping to establish Silicon Valley as North America's premier environment for solar innovation. By tapping into the enormous talent, creative energy and financial support focused in this region, we intend to do for solar energy what Silicon Valley has done for other high-tech industries."

According to SVTC, solar cell manufacturers and solar start-ups will be able to access the Roth & Rau equipment for product development purposes, while Roth & Rau will benefit from having these potential customers working on their tools. Additionally, Roth & Rau will use the Silicon Valley Photovoltaic Development Center as its North American demonstration showroom.

"It is a testament to the power of our mission, and to the respect that SVTC Technologies has gained worldwide, that companies of the calibre of Roth & Rau have chosen to join our Silicon Valley Photovoltaic Development Center at its inception," said Laetz. "Being able to offer an automated solar cell manufacturing line, as well as crucial certification services, will be extremely valuable for manufacturers of new solar products."

"SVTC Solar is providing a vital piece of the solar energy puzzle in the U.S., and we immediately recognized the importance of being a partner in their venture from the beginning," said Dietmar Roth, CEO of Roth & Rau AG. "We are pleased to bring our solar cell manufacturing equipment and extensive industry expertise to this exciting new photovoltaic development center and using it as our North American demonstration showroom."

JA Solar has also signed a letter of intent to locate its North American research and development operations in the Silicon Valley Photovoltaic Development Center.

"We are very impressed with the Silicon Valley Photovoltaic Development Center's facilities, services and goals," said Dr. Kang Sun, President and COO of JA Solar. "We look forward to a long and fruitful relationship with the centre and with SVTC Solar, which we expect will result in our ability to develop exciting new products for our customers worldwide."

Magnolia and Kopin to co-develop indium nitride-based quantum dot solar cells

Magnolia Optical Technologies and Dr. Roger Welser of the Kopin Corporation have announced their co-development of indium nitride-based quantum dot solar cells for NASA and defense applications. Magnolia and Kopin have carried out successful collaborative development of GaN-based materials in the past. The aim of the current research is to develop high-performance solar cells that can withstand such conditions as can be encountered in use in situations such as NASA space exploration and other defense applications.

"Quantum effects in nanostructured materials enable new innovative device concepts that can radically enhance the operation of traditional semiconductor devices," said Dr. Ashok Sood, President of Magnolia. "For example, a larger fraction of the solar spectrum can be harnessed while maximizing the solar cell operating voltage by using quantum wells and quantum dots embedded in a higher band gap barrier material. Nanostructured devices thus provide a means to decouple the usual dependence of short circuit current on open circuit voltage that limits conventional solar cell design. Ultra-high conversion efficiencies are predicted for solar cells that collect both low and high energy photons from the solar spectrum while maintaining high voltage operation."

NexTechFAS to collaborate with Abbie Gregg, Inc. on solar technology development

The partnership between NexTech Solutions, Inc. and FAS Holdings Group, LLC, entitled NexTechFAS, has announced that it is collaborating with engineering and consulting company Abbie Gregg, Inc. (AGI) on solar technology development.

The agreement has seen the companies work together on technologies being used in early stage organic photovoltaic and touch screen displays, and they have also announced significant orders from RPO and another unnamed organic solar cell company.

Day4 Energy claims 18% cell efficiencies for multi-crystalline cells

Day4 Energy, Inc. has said that its Generation II solar cell technology and processes have reached a new performance milestone with conversion efficiencies reaching 19 percent on mono-crystalline and 18 percent on multi-crystalline silicon materials in its R&D lab. Importantly, the company claims that when the Gen II technology is put into production over the next 18 months, production costs will have been reduced by up to 25 percent compared to conventional production costs.

"Our first generation 14.7 percent efficiency Day4 MC module, which has been in commercial production since 2006, already places us among the industry's highest performing multi-crystalline products," said Professor Leonid Rubin, Chief Technology Officer of Day4 Energy. "With the second generation of our proprietary solar cell designs we are taking a major step towards making solar energy cost competitive with conventional sources of electrical power generation."

Day4 Energy is currently in discussions with a number of partners in respect to its new process and has also recently filed a patent application in connection with this invention.

Dyesol signs €600,000 DSC development contract with Acrosol, Korea

Dyesol Ltd. has agreed to provide a turnkey R&D laboratory and comprehensive training in Dye Solar Cell (DSC) development with Korea-based Acrosol, a Korean University spin-out company. The €600,000 agreement will see the companies collaborate on the commercialization of Acrosol's DSC technology and products via materials supply and technical co-operation.

Acrosol is located in the business incubator at Chonnam National University and has particular expertise in Dye Solar Cell nanomaterials such as Phosphor-Doped DSC. The contract was finalized following the initial payment of €150,000 to Dyesol.

"Dyesol is increasingly being recognised as the world leader in DSC materials and technology," said Gordon Thompson, Dyesol Director Global. "There is a rapidly growing demand for our technology, turnkey facilities, materials, and practical expertise from an increasing number of companies entering the DSC market operating in diverse geographic locations."

AT&S to collaborate with Solland Solar on solar cell applications

AT&S and Solland Solar have announced their intention to collaborate on the development of a concept for solar cell applications. AT&S, the printed circuit board producer, and Solland Solar, manufacturer of standard and back-contact solar cells, have entered into the development partnership in an effort to reduce the cost and increase the efficiency of solar cells.

The companies intend to design an innovative solar module concept by using processes and materials common to both the photovoltaics industry and the printed circuit board industry. A fully functional prototype is planned, which will be presented and assessed for suitability to mass production.

Dow Corning's new Solar Solutions Application Center targets silicon sectors

The opening of Dow Corning's $3 million, 27,000 square foot Solar Solutions Application Center in Freeland, Michigan, USA, is designed to develop, evaluate and produce pilot quantities of materials designed specifically for the silicon PV industry across various PV technologies.

Dow Corning hopes to collaborate with the broadest range of potential customers

VACUUM SOLUTIONS FOCUSED ON SOLAR CELLS PRODUCTION

As a worldwide expert in vacuum technologies with extensive experience in the semiconductor industry, Alcatel Vacuum Technology offers a full range of energy efficient vacuum pumps dedicated to solar cells manufacturers and OEM's.

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adixen
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from all sectors of the PV industry as it claims to be one of the few companies able to provide silicon-based solutions throughout the entire photovoltaic value chain.

"Dow Corning's goal is to help the solar industry move towards being economically competitive with conventional energy sources, and become a sustainable energy option globally," said Eric Peeters, Global Executive Director, Dow Corning Solar Business. "This first application center represents our intention to be an active, eager partner with researchers, producers and governments as we help develop affordable and efficient solar energy for the global energy market."

"We're bringing the same kind of in-depth understanding of chemistry and technology that we've been applying to many other industries to the solar industry value chain," said Gaetan Borgers, Global Industry Director, Dow Corning Solar Business. "We're addressing key issues such as availability of raw materials and cost, durability and performance of solar modules. Today's energy needs require multiple solutions, and the diverse capabilities and extraordinary potential of solar energy will play a significant role in solving these challenges."

Dow Corning said it was investing to expand its portfolio of total solution packages for solar cell manufacturing, module assembly and installation applications.

News

Cell Production News Focus

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

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

"As one of the highest quality solar module manufacturers in the world, Solon is and will continue to be a strong industry partner for Suniva," said John Baumstark, CEO of Suniva. "This agreement marks another milestone in our growth strategy as we solidify Suniva's powerful position in the solar supply chain."

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

IBC SOLAR places 10-year solar cell order with ersol worth over €500 million

The second long-term supply order for IBC SOLAR over the past few days brings the company's total spend this week to approximately $2 billion. The company has placed an order with ersol Solar Energy AG for the supply of crystalline silicon solar cells over the next 10 years, an order that is worth over €500 million. The $2 billion total also takes the company's recent $1.2 billion order with Evergreen Solar into account.

The high-grade solar cells will be delivered to IBC's Bad Staffelstein location in Upper Franconia in Germany over a 10-year period. ersol will receive a downpayment from IBC SOLAR, which will later be credited to the company at time of purchase. This latest contract brings ersol's total order volume to close to €4 billion.

Evergreen Solar signs $1.2 billion sales agreement with IBC SOLAR

In a further extension to the company's order backlog, Evergreen Solar has agreed to supply IBC SOLAR AG with solar panels to the value of approximately $1.2 billion. The contract, which extends through 2013, brings the company's contractual backlog to almost $3 billion and is, according to Evergreen's CEO Richard Feldt, the company's largest single contract ever.

The panels will be manufactured at Evergreen's new 160MW facility in Devens, Massachusetts and also at its new facility that is expected to open in 2010. Evergreen Solar has contracted around 70% of its Devens production capacity until 2010 and approximately 100% of its Devens capacity from 2011 to 2013.

SolarWorld targets 1GW in Saxony; secures €750 million cell supply deal with Solar Semiconductor

Capitalizing on a new major crystalline silicon wafer supply deal worth €750 million with Solar Semiconductor Pvt. Ltd, SolarWorld AG, with its subsidiary Deutsche Solar AG, the solar silicon wafer producer, will expand production in Saxony at a new site that will reach 1GW capacity per annum.

"With the new wafer contract we are securing the capacity utilization of the new production facility in Freiberg in Saxony," said Frank H. Asbeck, Chairman and CEO of SolarWorld AG. "We come out clearly in favor of Germany as a production location. The Federal Republic is an international pioneer in the expansion of renewable energies. Motivation and employment qualification are appropriately high. In this environment our investments are well placed."

SolarWorld also reiterated plans for expansion at its Freiberg site to 750MW by the end of 2009, up from 500MW currently. In 2010 this is expected to increase by a further 250MW, the company said. The planned capacity expansions are expected to cost €350 million. The company projected that 500 extra jobs will be created as part of the expansion plans.

Emcore announces $40 million dollar concentrated photovoltaic cell orders

Leading CPV (Concentrated Photovoltaics) cell producer Emcore announced today that it entered into two new supply agreements for solar cells and receivers with a total value of over $40 million. The larger of the two purchase contracts is a multi-year supply agreement for solar cells, to be delivered over four years.

The primary application for CPV is in large-scale commercial and utility grade power generation facilities. While the global market for CPV is driven by Spain, Emcore's latest order is earmarked for deployment in California to take advantage of the attractive government support of the solar industry. Production for these orders has commenced and approximately $1 million of product is expected to be shipped in the present quarter.

Emcore was the first company to provide its customers with a 20-year performance warranty making the company extremely attractive to the long-term financers, typical in the power generation segment of the market.

ARISE Technologies starts volume production of 7N+ silicon PV cells

ARISE Technologies has said that it is now operating Line 1 of its photovoltaic cell plant 24 hours a day, seven days a week in Bischofswerda, Germany. The company started production in mid-April and is known for its strategy to produce silicon at 7N+ high-purity (99.99999 percent purity) to gain above-average cell efficiencies.

"With the successful completion of the Site Acceptance Tests for Line 1, we are ramping up our production levels to meet our customers' requirement for PV cells. This is another milestone for ARISE in our path towards becoming a leading supplier of PV cells for the solar energy industry," said Bart Tichelman, President and Chief Executive Officer. "We are achieving the targeted level of 15.0% average PV cell efficiency with a peak efficiency of 15.7%, as well as our targets for manufacturing yield and throughput. We were pleased to present our equipment supplier OTB Solar B.V. of Eindhoven, the Netherlands) with the acceptance letter certifying that it has met our specifications. We appreciate the efforts that they and our management team and staff at the plant have made to enable us to meet our rigorous requirements. In only a few months, we have progressed from producing our first PV cell in mid-April to where we have been able to move to 24/7 production," Tichelman said.

The company said that selected customers were now testing early production cells.


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Q.CELLS

Tool Order News Focus

ChengDu Tianwei New Energy PV Module Co. Ltd. (Tianwei) has selected stringing and tabbing systems from Spire as well as multiple 'Spi-Assembler' 6000 systems to fully automate the soldering of individual solar cells into strings ready for busing. Tianwei is automating these production steps as part of its plans to increase capacity of its solar cell products. Tianwei is expected to have 100MW of cell capacity and 60MW of installed PV module capacity by the end of 2008. In 2009, the company is planning to increase total cell and module capacity to 300MW.

Spectrolab has placed a multi-unit order with Veeco Instruments for its TurboDisc K-475 As/P (arsenic phosphide) metal organic chemical vapor (MOCVD) deposition system. The tools will be used for the fabrication of the Boeing-owned divisions space-based solar cells.

A Europe-based solar cell manufacturer has placed a significant follow-on order with Synova for 25 'Laser MicroJet' systems that will be used for a proprietary edge-defined film-fed growth (EFG) process for 125 and 156mm wafer cell trimming from polysilicon ingots. This is one of Synova's largest ever orders and marks a new application for its laser technology. Several systems have already been shipped and installed, with the remaining modules expected to be integrated in 2009 through 2010.

The Ludwig-Maximilians University (LMU) in Munich, have ordered an advanced sputtering tool from U.K.-based Surrey NanoSystems. The tool will be used in the creation of high-efficiency interconnection templates for organic materials, thereby greatly increasing the efficiency of the cells, according to LMU. The tool, a configuration of Surrey NanoSystems' Gamma PVD sputtering tool, will be put into operation at the LMU's Department of Physics and Centre for NanoScience.

A Europe-based photovoltaics manufacturer has ordered an automated batch-immersion system for advanced heterojunction solar cell production from Akrion. The solar wet station will ship to Europe later this year and will be used on monocrystalline solar wafers.

Tempress Systems, a division of Amtech Systems, has received a follow-on order from an existing customer and initial orders from two new customers, all based in Asia, the company said. The orders amount to US$8.5 million for Tempress' diffusion processing systems.

Hyundai Heavy Industries is to enter the solar cell manufacturing industry on the back of an order placed with centrotherm photovoltaics AG, for five 50MW turnkey crystalline solar cell manufacturing lines. All five lines (250MW) will be delivered in 2009 to Hyundai's Eumesong location in South Korea.

Other News

Canadian Solar revises capacity targets upwards

Strong demand for its lower cost e-Module products that use 100 percent Upgraded Metallurgical Grade (UMG) Si has seen Canadian Solar (CSI) raise production and revenue projections for 2008. The company said that it has firm orders for 35MW of e-Modules and another 20MW of potential new orders. The sales are to be realized in the second-half of the year, CSI said. The company estimates that it will ship approximately 10 - 12 MW of e-Modules to USA and South Korea in 2008. Overall, CSI now expects production output to be between 230MW and 260MW, compared to its previous projection of between 200MW and 220MW. Revenues are expected to increase to a range of $750 - $870 million, up from $650 - $750 million.

CSI also expects to increase its annual ingot and wafer capacity from the previous target of 40 - 60 MW to 150 - 200 MW. Internal cell capacity will be increased to 400MW, up from a target of 250MW. Module capacity will also increase to 800MW. The new capacity is expected to be commissioned by the beginning of 2009.

Yingli Green starts production at 200MW expansion

Yingli Green Energy has said that in late June 2008, it started small-scale production of polysilicon ingots, wafers, PV cells and PV modules from its latest 200MW expansion project. Tool installation is ongoing and on time, the company said.

"Given our accumulated experience over the past few years in expanding capacity, we believe that we will complete this project on time in the fourth quarter of this year," commented Mr. Liansheng Miao, Chairman and CEO of Yingli Green Energy. Tool installation is expected to be completed in the fourth quarter of 2008, with full production expected in late 2008. Yingli Green's total production capacity is on track to reach 400MW.

Kyocera fully converted to 180 micrometer solar wafer thickness

Kyocera has said that it has now converted all of its multicrystalline photovoltaic cell production plants to 180 micrometer wafer thickness, compared to the current industry standard of between 200 to 260 micrometers. "Long-term contracts with our supplier partners assure us of sufficient silicon stocks to expand our production output from about 207 megawatts of solar modules in 2007 to a target of 500 megawatts in the year ending March 31, 2011," said Steve Hill, President of Kyocera Solar, Inc. Kyocera also reiterated achieving a new world record of 18.5 percent efficiency in its multicrystalline silicon solar cells in October 2006. The cell design which uses electrical contacts mounted on the underside of the cell is expected to enter mass production by March 2010.

Product Briefings

SierraTherm

SierraTherm's new APCVD system offers 660mm deposition width

Product Briefing Outline: SierraTherm Production Furnaces has introduced its new 5500 Series APCVD system with a 660mm deposition width. This tool is capable of depositing a combination of up to five layers of doped (BSG, PSG) and undoped SiO_2 films in a single pass. Its throughput capacity of 1875 WPH for 156mm wafers or 2300 WPH of 125mm wafers make it compatible with today's high production cell lines. Films with thicknesses of up to 300nm can be deposited at this process speed.

Problem: Depositing doped and undoped SiO_2 films onto crystalline silicon solar cells has been problematic due to the unavailability of high throughput deposition equipment. Atmospheric pressure chemical vapor deposition (APCVD) systems transport wafers on a conveyor belt and deposit films at elevated temperatures as the wafers pass beneath chemical injector heads. The production capacity of in-line APCVD systems has only a fraction of requirements due to limitations on film deposition width across the conveyor belt used to transport the cells.

Solution: The 5500 Series APCVD conveyor furnace is well suited for continuous high volume processing of substrates requiring single as well as multi-layer thin films. SierraTherm's in-line system design assures that each substrate receives the same process treatment.

Applications: SnO_2:F. Transparent conductive oxide for sheet glass. Other conductive film applications include SiO_2, undoped; diffusion barrier or insulating layer for silicon wafers or soda-lime sheet glass; SiO_{2-}, boron- or phosphorous- doped (BSG or PSG) TiO_2. Antireflective layer for silicon solar cells.

Platform: Maintenance-conscious design allows chemical injectors and exhaust ducting to be cleaned in situ. Multiple injector heads can be used in series within a single furnace, maximizing process throughput, uniformity, and flexibility while minimizing cost. Modular chemical vapour injector head assemblies allow quick and easy installation and removal from the coating chamber.

Availability: July 2008 onwards.

MANZ

MANZ complete back-end line offers throughput of 2400 cells per hour

Product Briefing Outline: The MANZ I-series back-end line has a throughput of 2400 cells per hour, and is claimed to be the fastest backend system available in the market today. One single system includes printing, firing, laser edge isolation, cell testing and sorting for crystalline solar cells.

Problem: To manufacture crystalline solar cells, electrical contacts must be created on the front and back side of the solar cell. The three metal layers (one on the front and two on the rear side) are created using a screen printing process. Metal particles dissolved in a solvent are transferred to the solar cell through a textured screen. The wet paste must then be then dried in an oven after each printing step. Existing suppliers of screen printing machine have a maximum throughput of 1500 cells per hour.

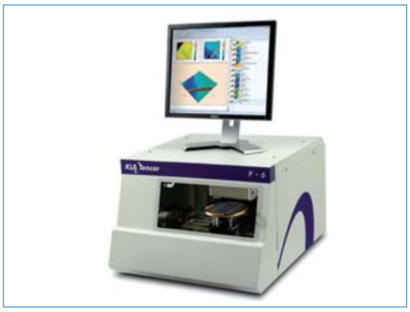
Solution: The MANZ Back-end line prints two cells at once and integrates additional process steps such as firing, laser edge isolation or cell testing and sorting. The system is able to replace two traditional screen-printing systems and saves investment, space, consumable and labour costs. Additional features include: printer; micro crack control system before the first printing step to lower the breakage rate in the system; automatic screen cleaning system; closed-loop print control after each individual printing step using MANZ vision systems; automatic paste dispenser; tester and sorter; electrical measurement using H.A.L.M; front- and rear-side measurement using MANZ vision systems' 3D contamination measurement and electroluminescence measurement.

Applications: Printing, firing, laser edge isolation and testing and sorting of crystalline solar cells.

Platform: Standardized modules from MANZ I-series: IML 2400 – Inline Metallization Loader; IPC 2400 – Inline Print Contact; IDF 2400 – Inline Drying furnace; IWB 2400 – Inline Wafer Buffer; IFF 2400 – Inline Firing Furnace; ILE 2400 – Inline Laser Edge Isolation and the ICT 2400 – Inline Cell Tester and Sorter.

Availability: September 2008 onwards

KLA-Tencor



KLA-Tencor's new P-6 surface profiler handles 2D and 3D surface analysis

Product Briefing Outline: KLA-Tencor has unveiled its latest stylus surface profiling system, the 'P-6,' offering a unique set of advanced features for scientific research and production environments, such as photovoltaic solar cell manufacturing. The P-6 system benefits from measurement technologies developed on advanced semiconductor profiler systems, but in a smaller, more economical bench top design for samples up to 150mm. The P-6 profiler has been qualified at BP Solar, a major photovoltaic manufacturer

Problem: For the solar market, the P-6 has the resolution, scan quality and automation needed to improve solar cell efficiencies in the development stage, as well as monitor process quality in production.

Solution: The P-6 offers complete high resolution 2D and 3D analysis of surface topography in a versatile platform, which is claimed to have the best price-to-performance capabilities available from any manufacturer. The system's three different measurement head configurations offer flexibility for a wide range of vertical topographies, and the P-6's 'point-and-click' user interface makes it easy to operate. New features include: low noise floor improves measurement sensitivity to characterize small topography; less than 6Å step height repeatability ensures stringent process control; 150mm X-Y sample stage enables single measurement to cover full substrate and 2D stress measurement and analysis minimises defects and improves yield.

Applications: The P-6 Stylus profiler is capable of addressing a wide range of measurements and applications such as thin-film and thick-film step heights; photoresist/soft films; etched trench depth; materials characterisation for surface roughness and waviness; surface curvature and form and 2D stress of thin films, amongst others.

Platform: Standard 2μm radius stylus, with options from sub-micron to 25μm radii available. Extensive list of standard measurement parameters, Apex report generating software and advanced 3D imaging.

Availability: July 2008 onwards.

Product Briefings

MTI Instruments

MTI Instruments launches its PV1000 thickness measurement system

Product Briefing Outline: MTI Instruments has introduced the PV1000, a thickness measurement system for the solar cell production industry. PV1000 can be incorporated into solar cell production lines to help them quickly determine quality control issues, saving manufacturers time and money.

Problem: PV1000 addresses a critical need for solar cell manufacturers around the world who are now experiencing significant growth and need to manufacture higher quantities of solar cells for mass consumption.

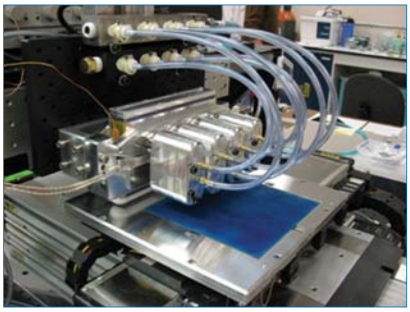
Solution: Using MTII's exclusive Push/Pull capacitance probe technology, each PV-1000 module provides up to three pairs of probes for measurement of maximum, minimum and average thickness, as well as total thickness variation (TTV) and wafer bow. For applications requiring additional thickness channels, multiple PV-1000 modules can be chained together for unlimited line scans on the wafer. Wafer saw mark detection and classification is accomplished by adding optional laser sensors to the PV-1000 module. Utilizing up to two of MTII's Microtrak – SA standalone laser heads, saw marks can be classified for orientation and depth simultaneously with wafer thickness scanning making the PV-1000 ideal for incoming wafer characterization and sorting.

Applications: Wafer Type: mono- or poly-crystalline silicon. Surfaces: As-cut, lapped, etched, SiN layer.

Platform: Each PV-1000 module comes with a complete software package for easy integration into the existing production line. The Windows-based interface package allows for quick set-up, calibration and data monitoring at the module or across the Ethernet network. Multiple PV-1000 modules can be monitored from a single location using standard TCP/IP protocols.

Availability: July 2008 onwards.

MANZ/Optomec



MANZ/ Optomec Aerosol Jet technology prints features below 40 microns

Product Briefing Outline: MANZ print station powered by Optomec Aerosol Jet Manz offers a new print station for contact-less printing of crystalline solar cells using OPTOMEC Aerosol Jet technology and will be the exclusive sales and marketing partner for the Optomec solar applications. Optomec has developed an advanced contact-free metallization process for crystalline solar cells. Manz will integrate the Optomec technology into its back end line platform.

Problem: To manufacture crystalline solar cells, electrical contacts must be created on the front and back side of the solar cell. The three metal layers (one on the front and two on the rear side) are currently printed using a screen-printing process. Metal particles dissolved in a solvent are transferred to the solar cell through a textured screen. The wet paste then must be dried in an oven after each printing step. However, the screen-printing process is reaching its limits as the industry pushes for higher efficiency solar cells and thinner wafers.

Solution: The MANZ/Optomec solution utilises a proprietary Aerosol Jet technology capable of depositing inks, pastes, or other liquid materials on a variety of surfaces with printed features below 40 microns. Aerosol Jet technology is a non-contact direct write process that is able to print much finer lines than is currently possible with traditional screen-printing. The narrower, high integrity collector lines have higher conductivity and a lower shadowing effect, thereby increasing photovoltaic cell efficiency. In addition, because the process is non-contact, Aerosol Jet technology can print on thinner wafers and with less breakage than screen-printing techniques. The Optomec solution, together with an additional electroplating process, shows efficiency improvements of solar cells of 0.5-1% or more in absolute figures as documented by Fraunhofer ISE.

Application: Contact-free printing of highly-efficient crystalline solar cells

Platform: Integrated Optomec Aerosol Jet into MANZ IPC module

Availability: September 2008 for selected customers.

Ultrasonic Systems, Inc.

Ultrasonic Systems' PV360 cell coating system offers uniform spraying

Product Briefing Outline: Ultrasonic Systems, Inc. (USI) has introduced the PV360, which is a production coating system for photovoltaic wafers. The system features USI's proprietary nozzle-less spray technology, which provides a more uniform, thinner coating application than conventional spray technology.

Problem: With a material transfer efficiency of 95-99%, this technology delivers a more controllable coating deposition than conventional spray nozzles, ultrasonic nozzles and other coating deposition techniques, according to the company.

Solution: The PV360 Coating System features USI's nozzle-free, ultrasonic spray technology to apply a thin, uniform layer of phosphoric acid, phosphoric oxide and other proprietary coatings for the production of solar cells. The system consists of a non-metal conveyor to transport the wafers and a synchronized, traversing nozzle-less ultrasonic spray head for coating application. The wafers are conveyed with a self-cleaning mesh belt conveyor, which is constructed from Teflon-coated Kevlar and is compatible with most phosphoric acid-based coatings. The conveyor utilizes a water-based cleaning system and an IR drying system to ensure that coating is not transferred to the bottom side of the wafers. The conveyor width is 914mm (36 inches) and can accommodate up to six rows of 125mm (5-inch) wafers. The conveyor transports the wafers at a constant speed up to 1,524mm/minute (60 inches/minute).

Applications: Deposition of phosphoric acid, phosphoric oxide and other proprietary coatings for the production of solar cells.

Platform: The Ultra-Spray ultrasonic spray head produces a rectangular, lineal spray pattern at a width up to 152mm (6 inches). The spray head is mounted to a traversing mechanism, which moves at an adjustable angle with respect to the direction of conveyor travel. Spray stroke – up to 2,000mm/sec (79 inches/sec). Return stroke – 2,000mm/sec (79 inches/sec)

Availability: August 2008 onwards.

Silicon nitride thin films in μc silicon solar cell production

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ABSTRACT

Ever since the introduction of attractive feed-in tariffs for photovoltaic electricity generation, there has been a huge surge in all kinds of photovoltaic applications. Products based on multicrystalline wafers still have the largest market share with thin-film products picking up in recent times. In the course of this process, production technology for wafer-based solar cells has been improved. With the second generation of tools, a trend towards standardization is apparent.

Deposition of silicon nitride is one of the key processes of solar cell production. While its technological significance is often underestimated, it is the only process step that serves a multitude of purposes. In this contribution we will present aspects of the deposition of silicon nitride thin films and discuss open questions with respect to the physics of the deposition process and its implication on machine technology.

Introduction

The deposition of thin films is a key technology for a large variety of technical and scientific applications. Among them is the deposition of silicon nitride (SiNx) to passivate the surface of silicon solar cells. The SiN film serves several purposes. It is a broadband anti-reflection layer, it serves to saturate dangling bonds and/or other surface states of the silicon, and last but not least, it is a protection layer to prevent alkali ions and other impurities from diffusing into the silicon causing perturbations of the performance of the solar cell. This multitude of properties to be fulfilled at the same time often causes difficulties in assessing the effect of a single process parameter, let alone the task of optimizing the SiN film in all required aspects at the same time. The aforementioned technical features of the SiN film provide the very property that largely determines the aesthetically pleasing appearance of a cell, and hence a PV module, as the colour of the module is determined by the cell composition. In order to complicate things further, there are numerous deposition techniques being applied both on a scientific level as well as in production environments.

Silicon nitride has been investigated intensively for a long time for a variety of purposes like passivation of InP (indium phosphide) [1], while its application to MIS solar cells has been known for quite some time [2]. It is therefore beyond the scope of this paper to discuss all aspects of various features of the SiN deposition, nor is it the goal of this article to discuss the machinery used and its implications on film properties. While to the best of our knowledge there is no comprehensive review article in existence, major aspects of the process have been covered elsewhere

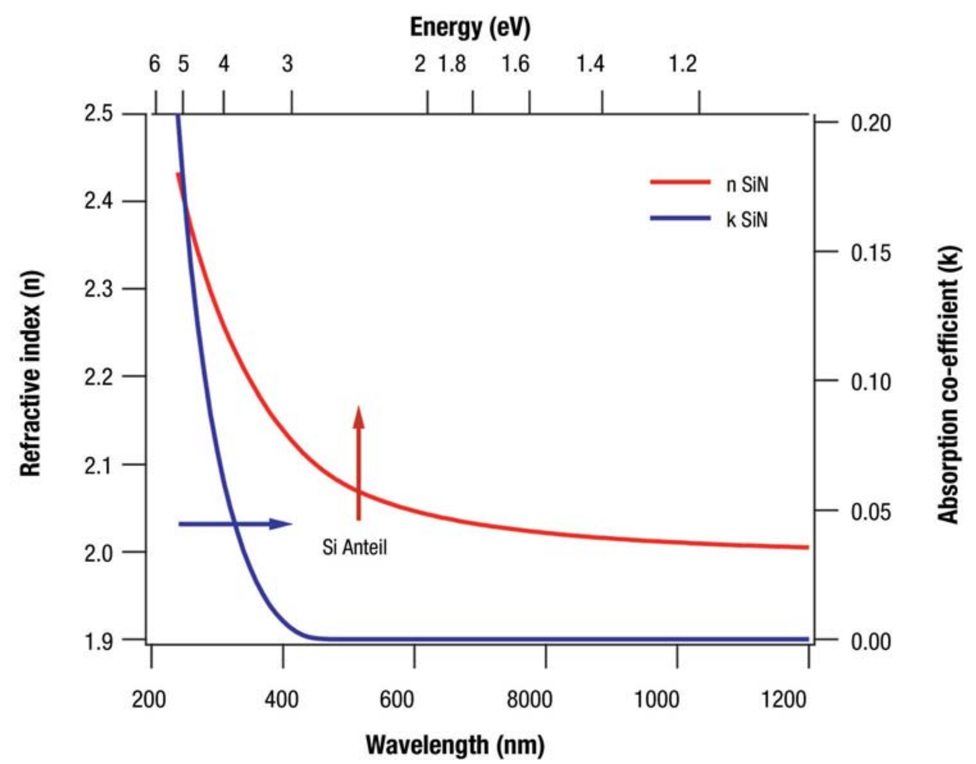

Figure 1. Calculated refractive index and absorption coefficient of a SiN_x film as a function of incident wavelength. The effect of a change in stoichiometry of the SiN_x film is indicated with red and blue arrows, respectively.

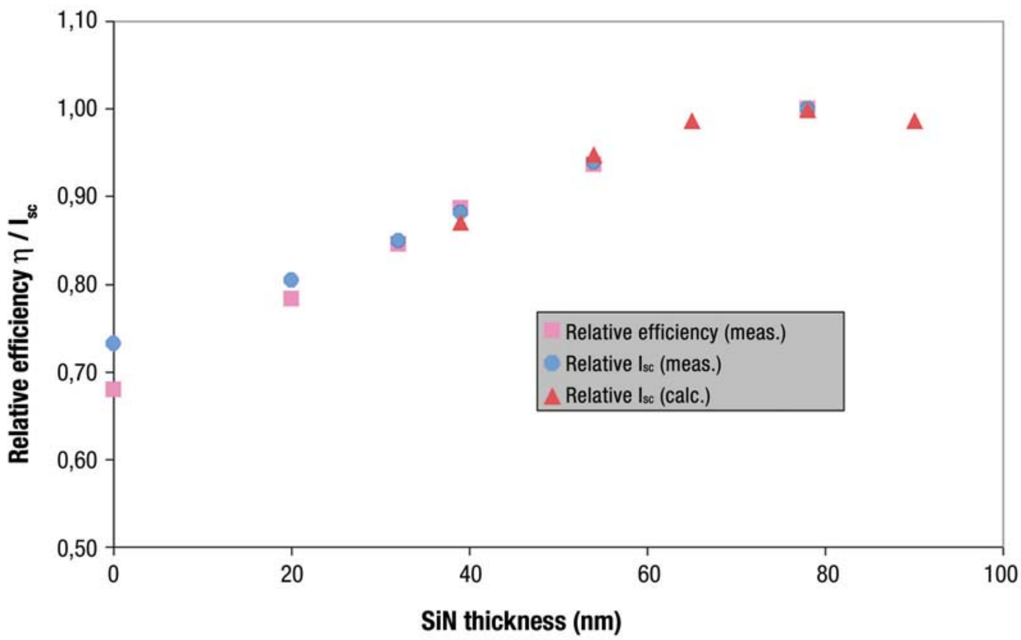

Figure 2. Relative efficiency and short circuit current as a function of SiN thickness. Data are presented in comparison with calculations using PC1D.

[3,4,5]. In this contribution, we will focus on assorted, globally measurable bulk properties of the SiN film and their impact on solar cell performance. We will concentrate mainly on the effect of a change in film thickness – at first glance a very simple parameter that appears to be easily controlled. Its effect can easily be demonstrated; nevertheless the underlying physics are a little more complicated.

Optical properties of thin SiN_x films

It has both been calculated [6] and shown experimentally [7] that for a single layer of antireflection coating, the maximum efficiency of light conversion for the Si/SiN/air stack is obtained at n_{633nm}~1.9 at a thickness of d~85nm, assuming zero or negligible absorption. Currently, most ARC coatings on solar cells are deposited using a slightly higher refractive index accounting for the encapsulation in a module. In most cases, a refractive index of n_{633nm}~2.05 [7] is used today. Considering the low refractive indices of glass and EVA, the optimum refractive index is even higher, which would also be desirable from a point of view of electrical passivation [8]. From Figure 1 it can be noted that the refractive index of an SiN layer is easily adjustable by changing the silicon content of the film, which in turn is achieved by changing the gas ratio between the Si-containing precursor (SiH_4) and the nitrogen-containing precursor (N_2 or NH_3).

> The maximum efficiency of light conversion for the Si/SiN/air stack is obtained at n_{633nm}~1.9 at a thickness of d~85nm, assuming zero or negligible absorption.

In Figure 1, the spectral behaviour of the absorption value k is also given. Films

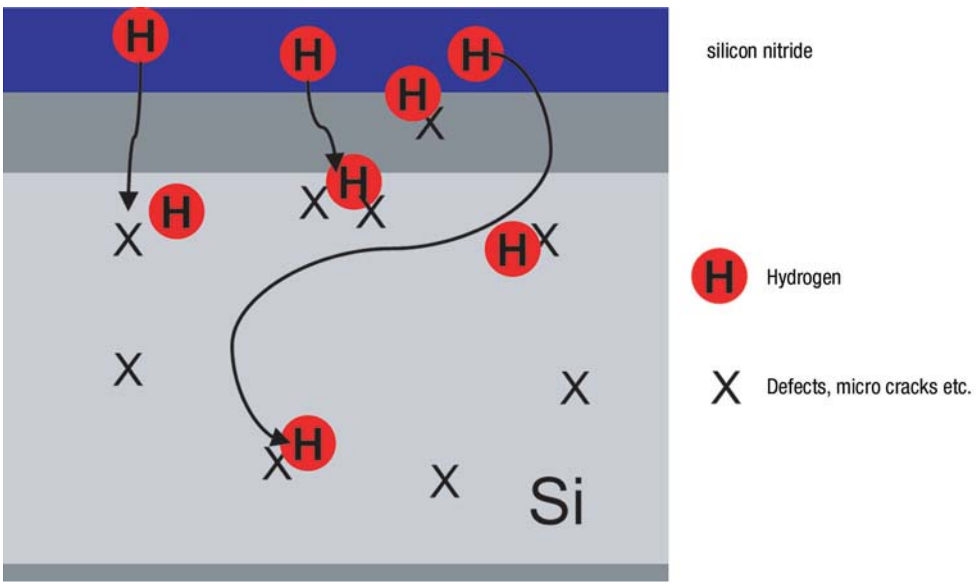

Figure 3. Model showing the effect of hydrogen diffusing to the interface of silicon to SiN and into the bulk of the silicon substrate.


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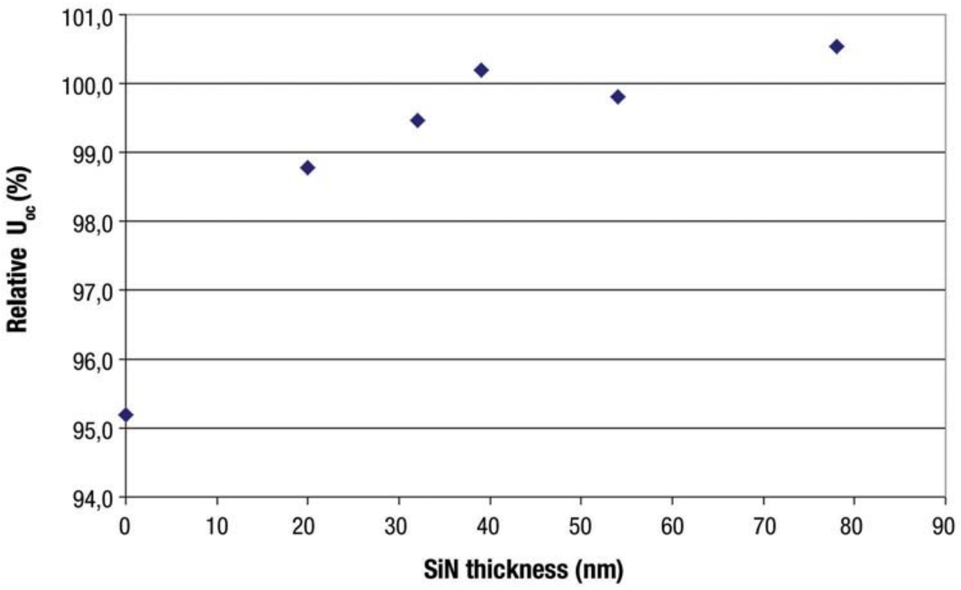

Figure 4. Relative open circuit voltage as a function of SiN thickness.

with low Si content (i.e. low refractive index) can be correctly assumed to exhibit zero or negligible absorption. On increasing the silicon content in the SiN film, the absorption of the film is also increased.

Figure 2 shows the relative efficiency of solar cells and their respective short circuit currents. The data given in Figure 2 has been obtained by preparing solar cells using different metallization procedures taking into account varying sintering properties of the films yielding well-contacted cells. Care was also taken in comparing films with the same refractive indices. Both the relative efficiency and the I_{sc} increase with increasing SiN film thickness to reach a maximum at the desired film thickness. The data obtained by experiments correlate well to calculations using PC1D, the solar cell modelling program.

In order to capture as many photons from the solar spectrum as possible, it is necessary to coat the silicon substrate with a broadband antireflection layer. The basic data for this AR coating can be derived from first principles. For economic reasons, it needs to be a single layer, thus exhibiting a single, broad minimum. Since photovoltaic devices are essentially photon counting systems, it is desirable for the AR coating to have a minimum in the spectral reflectivity at an optical thickness of approximately 650nm. Once the refractive index of the coating is known, the necessary geometrical thickness can be calculated. Assuming no absorption and a refractive index of n~2.05, it is concluded that a geometrical thickness of d~80nm should be deposited. The case is somewhat different in case of a layer exhibiting a gradient of the refractive index with layer thickness, although basic data can be derived in the same way.

Bearing these thoughts in mind, it is clear that the main effect given in Figure 2 stems from increasingly perfect matching of the optical film thickness to the optimum required to yield a broadband antireflection layer. Thus, it is also clear that from a standpoint of a cell manufacturer, utmost care needs to be taken to achieve and control good reproduction of data on a day-to-day basis in both the homogeneity of deposition on a cell as well as in run-to-run. Fortunately, this matches with the need to produce cells and modules with an aesthetically pleasing appearance.

Thus, it is also clear that from a standpoint of a cell manufacturer, utmost care needs to be taken to achieve and control good reproduction of data on a day-to-day basis in both the homogeneity of deposition on a cell as well as in run-to-run.

Silicon nitride is also supposed to be a source of hydrogen to saturate defects and micro fissures in the bulk of the silicon wafer. This process is schematically shown in Figure 3. The silicon nitride deposited on the wafer typically contains approximately 10-15 at. % hydrogen. It is shown by FT-IR that this hydrogen is both bonded to the silicon as Si-H as well as to the nitrogen as N-H.

In order to confirm correlations between the bulk hydrogen content of silicon nitride and the properties of the interface between silicon and nitride, we performed NRRA measurements [9,10] to evaluate a hydrogen depth profile on different parts of a wafer. It was expected that the depth profile of the samples in question would reveal differences in the depth distribution of the hydrogen. Interestingly, there was no clear correlation, a fact that was also observed by Hofmann et al [10]. This result indicates that the bulk properties of the passivating film may not correlate as clearly to properties of the silicon solar cells. On the other hand, this does not rule out a contribution of bulk SiN properties on the passivation of silicon surfaces. More investigation is needed to clarify the role of the SiN layer in passivating silicon solar cells.

The quality of a surface passivation is usually assessed by determining the emitter saturation current j_{oe}. The lower the j_{oe}, the lower the recombination rate of electrons. Assuming that the recombination of electrons is evenly distributed in the solar cell, so the recombination rate is by and large determined by the surface properties. The j_{oe} gives a good estimation of the quality of a surface passivation, which in turn has a direct impact on the open circuit voltage V_{oc}. As it is more difficult to correctly determine j_{oe} than V_{oc}, which is routinely measured together as part of the electrical characteristics of a solar cell, we took this value as associated with the quality of a surface passivation [11]. This assumption is especially justified in experiments in which all other factors (e.g. sheet resistance) determining V_{oc} are kept constant.

In an attempt to assess the influence of the SiN thickness on the passivation quality of the interface between SiN and Si, the V_{oc} data from the same set already discussed in reference to Figure 2 was

analyzed. The data shown in Figure 4 indicates that while a minimum thickness of around 25-35nm is required for surface passivation, little or no changes in V_{oc} are noted with increasing film thickness as required by the demands of optical light coupling as discussed previously.

While it appears to be necessary to supply a minimum amount of thickness passivation, there is no clear-cut correlation to solar cell properties with increasing film thickness other than optical optimization.

The data in Figure 4 also explains in a straightforward way the difference between the relative efficiency and the I_{sc} with decreasing film thickness as noted in Figure 2. Thus, we conclude that while it appears to be necessary to supply a minimum amount of thickness passivation, there is no clear-cut correlation to solar cell properties with increasing film thickness other than optical optimization. Hence, the passivating role of hydrogen stemming from the bulk of the SiN film needs to be investigated more closely. Moreover, there is no clear correlation of the amount of hydrogen in the SiN film to the minority carrier lifetimes as measured by μ-PCD. Our data suggests that the properties of

the SiN/Si interface with respect to density of surface states' impurities imposed by dangling bonds or crystal mismatch and their saturation by the passivating layer may play a more important role than is commonly assumed. We realize, however, that much more and detailed work needs to be done to clarify the physical principles underlying the interface properties and their respective correlation to solar cell functions.

Summary

Silicon nitride thin films of the stoichiometry $Si_xN_yH_z$ (SiN) are widely used in μc silicon solar cell production. As with most other thin-film applications in any industry, the SiN films serve multiple purposes:

1. They serve as an antireflection layer in order to increase light absorption in the wavelength range where a silicon solar cell can convert light to electricity.
2. The colour of the layer determines the 'look and feel' of the solar cell
3. They serve as a diffusion barrier to impurities like alkali ions and other ambient defects.
4. The hydrogen in the SiN films is assumed to serve as a means of saturating dangling bonds at the surface of the silicon, and also to passivate defect states stemming from microfissures and other mechanical faults deep in the substrate itself.
5. SiN films must allow for sufficient sintering through of the metallic pastes to ensure a reasonable ohmic contact.

We showed in this contribution that with all of the above properties, it is vital for the overall quality of the solar cell that the geometrical and optical film thickness is controlled within strict limits. Any deviation has direct impact on the efficiency of light conversion of the cell. While this may not be a problem on laboratory scale, the sheer volume of production puts forward high demands on the achievable reproducibility of the deposition machines, a feature that is very often underestimated. It is the firm belief of the author that any potentially successful machine concept needs to take reproducibility into account as a key parameter.

The data given in this article further affirms that while application of SiN in μc silicon solar cell production is used very successfully, a lot more work needs to be conducted to clarify the role of the Si/SiN interface, which to a large extent determines the efficiency of the solar cell. In particular, the role of the hydrogen from the SiN film and its effect on the Si surface remains to be investigated in detail.

Acknowledgements

Any work relies on the contribution of several co-workers. To this end, the author is extremely grateful for the work of Martin Hanke and Carsten Swiatkowski of Q-Cells, as well as Dieter Grambole from FZ Rossendorf for the NRRA measurements.

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About the Author

Dr. Hubert-Joachim Frenck studied physics at the University of Münster and took the chair of Prof. Kassing at Kassel to conclude his Ph.D. on 'Molecular engineering in PE-MOCVD thin film deposition' in 1988. The work included the tailoring of silicon nitride precursor molecules to best match the needs of a PECVD process. He has been working in thin-film technology ever since, albeit in various specialist fields. In 1999 he joined Ikarus Solar, where he was responsible for the division fabricating solar selective films for thermal collectors and for developing a range of solar thermal products. He continued this work at Viessmann SA from 2005-07. Dr. Frenck has been with Q-Cells since February 2007 and currently leads the vacuum division of the process development department. Dr. Frenck is married and has two children.

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Wafer, cell and module quality requirements

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ABSTRACT
Standardized requirements for the quality of PV modules, solar cells and wafers are given in the according IEC norms (e.g., IEC 61215, 61646, and IEC 61730 for modules). However, the manufacturers of cells purchasing wafers and the module manufacturers purchasing cells want information beyond the final check of the product and to monitor each step during the production process to identify harsh handling and/or machine faults at the earliest stage possible. With consequential improvements of the process enabled, continuous improvements in throughput and yield improvement of the factory are likely, also allowing an early feedback on quality issues to the raw material supplier. Furthermore, by knowing all characteristics and factors of the cell and the module, prediction of electrical energy yield during the life cycle of a PV power plant is becoming more accurate and more reliable.

Conventional production process

Conventional quality control during the production process of wafers

During the production process, the typical quality monitoring, like the resistivity measurements before and after crystallization, have a limited µ-PCD lifetime determination (see Figure 1). A weight control of the wafers at the end of the process allows checking of the dimensions of the wafer (length, width, and in particular, thickness) and mechanical defects (e.g., torn edges). By using a visual inspection unit, relatively large cracks and severe process irregularities can be detected. These checks cannot identify micro-cracks in the final wafer which are crucial for the performance of the final solar cell and its vulnerability to mechanical stress within operation lifetime.

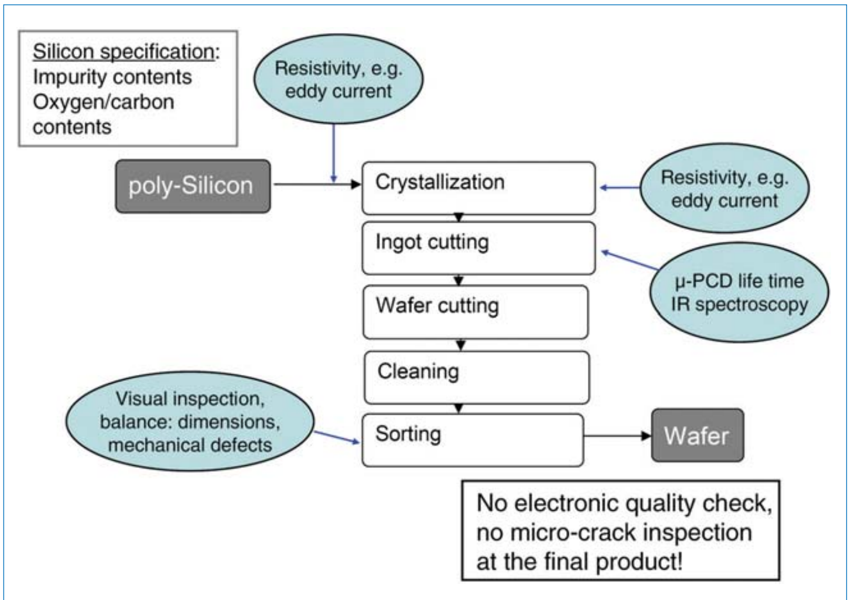

Figure1. Conventional quality control at wafer production.

Conventional Quality control during the production process of cells

During the production process, which is shown in Figure 2, typical quality monitoring is rather limited. At delivery, the incoming wafers are checked for mechanical defects and their dimensions. After wet etching (in order to take away the damaged area from sawing) and the diffusion process (usually where an *n*-type dopant such a phosphor is diffused into a *p*-type substrate), electric sheet resistivity is measured to control the correct amount of doping and diffusion. After de-oxidation (the wafer has been oxidized during its treatment the diffusion furnace) and edge isolation, silicon nitride (SiN_x) is applied as an anti-reflective coating (ARC) on the cell. While the wavelength of maximum absorption (minimum reflection) is given by the thickness of the ARC layer, the reflected part changes its visual appearance (by a slight change in color) that is typically used as a control method for the layer thickness. Also, the quality of the screen-printing process is controlled mainly visually. At the final stage, the cell is flashed to determine its maximum power output P_{max}, the short circuit current I_{sc}, the open circuit voltage V_{oc}, the series resistance R_{series} and the internal shunt resistance R_{shunt}. A supplier feedback can be given only after these test stages.

Quality control via electroluminescence (EL) and photoluminescence (PL)

Principle of EL and PL

Electroluminescence (EL) is the use of a solar cell in a reverse format as it was originally designed. Instead of converting irradiance into electricity, at EL, electricity (supplied via the cell's electrical contacts) is converted into IR-radiation that is emitted via the cell's surface. The intensity of the radiation emission is an indicator for the local efficiency and quality of the conversion process. This method works well for cells and modules, but not for wafers. However, with wafers the radiation emission can be provoked by absorbed photons at a smaller wavelength: the so-called photo-luminescence (PL).

History

PL was discovered at first as a tool for the detection of faults and defects at wafers and solar cells [1]; however, older publications exist that discuss photoemission microscopy (PEM) for failure analysis in microelectronics. During the last two years, a considerable increase in popularity and application of EL and PL could be observed [2]. Meanwhile, EL and PL are even used to identify specific defects, e.g., using PL for the exposure of problems with grid fingers and the related screen-printing process [3], or for the selective identification of defects and faults in cells via electroluminescence

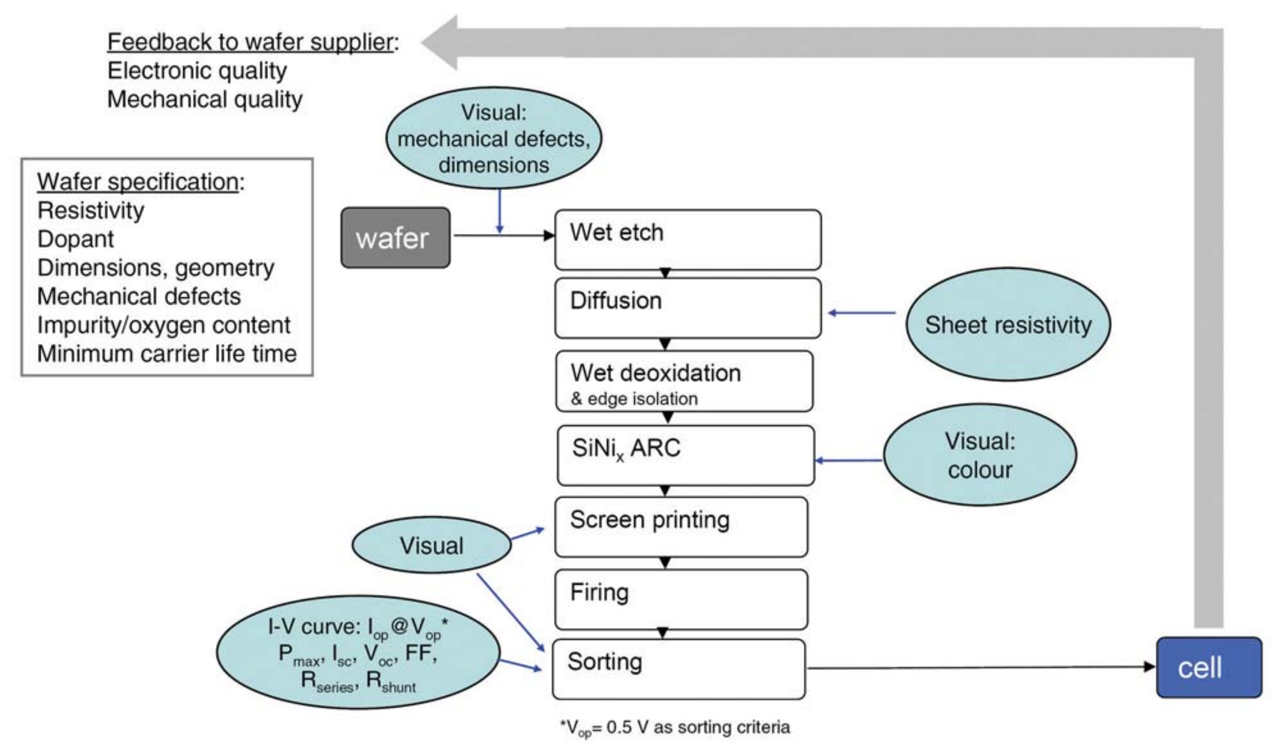

Figure 2. Conventional quality control at cell production: feedback to supplier of wafers only after finished cell; no intermediate quality control possible.

differentiated in temperature [4]. A further method [5] strove to find defects by the detection of longer wavelengths. The original electroluminescence radiation works mainly for cells but not for modules, while the cover glass of the module is opaque for wavelengths longer than 1,200nm.

Application of EL and PL

This section shows effective applications of EL and PL in a production line to quickly diagnose typical problems as shown in Figure 3, to reduce stop times and increase production yield. It allows fast feedback to the operators, production equipment manufacturers and suppliers of raw materials.

The consequent use of PL and EL along the production process of a cell is demonstrated in Figure 5. As early as at delivery, the incoming wafers can be checked for hidden micro-cracks or poor electronic quality via PL; in the case of insufficient wafer quality the wafers can be returned straight away to the supplier, thus saving time and money, as the following processing steps are aborted in a very early stage. The same is true for the result of every subsequent treatment (diffusion, wet etching, ARC application, screen printing, firing). If errors are detected via PL, the location of the processing station where the faults are caused is identified at once, and action to solve the problem can be taken immediately.

The suggested locations for the use of EL cameras within quality control during module production are shown in Figure 6.

As for cell production, a quality check at the delivery of the incoming cells is carried out.

Cost-benefit ratio of tools and methods for quality control

Even relatively small gains in power output and energy yield are advantageous, though the suggested methods are relatively cheap, especially taking into consideration the actual costs and production output of state-of-the-art production lines for cells and modules.

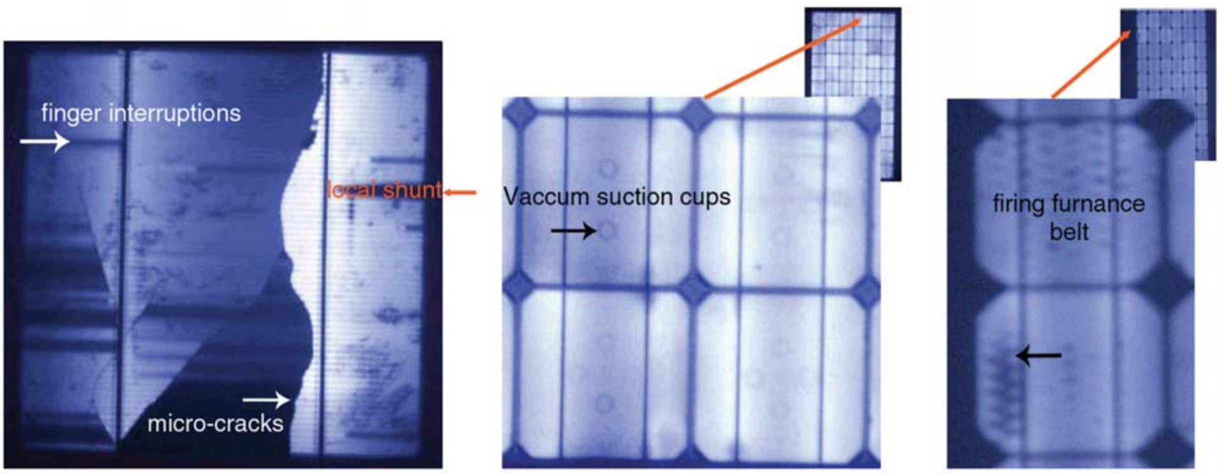

Figure 3. Examples for electroluminescence (EL) as a useful tool for the detection of suboptimal production processes and inadequate cell handling (close-up images of entire module EL photos).

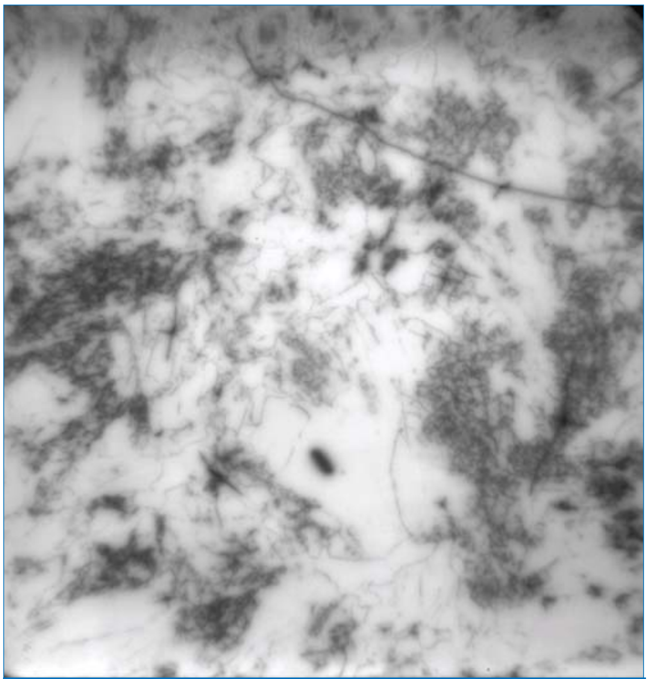

Figure 4. Photoluminescence (PL) as a tool for the detection of suboptimal production processes and inadequate cell handling (see T. Trupke et al [2]).

Example

A prominent illustration of the positive results of quality control via a closer monitoring of production is the binning of cells or modules in power classes, thus reducing mismatch reduction in the module or in the system and increasing power output and yield. Cell sorting in 0.2% steps for cells between 14%-17% leads to 3% more in average module power. The price for such a sorter is within 3% of total investment costs. At present, cell prices for crystalline cells (ex-factory) are about €2/Wp, while module prices are approximately €3/Wp. For a factory with a production capacity of 30MWp per annum, the gain of 3% more saleable power is a gain of 0.9MWp, worth €2.7 million per annum.

Cost-benefit ratio for PL and EL

The threshold for an investment (e.g., for EL equipment) of €100,000 per annum to achieve a positive cost-benefit ratio is reached for a yield improvement of 0.1%. For an expected lifetime of the system of five years, and an increase of 65% of the product price as implementation and operation cost, a produce price of €300,000 is covered by the 0.1% yield increase.

Results

The procedure for energy yield simulation is shown in Figure 9. The accurate simulation of direct and diffuse irradiance via their spectral-spatial appearance allows for an accurate representation of the module reaching irradiance. After passing the different layers of the encapsulation, being reflected according to the Fresnel laws - considering actual incidence angles and refractive indices - this irradiance forms the cell-reaching spectrum. The photo-electric conversion efficiency depends on matching of the cell-reaching spectrum with the cell's spectral response and the actual operating cell temperature (which is derived from a balance of energy flows of absorbed irradiance, electricity generation, and heat dissipation).

An example of the course of conversion efficiency during a single clear day is shown in Figure 10 for a multi-crystalline Si-module installed in Northern Africa. An interesting effect is that the inclination angle of the module is not influencing the irradiance on the plane of the module, but also has a significant effect on the convective heat transfer of the module. For horizontal mounting (module elevation angle: 0°), the convection capability and convective heat transfer at the module are reduced, thus causing high operating cell temperatures and a considerable dip in conversion efficiency around noon. This

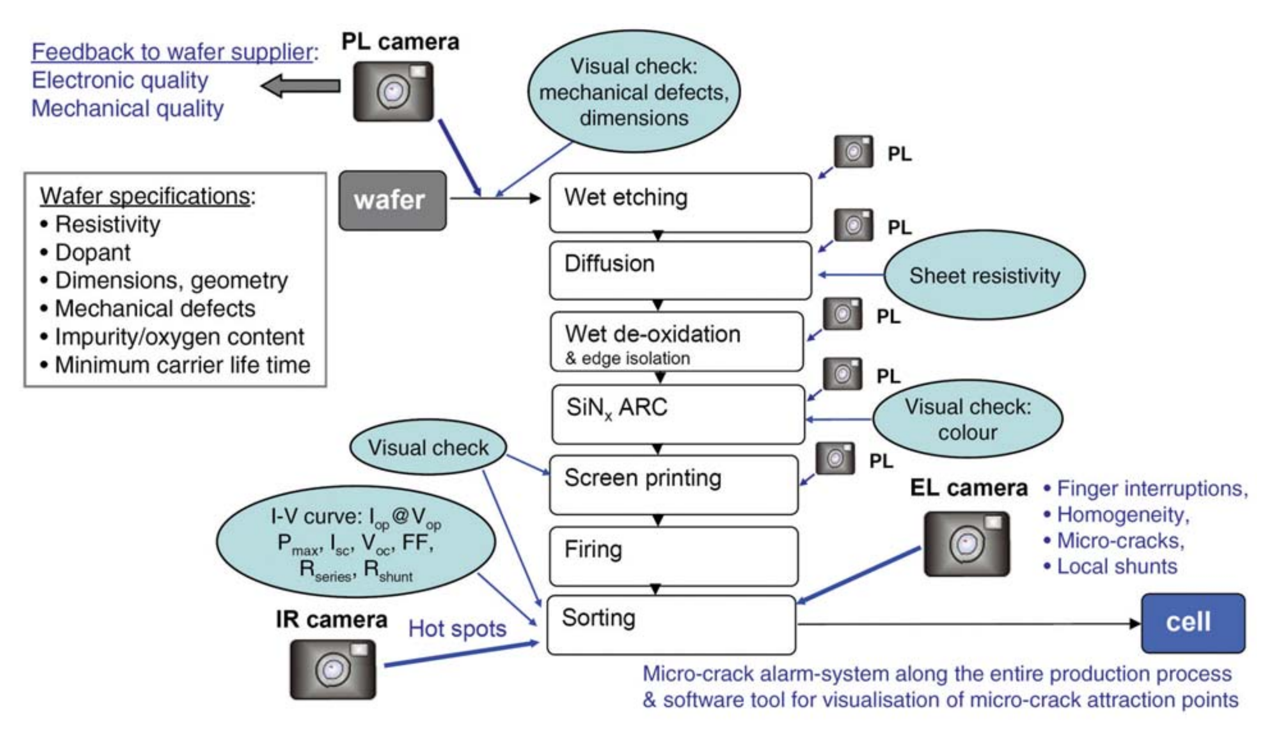

Figure 5. Enhanced quality control during cell production process via Electroluminescence cameras (EL) and Photoluminescence (PL) cameras.

dip is drastically reduced for more inclined modules, allowing an effective flow of air and convection along the module.

The minima of conversion efficiencies 20 minutes after sunrise at 6 a.m. and 20 minutes before sunrise at 6 p.m. can be explained by the extremely flat angle of incidence of the direct irradiance during that part of the day. This example shows how the quality of yield prediction depends rather on the comprehension of the entire optical-thermal-electrical composition of the installed PV panel than on the knowledge of an isolated PV module.

Conclusion

The tools presented offer an excellent cost-benefit ratio. The expected minimum yield improvement is in the vicinity of 1%, but already a yield improvement of 0.1% would justify the investment of €100,000 in a 30MW combined c-Si cell and module line at today's (2008) pricings.

Electro- and photoluminescence are powerful tools for fast in-line imaging of electronic and mechanical properties on wafers, cells and modules, allowing for a fast detection of process faults and handling errors and enabling a quick feedback (with a proofing image) to the suppliers of raw materials and to the providers of production and handling equipment.

Thus, the highest benefit is expected for micro-crack detection, in particular

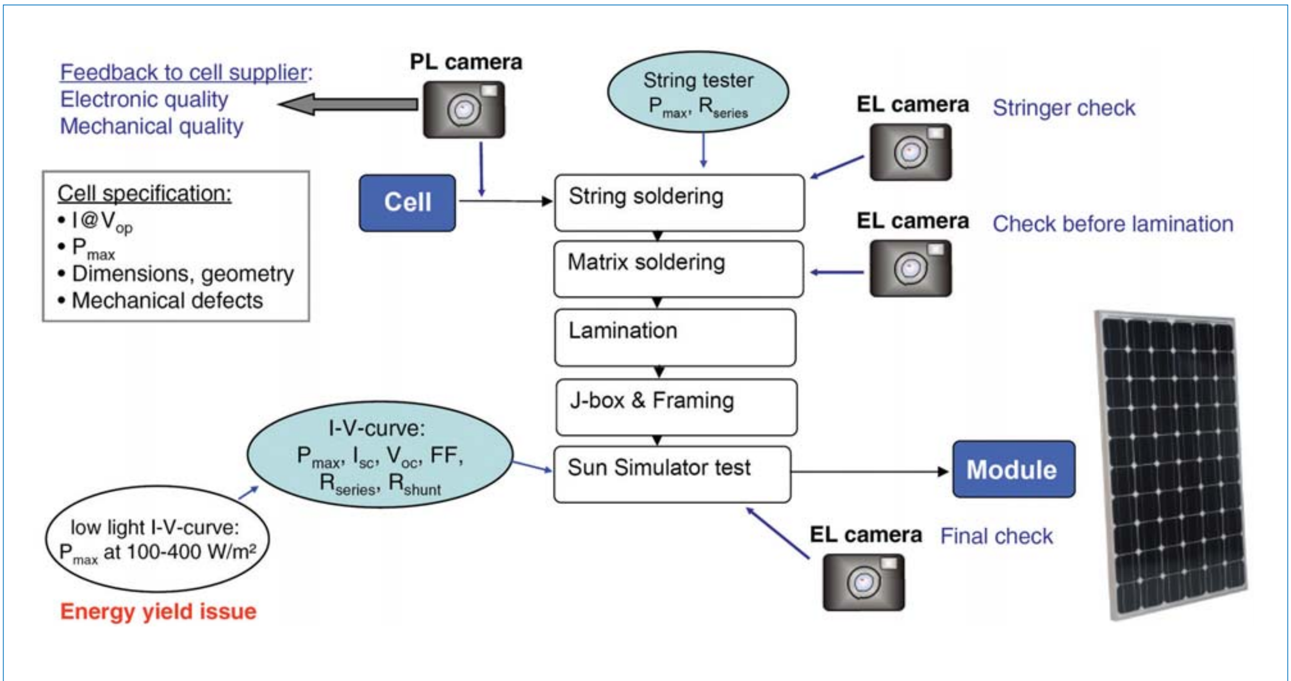

Figure 6. Enhanced quality control and collection of yield parameters at module production via three electroluminescence cameras (EL) and one photoluminescence (PL) camera.

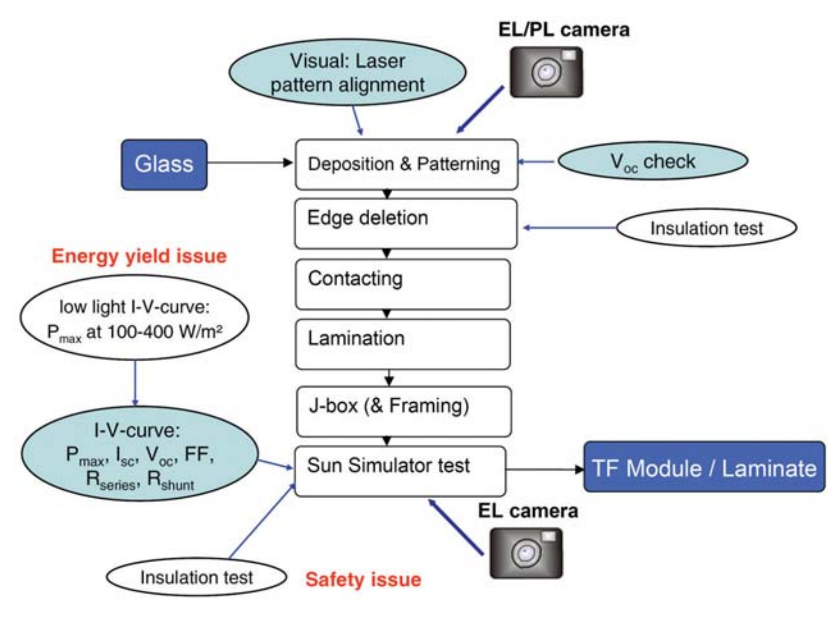

Figure 7. Enhanced quality control and collection of yield parameters during thin-film (TF) module production process via electroluminescence (EL) and photoluminescence (PL) cameras.

for highly automated production lines. As CCD cameras are used, they can be combined with or replace conventional visual inspection stations.

Outlook

Safety risks (i.e., hot spot and isolation) and energy yield potential of the finished modules are important product properties in the field and should be covered with similar investment efforts (recommended product strategy).

Electro- and photoluminescence are powerful tools for fast in-line imaging of electronic and mechanical properties on wafers, cells and modules.

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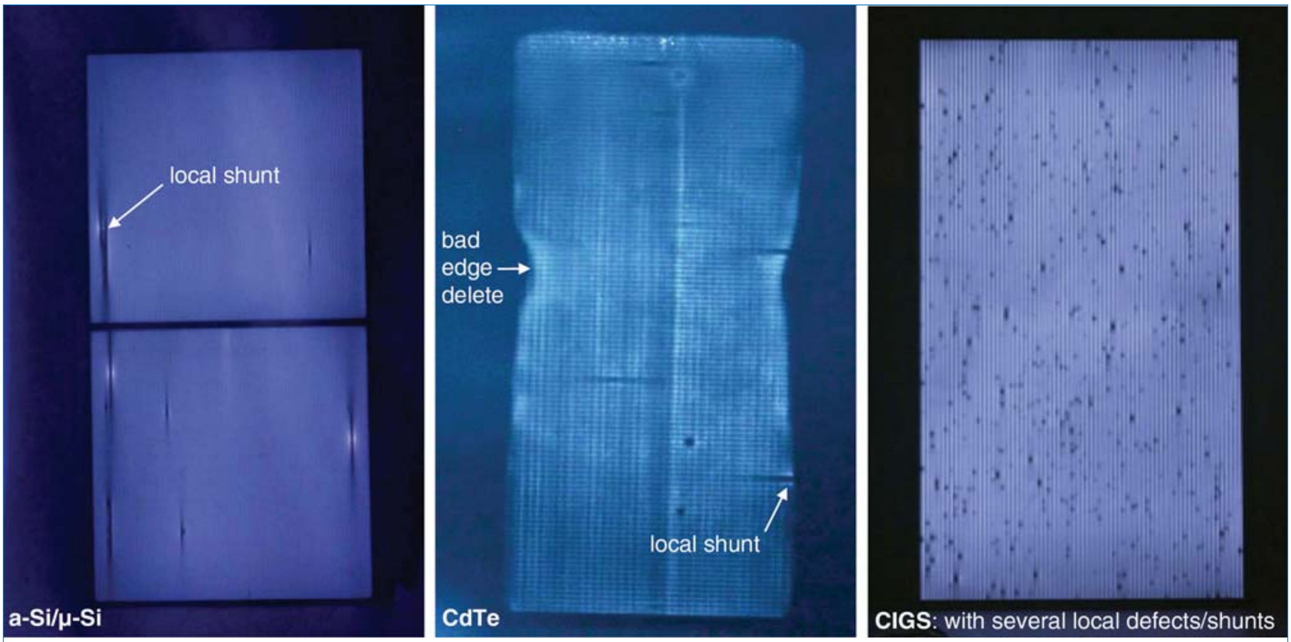

Figure 8. Electroluminescence (EL) pictures and visibility of process faults during production of thin-film modules with different technologies (a-Si/µSi, CdTe, and CIGS).

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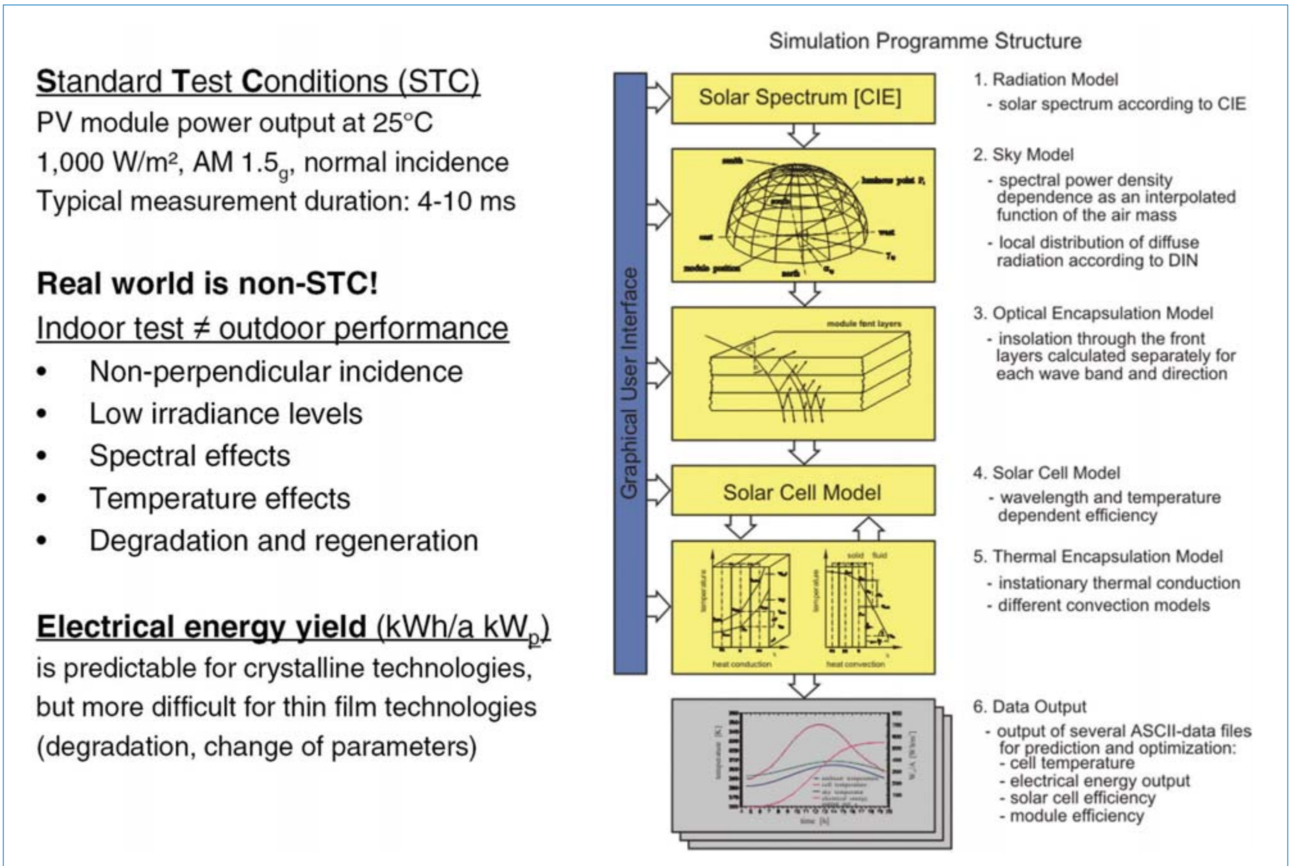

Figure 9. Yield becomes more important than power output at STC: Structure of a state-of-the-art simulation.

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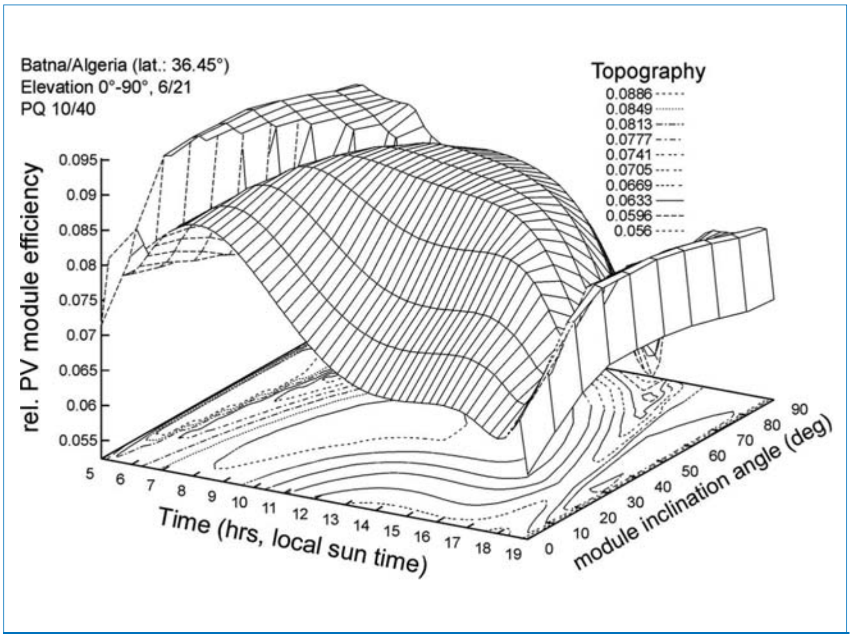

Figure 10. Results of a real-world simulation of a PV module showing the course of PV conversion efficiency during a day as a function of inclination angle of the module.

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Etching, texturing and surface decoupling for the next generation of Si solar cells

Guy Beaucarne, Patrick Choulat, B.T. Chan, Harold Dekkers, Joachim John & Jef Poortmans, IMEC, Belgium

ABSTRACT

Si etch processes are vital steps in Si solar cell manufacturing. They are used for saw damage removal, surface texturing and parasitic junction removal. The next generation of Si solar cells, featuring thinner wafers and passivated rear surfaces, will pose more stringent demands on those steps. Surface decoupling (achieving different surface treatments on the front and the rear) has to be achieved while minimizing Si consumption. Plasma texturing is an emerging technique that appears very promising in that respect, as efficiencies as high as 17.4 % have been achieved on screenprinted multicrystalline Si solar cells incorporating this process.

Introduction

Bulk crystalline Si is presently the dominating photovoltaic technology and will probably remain so for the next two decades. The present solar cell processes make extensive use of Si etching steps [1,2]. It is expected that these types of processes will gain in importance in the next few years, but also that they will face more stringent requirements in terms of Si consumption and surface morphology as the wafers used in the industry become thinner and more fragile.

There are three steps in which Si etch is involved:

- Removal of the region near the surface of the wafers with many defects induced by the wire sawing process (saw damage)
- Texturing the front surface
- Removing the parasitic junctions formed at unwanted locations on the cell during the diffusion process

In this paper, we will first review the state-of-the-art in terms of Si etch processes in Si solar cell production. We will then sketch the trends and link them with new requirements for the Si etch steps, concluding with a discussion of alternative techniques to the traditional wet chemical processes and the challenges presented by these techniques.

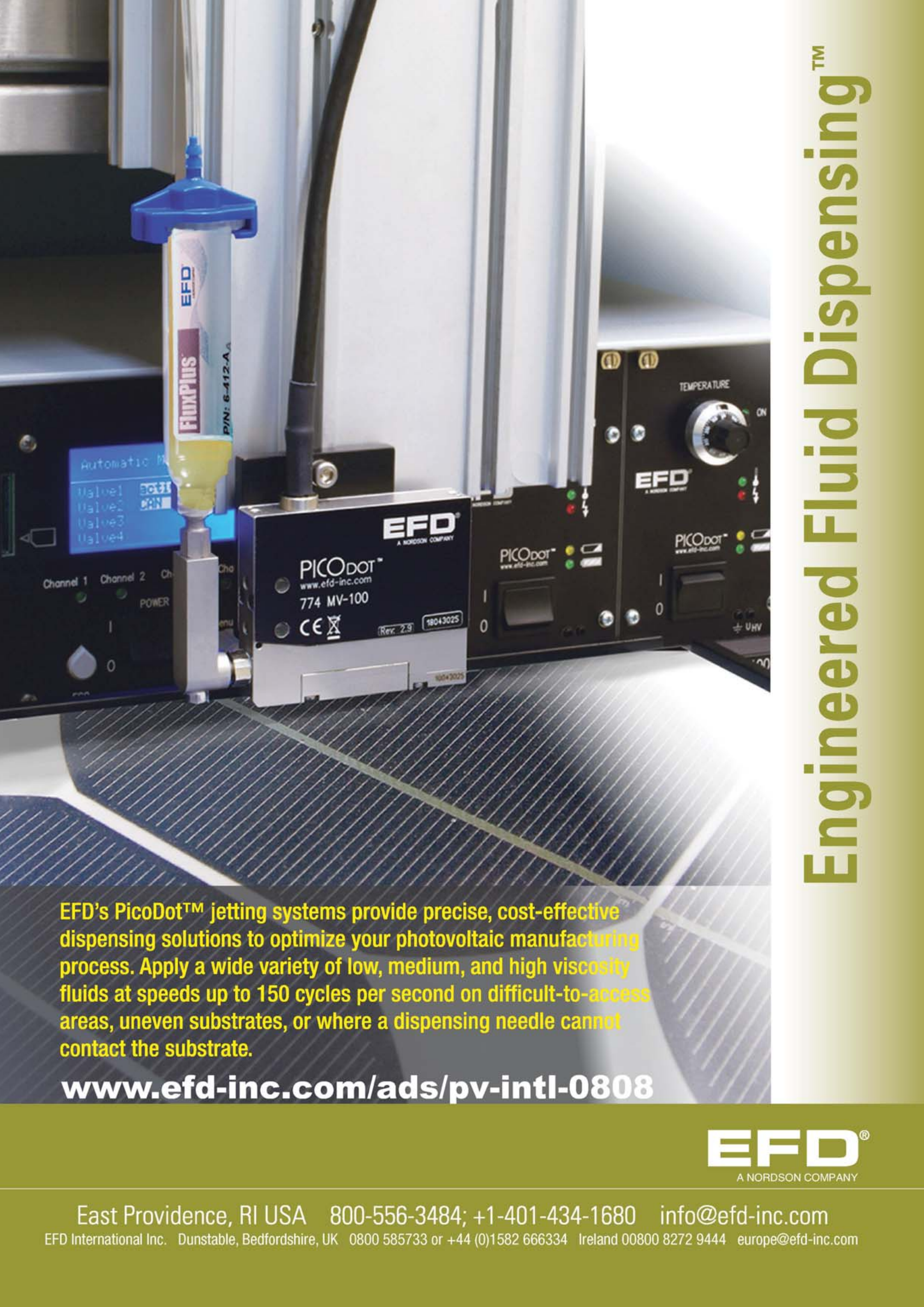
State-of-the-art

Silicon substrates used in commercial solar cell processes contain a near-surface saw-damaged layer that has to be removed at the beginning of the process. A layer with thickness of 5 to 10µm has to be etched from both sides of wafers. The damage removal etch is often done in a 20-30 wt. % aqueous solution of NaOH or KOH at 80 - 90°C. This process is a batch process where the wafers are placed in a cassette and immersed in a bath with the appropriate solution. The reaction takes place on both sides simultaneously. For multicrystalline Si, one should monitor and control the etching process to limit the formation of steps at grain boundaries, which can lead to problems during metallization.

The wafer surface after such alkaline saw damage etch process is flat, and therefore shows a high reflectance. If solar cells are made with such surface, the currents will be low, leading to low conversion efficiencies; therefore, most industrial processes today include a texturing step, which has two beneficial effects. Firstly, rays reflected at the facets get a second chance to be coupled into the cell. Efficient surface texturing can reduce the reflectance from more than 35% to less than 10%, which is in practice lowered further by using an anti-reflection coating (ARC). Secondly, front surface texturing ensures that light rays are coupled into the solar cell under an oblique angle, making it less probable that they will escape from the front surface after reflection at the rear. This effect is especially important when using thin silicon substrates (<200µm).

If the substrate is monocrystalline, it is advantageous to make use of the anisotropic etching properties of Si in an alkaline solution. As the {111} planes get etched more slowly than other crystal planes, {111} facets are developed. On <100> wafers, this leads to pyramidal shapes at the surface that are particularly effective in reducing reflectance. In laboratory cells, an oxide etch mask formed by photolithography is sometimes used, resulting in a regular array of pyramidal pits (with facets at 54.7° to the horizontal plane) called inverted pyramids (see Figure 1), with reflectances as low as 8% without ARC. In industrial processes, however, masked processes are avoided. It is possible to achieve almost the same level of reflectance by maskless etching where one relies on random processes to create locally the different etch rates needed to initiate the pyramid formation. This process is carried out in a weak solution (weaker than for saw damage etching) of NaOH or KOH with addition of isopropanol to improve wettability [3]. The process results in a surface covered with randomly distributed upside pyramids, as shown in Figure 2. The process requires careful control over the etch parameters and solution composition (in particular to keep the isopropanol concentration constant in spite the evaporation effect). When the process is under control, uniformly distributed pyramids with a height of 3-5µm are obtained. This process step is also done in a batch wetbench, and results in texturing on both sides unless special precaution is taken to avoid such an outcome. From a manufacturability point of view, it is advantageous to combine the saw damage step and alkaline texturing in one single step, in which case a trade-off has to be found between process speed and quality of the texturing. After alkaline etch, a neutralization step in a dilute HCl solution is required.

> Isotropic wet texturing requires the presence of surface defects to work effectively. On substrates without saw damage such as Si ribbons, acidic texturing either does not work or presents issues of uniformity and reproducibility.



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Alkaline random texturing is not effective on multicrystalline silicon substrates due to its anisotropic nature. Some grains (typically those with an orientation close to <111> normal to the surface) remain untextured, leading to a high average reflectance. A very elegant technique of texturing multicrystalline silicon is to etch the wafers in an acid mixture based on HF and HNO_3 [4]. The HNO_3 tends to oxidize the surface, while the HF etches the oxide away. The etching process occurs preferentially at defects. Therefore, when saw damage is present, this etching process structures the surface in a way that is independent of the crystal orientation. This acidic isotexturing results in lower reflection than traditional anisotropic etching on multicrystalline material, and better conversion efficiency [4,5]. A SEM picture of the surface of an acidic isotextured wafer is shown in Figure 3.

This process was first successfully developed at IMEC, but similar developments were later on carried out at other institutes [6,7]. The process has by now become a standard for multicrystalline Si solar cells. For a sufficient lifetime of the etching bath, it is important to monitor the amount of Si etched and to replenish the solution accordingly, to ensure that the necessary reagentia are not depleted.

If properly monitored and replenished, the bath can be used for many thousands of wafers, and the chemicals consumption per wafer is very limited. Apart from the batch approach, such processes can also be done in in-line wetbenches, which are now available from equipment vendors. In both batch and in-line systems, the wafers are typically completely immersed in the solution, resulting in texturing on both sides. After acidic texturing, wafers are usually dipped in a dilute alkaline solution to remove a thin porous silicon layer that is formed during the texturing step (stain etch). This is followed by a neutralization step to remove all Na or K atoms from the surface before emitter diffusion.

It should be noted that isotropic wet texturing requires the presence of surface defects to work effectively. On substrates without saw damage such as Si ribbons, acidic texturing either does not work or presents issues of uniformity and reproducibility.

The P-diffusion process that follows texturing usually creates a junction all around the wafer. As a result, some regions are doped where doping is not desired and can actually be detrimental to the solar cell operation. Therefore, an Si etch process is often applied to locally remove the undesirable P-doped regions. A few years ago, the standard technique was plasma etching in a plasma reactor, where the cells were stacked on top of each other with (possibly) rubber sheets in between. The stack is then exposed to the plasma, removing about one micrometer of Si at the edges of each wafer. The parasitic junction at the rear remains, but nevertheless the step is effective in a conventional process as most of the rear surface is converted into p-type during the final BSF formation while the shunt paths at the edge are removed. However, because it involves extensive handling, significant forces applied onto the wafers and the need for gas abatement, this technique has to a large extent been replaced in the last few years by laser scribing along the cell edge. More recently, in-line wetbenches have been introduced that completely etch away the doped region at the rear of the wafer. The solar cells are transported just above the etch bath level (typically an aqueous solution based on HNO_3 and HF), so that only the rear side is etched, leaving the emitter at the front intact. This process is usually combined with phosphorous glass removal in the same wetbench, just prior to the rear side etch.

Quite a large volume of water is required for rinsing after wet chemical etch steps. The typical 5 litre/Wp for a conventional process is not only an environmental issue (proper waste treatment has to be foreseen), but can be a significant supply and cost issue, which is anticipated to increase in importance as water resources become scarcer. Optimizing the process towards minimal water consumption is therefore vital both from the environmental and from the economic points of view.

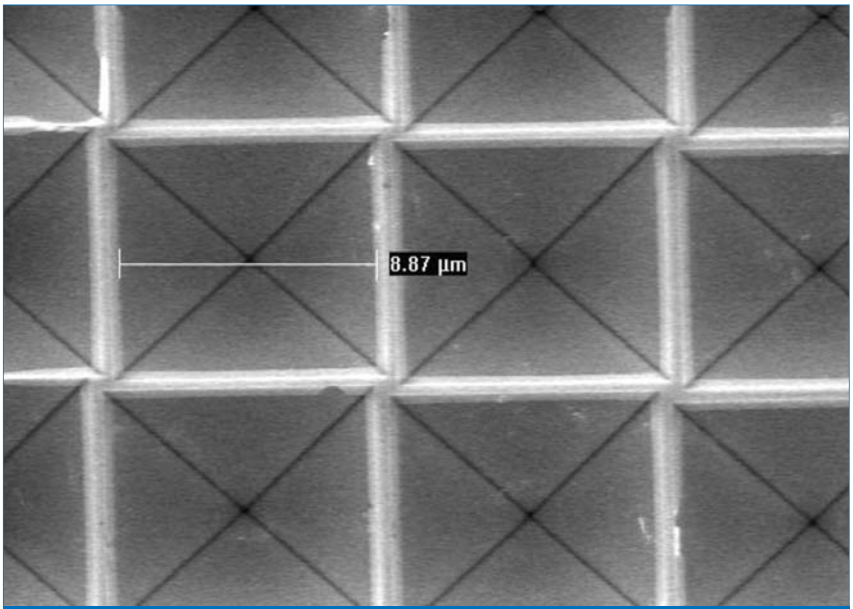

Figure 1. SEM top view of a silicon surface with inverted pyramids.

Surface decoupling

The conventional Al-BSF, formed by an alloying process during the screenprinting metallization step, provides only moderate surface passivation, with recombination velocities in the order of 1000cm/s. For very thin cells, however, recombination at the rear surface gains in importance, and substantially lower surface recombination velocities are required. Below a thickness of 200µm, the Al-BSF passivation is no longer sufficient and one observes a substantial loss in both V_{oc} and J_{sc}. Another issue with Al-BSF on very thin wafers is the wafer bowing induced by the different thermal expansion coefficient between Si and Al, which may lead to problems with cell handling and module manufacturing. A last drawback of the Al-BSF is the absorbance that takes place in the BSF region. A BSF is typically 5µm thick, and all photons absorbed in this region are lost for conversion. While small for standard thicknesses, this loss becomes very large as wafer thickness decreases and light confinement gains in importance. For all of these reasons, a new concept of rear structure is required to provide low recombination at the rear surface, with dedicated passivation layer and local contacts. Possible candidates for the passivation layer are silicon oxide layers, adapted silicon nitride layers, amorphous Si layers, and stacks of such layers. Prominent examples of solar cell concepts based on dielectric passivation at the rear are shown in Figure 4.

These structures are depicted with a textured front surface (needed for any high-efficiency cell) and a flat rear surface. In other words, the surface treatments of the front and rear of the wafers are

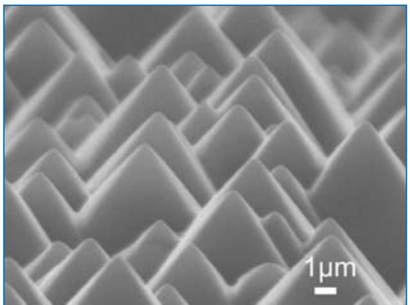

Figure 2. SEM picture of a monocrystalline Si surface with random pyramids, textured in an alkaline solution.

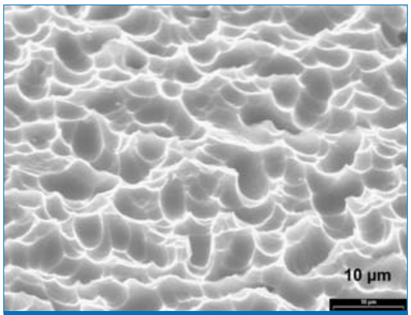

Figure 3. SEM picture of an acidic textured surface of a multicrystalline Si wafer.

decoupled – a significant feature of these new solar cell concepts, which is related to the quality of the surface passivation at the rear. It appears that it is much more difficult to achieve the high level of surface passivation required if the rear surface is rough. For surface passivation schemes that rely on lowering the density of interface defects, such as with intrinsic amorphous Si and silicon oxide, this is easily understood. A rougher surface has a much larger effective area and therefore effectively many more sites where harmful defects can be present, making exhaustive passivation difficult. For surface passivation layers that rely on a field effect, such as stoichiometric PECVD silicon nitride layers, this is not as obvious. One would expect that the surface passivation is much less dependent on the roughness than on the density of fixed charges in the dielectric, and this has been confirmed at lifetime test structure level [11]. However, in solar cell structures, a non-textured rear surface appears to be needed to reach low effective recombination velocities and high efficiencies.

Achieving surface decoupling in a practical way is not straightforward. One can possibly use similar in-line etch systems as for rear parasitic junction removal since this is an existing one-side treatment, but the requirements for the etch steps are different. If one starts with wet chemical texturing (which in all commercially available systems today occurs on both sides) and proceeds with one-side rear surface etching to polish the rear surface, the process is relatively long and one that tends to consume a substantial amount of Si, clearly an unwanted effect when the wafers are already very thin to start with. The development of practical and manufacturable one-side texturing process steps (alkaline and acidic) and of one-side saw damage removal process steps is desirable and would be directly implementable in many advanced process flows.

Alternatives to wet chemical etching processes

Etching silicon substrates can also be realized by means of plasma technology. In this technology a plasma discharge is created and molecules are partially dissociated into radicals upon electron impact. Those radicals, with or without the assistance of ions, etch the silicon. The radicals that etch silicon are typically halogens, of which the fluorine atom is the most effective.

A distinction has to be made between Reactive Ion Etching (RIE) and other types of plasma texturing. RIE relies on the ion bombardment that creates damage on the surface. This technique has proved to yield uniform and low reflectances [12], but the defects induced by the ion bombardment is a problem. A possible solution is etching the damaged region subsequently by wet chemical means. At IMEC, we have developed a process based on microwave-powered antennas [13]. These antennas are positioned above the substrates providing sufficient radical density to cause chemical etching on the surface. Ions do not play a role in this process unless an RF bias is applied. The gas chemistry is based on SF_6, N_2O and Cl_2. The process is self-masking, in that the residues of the etching process temporarily get deposited on the surface, leading to a locally lower etch rate and the formation of a texture. The etching process is isotropic, leading to the same texture regardless of the grain orientation. With the right process parameters, one can obtain a uniform, moderate reflectance (15-22% before ARC deposition) and a low surface area enhancement (required to maintain high V_{oc}). The features of the surface texture are much finer (about 10 times smaller) than those of alkaline or acidic textured surfaces (see Figure 5).

Plasma texturing should be seen as an enabling technology for advanced Si solar cell technologies.

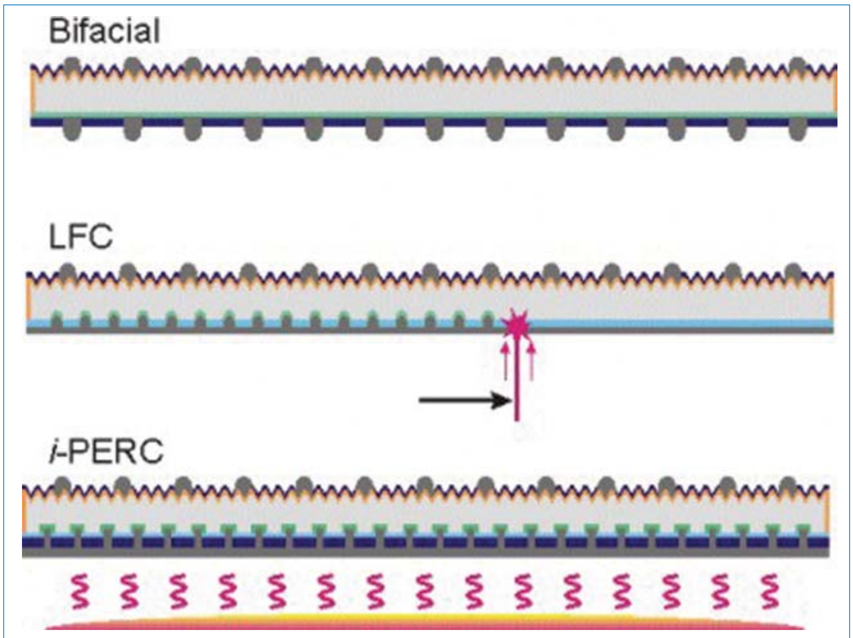

Figure 4. Three different concepts for industrial passivated rear surface solar cells: bifacial solar cells with fire-through contacts (as in [8]), laser-fired contact solar cells (LFC [9]), and selective alloying, thermally-fired local BSF solar cells (*i*-PERC [10]). All concepts feature a very good surface passivation with a dielectric layer at the rear and local contacts to the silicon.

When plasma texturing is applied as a replacement for acidic isotexturing in standard, thick (200µm) screenprinted solar cells, it yields similar or only slightly higher conversion efficiencies: the real benefit of plasma texturing is apparent in advanced structures and for very thin wafers. Since plasma texturing is inherently a one-side process, it is straightforward to achieve the surface decoupling discussed above, whereas it is a challenge with wet chemistry. Moreover, the process consumes only a minimum of Si (can be as low as 1µm). It is therefore possible to devise a process scheme removing the absolute minimum amount of Si required, e.g. a saw damage removal step removing ~5µm of the saw damaged region on each side, and then 1µm for texturing. Plasma texturing should therefore be seen as an enabling technology for advanced Si solar cell technologies. At IMEC, we achieved a conversion efficiency of 17.4% on a screenprinted multicrystalline Si solar cell with the *i*-PERC process, which includes plasma texturing [14].

Plasma texturing is also particularly appropriate for wafers produced without surface damage such as Si ribbons and epitaxial layers on low-cost Si substrates, for which no easy wet chemical texturing process is available. Plasma texturing has proved to bring a significant advantage on both types of substrates [15], [16 – *see IMEC paper, page 83*].

Before plasma texturing can be applied on an industrial scale, several issues have to be dealt with successfully. First, the process needs to be upscaled such that it provides the necessary throughput while providing low cost of ownership. Moreover, excellent uniformity has to be reached over large areas. Both issues are serious technical challenges and will no doubt require substantial development efforts. However, the history of successful development of vacuum in-line systems for the PV industry inspires confidence that it can be achieved. Another important issue is gas abatement. While replacing wet texturing by plasma texturing would reduce the amount of wastewater dramatically, the release of greenhouse gasses could offset that environmental advantage completely if not properly tackled [17,18]. SF_6, for instance, has a huge Global Warming Potential of 24000. Just a few percent of the SF_6 flow getting past the abatement system leads to a poor environmental balance, which is unacceptable for a PV product. This problem, however, is common to several processes in microelectronics and, increasingly, thin-film photovoltaics (reactor etching). Producers of gases and abatement systems have responded to the challenge and are now developing solutions that can lead to zero release of GWP gas, either by effective recycling of the fluorinated species, or by offering alternative gas systems with low GWP [19]. Typically, these installations only make economic sense for very large plants. Taking into account the soaring scale of solar cell manufacturing plants, this should not be a problem in the future.

Another possible application of Si etching by plasma is a shallow uniform etch for junction removal at the rear, advantageously combined with phosphorus glass removal in the same step. The feasibility of such a process has been demonstrated in in-line or quasi-in-line systems [20,21] but needs further development. The combination of three plasma processes (PSG removal, rear junction removal and silicon nitride deposition) in the same vacuum in-line chain is very appealing from a manufacturing point of view.

Finally, it should be mentioned that laser ablation is also being investigated as an alternative to etching of Si, for surface texturing [22] or the formation of special topographies enabling high efficiency structures [23]. The advantage of laser structuring is that it enables the formation of sharp and precise features on the surface without the need of prior patterning of a mask. However, the silicon in laser-ablated regions is damaged, and typically needs a subsequent wet chemical damage etch. Process speed (particularly if the complete substrate surface needs to be scanned) and cost are presently significant issues for laser structuring, although they may be solved in the future thanks to the fast progress in laser development.

Conclusion

Si etching steps are used extensively in present Si solar cell manufacturing, and it is expected that those steps will gain in importance in future technologies. The main processes used today are random texturing in dilute alkaline solution for monocrystalline Si, acidic isotropic texturing for multicrystalline Si, and one-side shallow etching for parasitic junction removal. It is anticipated that new processes will be introduced in the future that enable fast texturing and deep silicon etching on only one side, as surface decoupling is desired for many advanced solar cell structures. An emerging field is that of plasma-based Si etching processes for solar cells. Plasma texturing has proved particularly suitable for advanced solar cell structures and new low-cost substrates.

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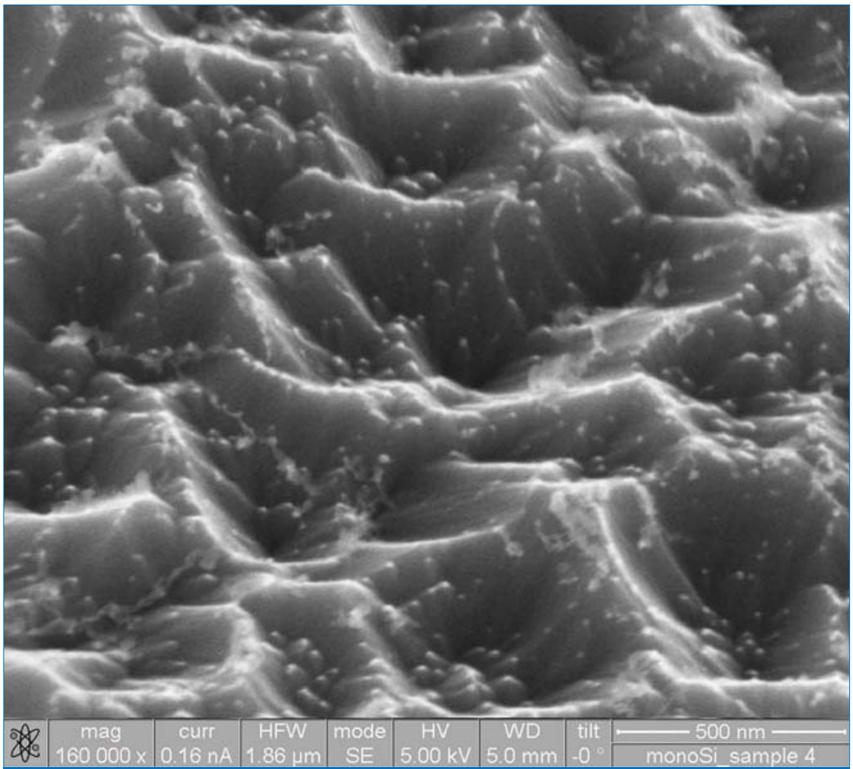

Figure 5. SEM picture of an Si wafer after the IMEC plasma texturing.

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About the Authors

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Existing and emerging laser applications within PV manufacturing

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ABSTRACT

Increasing the efficiency and yield of production line processes forms an integral part of PV manufacturers' technology roadmaps. For their next-generation production lines, non-contact processing equipment is considered essential. This prioritizes laser-based processing, already established at several steps in c-Si and thin-film cell manufacturing. This paper summarizes the key issues when using lasers within PV production lines.

Introduction

Laser processing offers a 'non-contact' means of scribing, drilling, and melting specific materials used within production line steps for crystalline-silicon (c-Si) and thin-film manufacturing. Non-contact techniques enable key roadmap drivers in cell and panel manufacturing today to increase yield levels by reducing bulk microcrack formation, and to combine this with high throughput. As explained by Carmen Morilla, Research Technologist at BP Solar, "Lasers will play an important role in future technology especially given the industry trend of using thinner wafers." The transition point in this respect is a wafer thickness of around 160-180µm.

Compared to other technologies (plasma/chemical etching, screen printing, and mechanical cutting), laser processing offers specific advantages such as 'green' equipment types, low cost-of-ownership, and increased micromachining quality. Greater scrutiny is being applied to the environmental aspects of solar production and PV emission life cycle. Viren Rana, Senior Manager at Applied Materials, Inc. Solar Business Group: "Laser processing systems provide green processing in general, not requiring harmful liquids or gases."

The ability of lasers to enable high-efficiency – or 'advanced' – cell concepts is another exciting aspect when applied to solar manufacturing. These concepts are achieved via selective material layer modification (scribing, drilling, or melting) without affecting neighbouring layers or the bulk absorber material. This also avoids the cost and complexity of implementing active depth control. Laser processing can be applied with unique flexibility and selectivity as every material has its own absorption characteristics as a function of wavelength. Thus, choosing the correct laser wavelength permits selective material removal, and also controls the removal rate for a given material. Similarly, varying laser pulse characteristics allows precise control over material removal rates and the size of the heat-affected zone ('HAZ').

Therefore, exploiting laser processing for high-efficiency cell concepts provides a clear route for both technical differentiation and productivity enhancements.

Lasers within the value chain

Whilst niche applications for lasers exist upstream and downstream from cell manufacturing, it is predominantly in the realm of manufacturing that lasers find their ***raison d'être*** within the solar industry. This is true for both c-Si wafer-to-cell and thin-film panel-to-cell processes, despite the different production steps involved.

Today, laser-based tools are introduced directly by cell manufacturers via customized inline and batch integration, or by production line equipment suppliers offering either full or partial turnkey solutions. This results in a wide range of laser-adoption 'maturity' from one solar cell manufacturer to another, symptomatic of the evolving equipment supply-chain. Further, there is a myriad of laser applications presently at the research phase, some of which will soon transition from research to production. Therefore, keeping track of which laser-based processes can add immediate value is often done on a case-by-case basis directly between cell manufacturer and laser equipment supplier. Table 1 summarizes the status of the laser applications within the industry today, separated into c-Si and thin-film.

Applications within c-Si cell production

Laser adoption in c-Si production is most prevalent today with cell manufacturers who are implementing ambitious

	Laser Process	Production Status		
		Widespread Production	Partially Adopted	R&D or Pilot-Line
c-Si	Edge Isolation	✓		
	Laser Grooved Buried Contacts		✓	
	Texturing			✓
	ID Marking		✓	
	Selective Ablation			✓
	Wrap-Through		✓	
	Cutting		✓	
	Dopant Diffusion			✓
	Laser Fired Contacts			✓
	Wafer Inspection			✓
	Defect Repair			✓
	Singulation			✓
	Interconnection			✓
Thin-Film	Patterning	✓		
	Border Deletion		✓	
	Crystallization			✓
	Pulsed Laser Deposition			✓
	Sintering			✓

Table 1. Current status of laser applications within c-Si and thin-film cell and panel manufacturing.

roadmaps to increase efficiency and yield. Applications currently include laser edge isolation, laser grooved buried contacts (LGBC), and emitter wrap-through (EWT).

The most widespread application of lasers is for edge isolation. In this process, lasers scribe an isolation groove on the front surface, typically 10-20µm deep into the underlying p-type Si, to eliminate shunt pathways. This groove is located close to the edges to minimize 'dead' area (as shown in Figures 1a and 2a).

In addition to 'greener' manufacturing, lasers used for edge isolation can improve yield and efficiency.

Lasers compete with two equipment types for edge isolation. Plasma etching was an early front-runner, but suffers from limited throughput due to batch processing, and from wafer breakage issues due to the necessity to handle – or 'coin-stack' – increasingly thinner wafers. Chemical or wet etching can also be applied and is sometimes the choice of suppliers offering chemical etching at other stages. The high electrical efficiency (single-phase electrical input) and closed-loop water-cooling abilities of lasers make them the only near-ideal 'green' tools for this application.

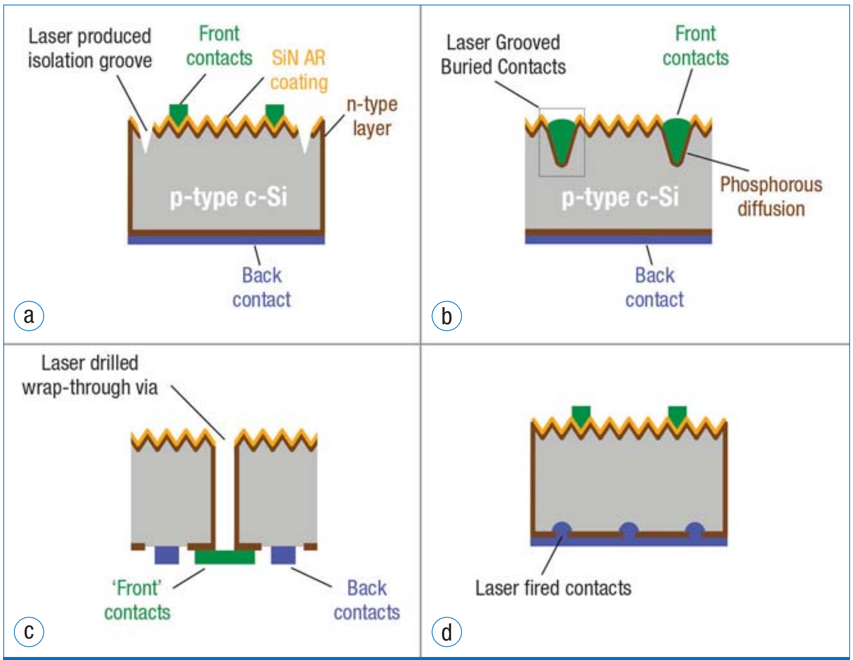

Figure 1. Laser applications include (a) edge isolation, (b) LGBC, (c) EWT, (d) LFC.

In addition to 'greener' manufacturing, lasers used for edge isolation can improve yield and efficiency. This requires optimizing the laser 'type,' as evidenced by increased use of visible (532nm) and ultraviolet (355nm) lasers, due to significantly stronger absorption of c-Si at short wavelengths [1]. Silicon absorption is 4-5 orders of magnitude stronger at 355nm, compared to infrared (1064nm), allowing highly-localized front surface scribing (see Figure 3). In addition to shorter penetration depths, UV laser scribing provides higher resolution by virtue of the shorter wavelength. This allows narrower grooves to be scribed in a 'colder' process, with minimized peripheral thermal damage such as microcracking.

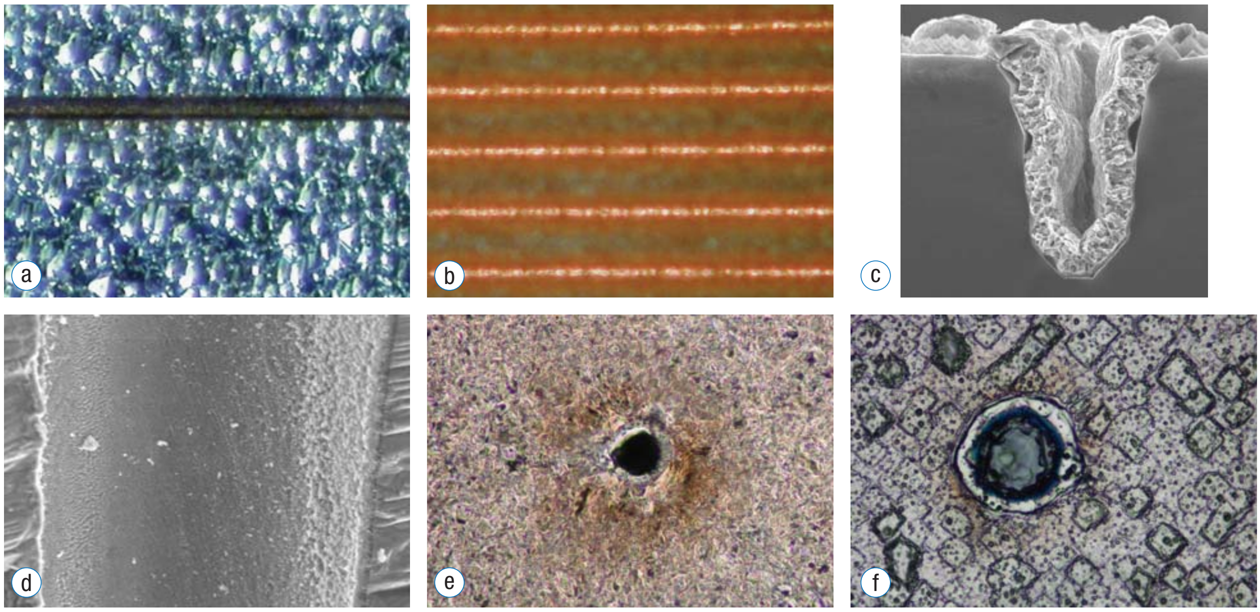

Figure 2. Scribing processes are used in edge isolation (a); LGBC (b, c); EWT employs laser drilling (d, e); LFC is a melting process (f) (image 2c courtesy of BP Solar).

The laser grooved buried contact (LGBC) method was pioneered at the University of New South Wales, Australia in the mid-1980s, and was exploited by a leading cell manufacturer [2]. LGBC is a laser-specific technique and was groundbreaking in both concept and efficiency-enhancement potential. Indeed, LGBC paves the way for other high-efficiency laser-based techniques to move from research lab to production line.

The laser part of LGBC is similar to edge isolation in that it involves scribing trenches at high speed on the front surface, tens of microns wide and deep. However, LGBC is a front-end-of-line manufacturing step, with trenches running in parallel across the front surface every 2-3mm (see Figures 1b, 2b and 2c). Two discrete efficiency-enhancing methods can be implemented. The walls of the trenches are locally (or 'selectively') phosphorous-doped. Contacts are then recessed or buried beneath the front surface where the reduction of 'shadowing,' an undesirable feature of screen-printing, increases cell efficiencies considerably. BP Solar's Carmen Morilla said, "We've been using lasers in high-volume manufacturing of our LGBC technology since 1993. They have proved to be reliable equipment with low maintenance cost and high uptime."

While edge isolation and LGBC exploit front-surface laser scribing, lasers are also ideal for 'drilling' tiny holes through the bulk silicon. Typically, the sidewalls are diffusion-doped with n-type material and metal-plated to create wrapped-through conducting pathways, or vias. One application of through-silicon vias enables 'front-contacts' to be relocated at the rear of the cells, leaving the front surface free of metallization (as in 'back-contact' cells). The most successful laser-based scheme is emitter wrap-through (EWT), where, according to James Gee, CTO at Advent Solar, "improvements in lasers, like DPSS, have enabled new and advanced solar cell designs like wrap-through solar cells." Here, both emitter and base electrodes are relocated at the rear surface, as shown in Figure 1c. Interestingly, 'wrap-through' of c-Si solar wafers has direct analogy to laser-drilled silicon through via interconnects in the manufacturing of integrated circuits; an application where sidewall hole quality and wafer structural 'integrity' are strongly dependent on laser wavelength and pulse width (see Figures 2d and 2e).

The remaining laser/material interaction mechanism within c-Si cell production is 'melting.' There are several high-efficiency techniques proposed that take advantage of laser-induced melting, but the most prominent one is the laser fired contact (LFC) method developed at the Fraunhofer-ISE in Germany [3]. LFC is a rear-surface process, where scanned laser beams 'drive' deposited aluminum through the rear surface passivation layer (typically SiN or SiO_2) several microns deep into the bulk c-Si to create localized Al/Si alloys, as illustrated

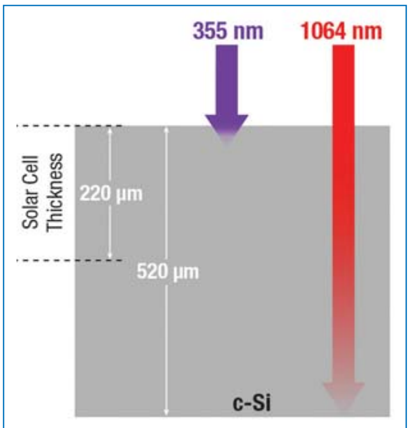

Figure 3. Relative absorption depths in c-Si for incident infrared (1064nm) and UV (355nm) wavelengths [1].

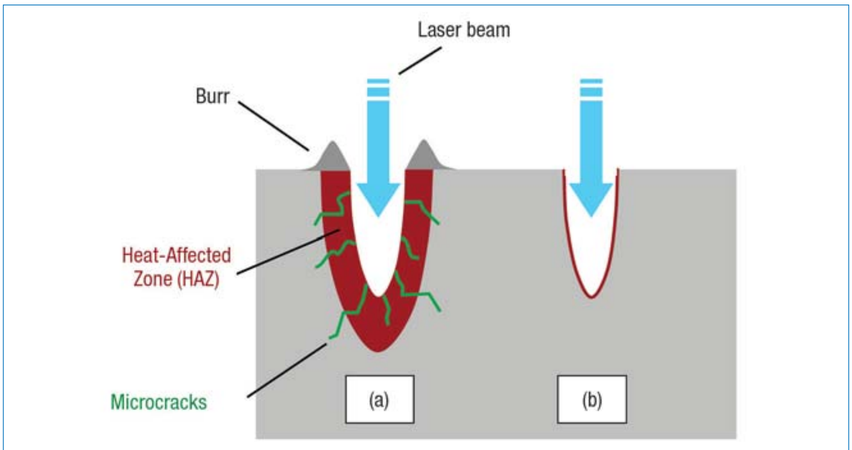

Figure 4. Schematic representation of factors affected by (a) non-optimized and (b) optimized laser selection in c-Si laser applications.

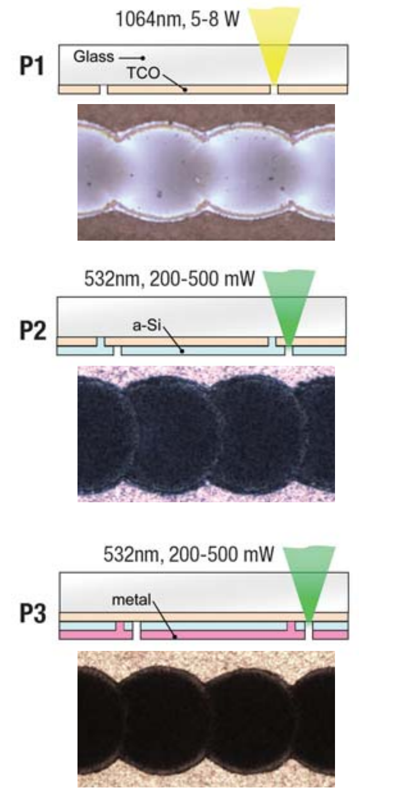

Figure 5. Patterning process for a-Si thin-film production and typical scribe lines for each of the P1, P2, and P3 steps.

in Figures 1d and 2f. The LFC technique is readily compatible at the back-end-of-line in today's c-Si production lines. The most pronounced efficiency and yield benefits are anticipated for sub-180µm-thick wafers, where existing high-temperature and contact-based processes can increase the risk of wafer warping and breakage.

Optimizing lasers for c-Si manufacturing

Scribing, ablating, drilling, and melting applications typically require lasers operating in a non-continuous or pulsed mode where the instantaneous (or peak) power is above the processing threshold.

The most common and lowest cost pulsed lasers deliver pulse-widths of a few tens of nanoseconds at an output wavelength in the infrared range at around 1064nm. For some applications, these lasers are fit-for-purpose and no further optimization is required. However, to enable the full benefits of most laser processing on c-Si wafers, it is essential to optimize laser parameters. Indeed, most applications in c-Si production work best with pulsed lasers offering different wavelengths and pulse-widths from these 20-50ns/1064nm platforms. Crucially, any higher capital equipment cost for more dedicated laser types is easily justified by significant efficiency and yield paybacks to manufacturers. In fact, laser adoption within the solar industry is aligned with this progression; 'proof-of-principle' research or first pilot-line tooling using

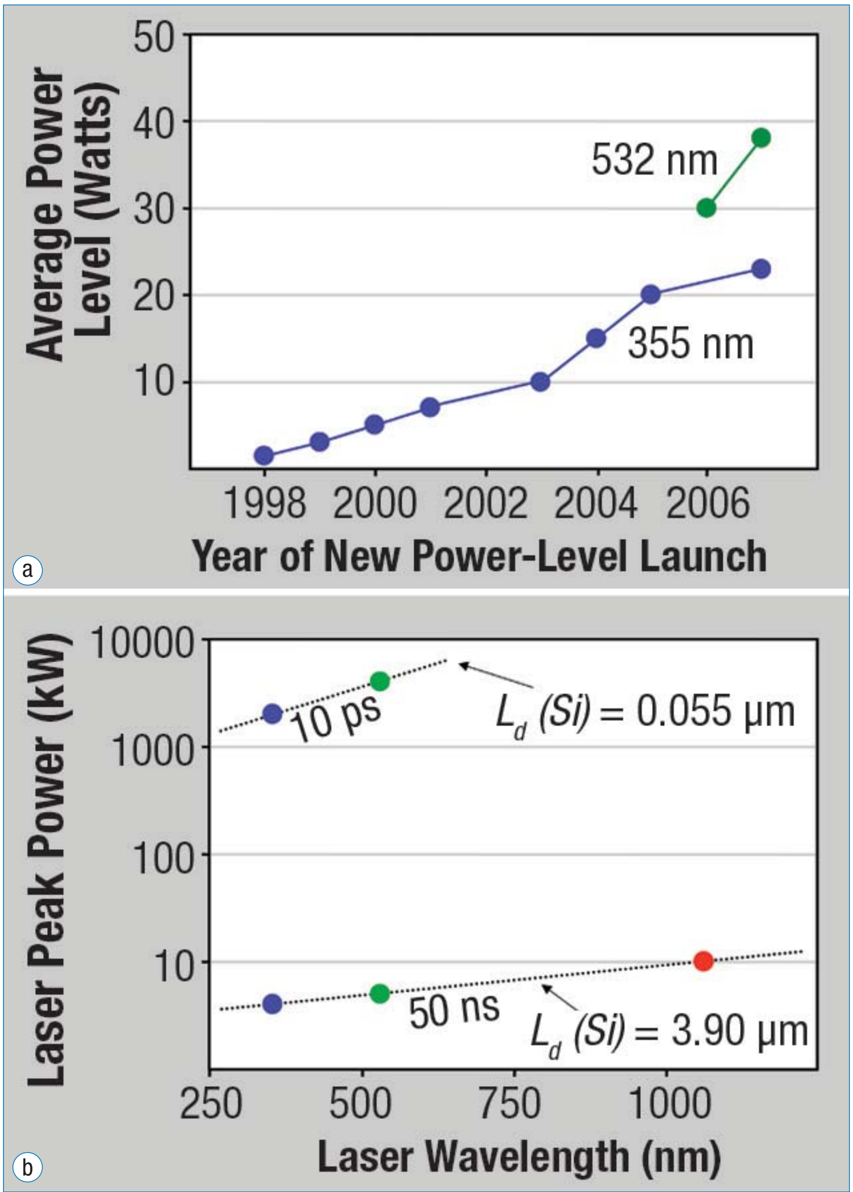

Figure 6. (a) Maximum power levels from state-of-the-art, short-wavelength, nanosecond AVIA lasers.
(b) Peak-power and thermal diffusion depth in silicon (L_d) of a high-energy picosecond Talisker laser (upper data), compared to high-power 50ns platforms (lower data).

legacy short-pulse nanosecond lasers at 1064nm, followed by optimization of the laser parameters to maximize efficiencies and yield levels in production. The rationale for this transition is explained by reviewing the materials used within c-Si solar cells, and the effects of the laser/material interactions.

Laser optimization criteria for c-Si applications can be divided into two categories. The first is generic to most equipment tools used within cell production today. This includes increasing the throughput to greater than 3,000 wafers per hour, decreasing the per-wafer cost component attributed to capital equipment, and enabling inline automation. Laser tools are optimized for these parameters by increasing the average power and scanning speeds, by using turnkey Diode-Pumped Solid-State (DPSS) lasers, and by providing handling interfaces compatible with neighbouring production line stages, respectively. The second category is unique to laser processing. Optimizing laser-specific parameters provides the key differentiator between a laser-based process being competitive with existing contact-based technologies and the process being significantly improved with enhanced cell characteristics. The two laser parameters that most require optimization are the wavelength and pulse-width. Figure 4 highlights detrimental effects that result when using non-optimized parameters. For c-Si processing, the most problematic defects are the damaged regions immediately surrounding any scribed grooves or drilled/ablated holes (HAZ), and microcracks emanating from grooves and holes. Depending on the application within Table 1, reducing these effects can often be achieved through (i) wavelength optimization, in particular shorter wavelengths at 532 or 355nm; (ii) shorter pulse-widths (picosecond pulse-durations) which decrease the laser energy's thermal diffusion depth; or (iii) a combination of both.

Applications within thin-film panel production

Laser adoption within thin-film production differs from c-Si, both in the more limited range of efficiency-enhancing techniques and the increased level of laser maturity. Laser use within thin-film PV dates back to when the first thin-film production techniques were developed [4]. This is because lasers were quickly recognized to be the preferred and enabling technology available (compared to photolithography or mechanical scribing), due to depth selectivity, edge quality, process repeatability and high throughput.

Lasers represent the preferred equipment type mainly due to the precision and quality when selectively ablating thin layers of material.

Within thin-film production, pulsed DPSS lasers are used to generate discrete cell isolation and interconnection strips by scribing up to a few hundred thin lines on each of the three material layers deposited during manufacturing [5]. These scribing processes, referred to as P1, P2 and P3, are collectively called 'patterning' and are fundamental to so-called 'monolithic integration' for thin-film panels. Lasers represent the preferred equipment type mainly due to the precision and quality when selectively ablating thin layers of material, without any damage near the scribe lines or within overlying or underlying layers.

The principles of thin-film patterning are similar for the three common material groups (a-Si, CdTe, CIGS). Laser adoption scales with the installed capacities associated with each type, with 'single-junction' amorphous-Silicon (a-Si) laser tools having the highest level of maturity. Figure 5 illustrates the patterning processes specific to a-Si production, with magnified views of the three scribe lines.

Key issues for laser processing in thin-film

While lasers are established tools for patterning, process improvements are ongoing. These include increasing production line capacities and throughputs and improving the cut integrity of the scribing process. Capacity throughput increases are not satisfied simply by increasing average powers, which requires the ability to scan beams over increasingly larger panel sizes with high scribe uniformity across different material layers (smooth edges, no recast debris, minimized HAZ). However, the speed of optical scanning technology is limited, necessitating the use of multiple laser beams configured in parallel to cover up to a few hundred meters of scribing with a processing (TAKT) time of a few minutes. A more critical requirement is pulse repetition frequency (PRF), or how 'fast' the laser pulses. With target scan rates in excess of 2m/s, the PRF needs to be high (≥ 100kHz) to achieve a desired 'scalloped' profile, while optimizing parameters such as wavelength, pulse-width and pulse-to-pulse repeatability.

Next-generation lasers and characterization

Historically, the microelectronics and flat panel display industries have fashioned the specifications of industrial-qualified lasers. However, increased adoption by the solar industry has resulted in lasers being optimized for solar manufacturing, such as new ultra-short-pulse picosecond lasers. With pulse-energies and PRFs analogous to existing nanosecond lasers, lasers such as the Coherent Talisker offer wavelength flexibility from infrared to UV. Figure 6 captures the dual benefits of increased peak power and minimized thermal diffusion depth in c-Si. With very low cost-of-ownership, the key issue, again, is that cell efficiency and yield enhancements far outweigh any increase in capital equipment cost for higher specification/performance laser sources.

Another requirement for increased laser adoption is to perform detailed wafer characterization, as outlined by Applied Materials' Viren Rana, both "during process development to ensure that there is no material damage or unwanted effects, or during production, to check on microcracks, etc." This includes undertaking techniques such as carrier-lifetime measurements, X-ray diffraction, I-V curve analysis, and breakage tests. The differences can be subtle, often only surfacing in statistics generated after thousands of wafers are processed in a production environment. Understanding these to a greater extent will improve the selection of optimized lasers for each application.

As the solar industry evolves with increasing laser-enabled manufacturing process steps, more solar-specific laser tools will be developed for next-generation forward-compatible production tools. At this point, laser processing will move from bearing the status of competitive to that of an 'accepted,' incumbent technology.

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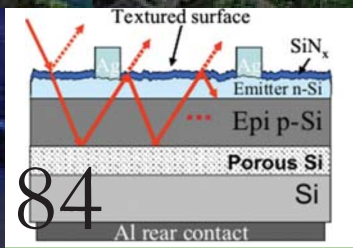
Thin Film

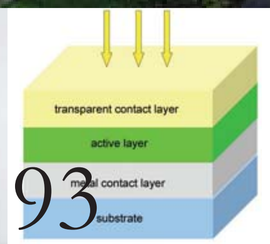
Phase III
350MW
Phase II
350MW
Phase I
350MW
78

82



Textured surface
SiN_x
Emitter n-Si
Epi p-Si
Porous Si
Si
Al rear contact
84

86



transparent contact layer
active layer
contact layer
substrate
93

News

IBM and TOK team on CIGS thin-film materials and processes; target 15% efficiencies

Continuing its strategy to leverage semiconductor and related technologies to the photovoltaics industry, IBM has said that IBM Research is targeting 15 percent plus conversion efficiencies for CIGS solar cell modules. Current CIGS thin-film cells achieve efficiencies in the range of 8 to 12 percent.

To reach its stated efficiency goals, IBM has teamed with Tokyo Ohka Kogyo (TOK), a specialist chemicals company known well for photoresist materials used in lithography processes.

"Our goal is to develop more efficient photovoltaic structures that would reduce the cost, minimize the complexity, and improve the flexibility of producing solar electric power," said Dr. Tze-Chiang Chen, IBM Vice President of Science and Technology, IBM Research. "Now, IBM's advanced technology combined with TOK's expertise in equipment design and manufacture, have the potential to broaden the use of alternative energy sources."

Yoichi Nakamura, President and Chief Executive Officer of TOK, said, "We believe that this joint development is a great opportunity to expand the applications of our technologies into the photovoltaic industry, bringing a new solid business block for us."

The two companies are developing new, non-vacuum, solution-based manufacturing processes for CIGS that include equipment and materials.

Research and Development News Focus

Sunovia claims lab breakthrough for commercialization of single crystalline epitaxial CdTe/Si

Technology development partners Sunovia Energy Technologies and EPIR Technologies have claimed a breakthrough in growing single crystalline CdTe/Si more rapidly in a molecular beam epitaxy (MBE) tool that could lead to the faster commercialization of their proprietary solar cell technology.

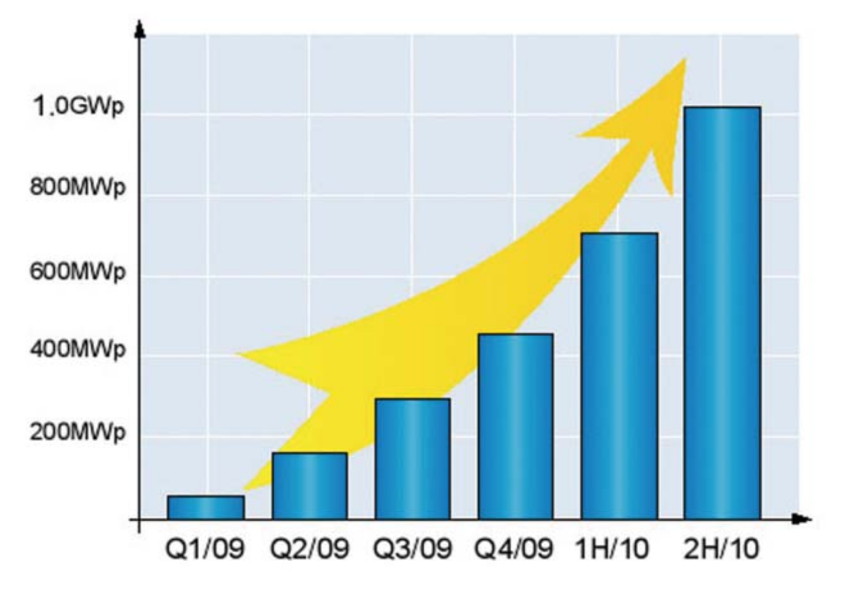
The companies said that the results have been independently validated, readily reproducible with an extremely high yield and an unprecedented high crystal quality. No further technical details were provided, nor was the date given for when the commercialization could take place.

Thin Film Production News

Best Solar to invest US$2.5 billion for 1GW thin-film capacity in 2010

Exhibiting for the first time at Intersolar last week was Best Solar Hi-Tech Co., Ltd., the thin-film PV manufacturing start-up, created by LDK Solar's founder and CEO Xiaofeng Peng. Brochures displayed by the company detailed the plans to spend US$2.5 billion over the next three years to reach a capacity of over 1GW annually using Applied Materials' 'SunFab' turnkey large 5.7m^2 glass substrate (Si) thin-film technology. This would seem to give confirmation to the fact that Best Solar, a privately held company, was the un-named company that Applied Materials referred to in a U.S. Securities and Exchange Commission filing in March, 2008 as having placed a US$1.9 billion order for its SunFab lines.

"By working closely with world leading Solar Equipment provider Applied Materials, the company is deploying the most advanced technology and equipments to thin film solar market," was how the Best Solar brochure phrased the news.



Best Solar Hi-Tech Co., Ltd planned capacity ramp.

Best Solar also stated that they were currently building one of the largest thin-film fabs in the world to date. An artist's drawing of the manufacturing complex highlighted three side-by-side facilities each with a capacity of 350MW labeled Phase 1, 2 and 3. The facilities are being built in the Wuzhong Economic Development Park, Suzhou Jiangsu, China.

Using tandem junction technology with an expected conversion efficiency of 8.5 percent initially, Best Solar plans to reach 12 percent efficiency levels in 2011.

Initial production is planned for the end of 2008, and with the completion of certification in Europe and North America, shipments are expected in the first quarter of 2009.

Best Solar Hi-Tech Co., Ltd planned manufacturing centre in the Wuzhong Economic Development Park, Suzhou Jiangsu, China.

Solyndra secures US$325 million CIGS supply deal with Solar Power

CIGS thin-film photovoltaic start-up manufacturer Solyndra has won a US$325 million supply deal with U.S.-based PV turnkey installer, Solar Power, Inc. The agreement runs from 2008 through 2012 with yearly increasing volumes and decreasing price per watt of peak output.

"Solyndra's panels are highly innovative and offer unique design features that differentiate them from conventional panels," said Steve Kircher, CEO of Solar Power, Inc. Their panels and simple mounting systems are quick to install and have outstanding energy production. The addition of their products to our portfolio extends the range of installation opportunities we now have; especially where available space and/or system weight are considerations."

Solar Power said that it would be one of the first companies in the U.S. to offer Solyndra's CIGS product.

Ascent Solar mulls faster capacity ramp in 2009; evaluates overseas production

In conjunction with its Annual Shareholder Meeting, Ascent Solar Technologies said that the company was evaluating whether to bring forward its planned 110MW production capacity of its thin-film modules. The firm is currently in development and limited production operations with its 1.5MW line that is expected to be in full-scale production by the end of 2008.

"We are trying to implement a systematic and realistic approach to expanding production capacity, including the prospects of possibly accelerating our existing production capacity timeline, which presently contemplates 110MW of aggregate production capacity by 2012," noted Matthew Foster, President and CEO of Ascent Solar Technologies.

Foster also noted that the company was continuing to weigh up manufacturing opportunities in Europe, Asia and the Middle East.

Ascent Solar is also working on electronic integrated photovoltaic (EIPV) applications, as these require lower levels of certification compared to BIPV products and therefore offer the potential to market products much quicker than the typical six months or more for normal certification.

Centrosolar to use United Solar Ovonic's flexible thin-film technology

Centrosolar has signed a four-year supply agreement with United Solar Ovonic, a subsidiary of Energy Conversion Devices for the use of its flexible thin-film solar cell product for the building-integrated photovoltaics (BIPV) market. Although the megawatt amount was not disclosed, the companies said that the supply contract was 'substantial.'

The deal is in support of Centrosolar's subsidiary, Biohaus, which is claimed to be a market leader for BIPV products. The deal supports the majority of Biohaus' BIPV requirements for the next four years.

Solutia creates dedicated thin-film materials division

Specialty chemicals company Solutia, Inc. has set up a dedicated business unit to supply the thin-film photovoltaics manufacturing sector with its 'Saflex' polyvinyl butyral (PVB) encapsulation materials. Solutia said that it was also increasing PVB capacity at span production sites in Belgium, China, Mexico and the United States.

"As energy demand and public policy drive the rapid adoption of renewable energy, the global market for thin-film solar panels is growing at a rate of 40% per year," said Jeffry N. Quinn, Chairman, President and CEO of Solutia Inc. "Our Saflex business is the world's leading producer of polyvinyl butyral (PVB) interlayer, which is emerging as the encapsulant of choice in the thin-film solar panel market. Within the next 7-10 years, our Saflex business expects to build photovoltaic into a third major market, which will be comparable in size to its traditional architectural and automotive markets."

Sunwell places 180MW order with Oerlikon Solar

Oerlikon Solar has announced that it has received an order for two end-to-end thin film silicon production lines from Sunwell, a wholly owned subsidiary of CMC Magnetics. The first 60MW delivery will be to Sunwell's Taiwan facility, while the remaining 120MW will be for Sunwell's new site that is currently under construction.

Production of the lines, which use Oerlikon's tandem cell technology, is scheduled for 2009. CMC has adhered to its plans to increase capacity to 1GW per annum, and this additional 180MW will bring CMC's yearly production capacity to 226MW.

"To execute our rapid growth plans it was crucial to identify the most competitive and responsive thin film PV equipment supplier," said Bob Wong, Chairman of CMC Magnetics. "Oerlikon Solar is the right company to deliver on our demanding plans."

Applied Materials gains first Italian 'SunFab' customer

Applied Materials has announced that it has won its first customer in Italy for its 'SunFab' 5.7m^2 turnkey thin-film line. The new customer is Moncada Energy Group s.r.l., a leading private Italian producer of renewable energy currently using wind farm technology. Moncada is expected to build a 40MW plant in Campofranco, Sicily.

"We believe that the large 5.7 square meter modules produced by the SunFab line will enable lower production and installation costs, making them an excellent solution for quickly achieving grid parity in Italy," said Salvatore Moncada, CEO and founder of Moncada Energy Group. "Based on Applied's strong leadership in manufacturing, and its capability to provide complete service support – which is unprecedented in today's solar industry – we are confident that Applied can help us quickly start up our SunFab line and achieve production in 2010."

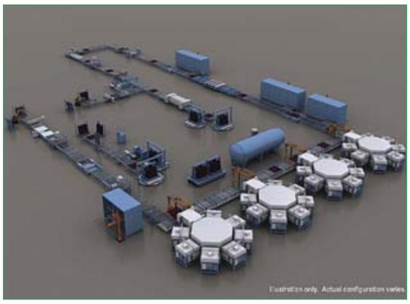
"Applied Materials is very pleased to have the opportunity to work with Moncada on its first solar venture and we appreciate their confidence in our capabilities," said Dr. Mark Pinto, Senior Vice President and General Manager of Applied's Energy and Environmental Solutions Group. "We are excited to expand our role in Italy – which has the geographic potential to realize early grid parity – from supplying crystalline silicon equipment through our Baccini business to producing the world's largest thin film modules with our SunFab line."

The SunFab line will initially produce large 5.7m^2 single junction PV modules and will be used for Moncada's own energy projects.

Applied Materials to service GET's 'SunFab' thin film line

Green Energy Technology, Inc. (GET) has signed a five-year service contract with Applied Materials to support GET's 'SunFab' production line, located in Taiwan. GET also produces multi-crystalline silicon wafers.

"Green Energy Technology sees substantial advantages in aligning with Applied Materials to provide the support infrastructure, service technology and global expertise that can help make our new venture a success," said Mr. Hurlon Lin, President of GET. "We believe the SunFab Performance Service program will allow us to run at the lowest possible costs and maximize our profitability, enabling us to focus on delivering world-class solar PV modules to our customers."



Oerlikon Solar gains two new thin-film customers

Oerlikon Solar has secured business from two new thin-film start-ups. Spanish firm Gadir Solar SA has ordered a complete turnkey a-Si thin film production line, capable of producing over 300,000 panels per year and China-based Chint Solar, has ordered Oerlikon's 'micromorph' R&D line and first-phase production equipment. The equipment will be delivered in 2008 with ramps expected in 2009.

"By securing both contracts, Oerlikon Solar enlarges its share in important growth markets. This further strengthens our market leading position as provider of proven thin-film silicon PV solutions," says Jeannine Sargent, CEO Oerlikon Solar.

In recent months, Gadir Solar was reported to be planning a production capacity of 40MW at a new plant built in Cadiz, Spain with plans for a further 20MW in a second-phase ramp.

Oerlikon said that Gadir Solar would also receive an R&D line for Oerlikon's micromorph technology as well as doubling capacity and migrating to the micromorph technology at a later date.

Chint Solar was said to be planning production in Hangzhou, Zhejiang province to start by mid-2009 and add capacity of up to 180MW by 2010 and is also Oerlikon Solar's first customer in mainland China.

Product Briefings

ABB

ABB's IRB6640 robot meets thin-film PV class 5 cleanroom standards

Product Briefing Outline: ABB's new IRB6640 cleanroom robot is designed to help the thin-film photovoltaic sector to improve productivity by lowering manufacturing costs, while at the same time raising production output. The new cleanroom version of the IRB6640 meets all necessary process and cleanroom specifications for the thin-film photovoltaic industry, according to ABB.

Problem: Thin-film manufacturing consists of applying semiconductors and electrical interconnecting layers to a glass substrate carrier. Any contamination, even in the micron range, reduces the power rating of the modules. The degree of cleanliness required, plus the size and weight of the modules, precludes using traditional manual production methods. It is therefore impossible to construct the modules in an economic way without using 'clean' robots.

Solution: ABB cleanroom robots have three paint layers: a prime coat, a white paint layer and a clear top coat. Screws and inspection panels are covered with plastic prior to painting, which is subsequently removed when the paint dries. Some screws and panels are then protected again using removable covers, which facilitates cleaning. Inspection panels are not painted. Some of the cables are installed in an enclosed cable carrier, which enables them to be properly transported and at the same time prevents worn areas – even those that are not visible – from being exposed. Any areas that could potentially cause contamination are sealed at the factory using metal plates.

Applications: Thin-film photovoltaic module manufacturing in Class 5 cleanrooms.

Platform: Certification was undertaken by The Fraunhofer Institute for Manufacturing Engineering and Automation IPA in Stuttgart. They rigorously tested the six-axis articulated robot over a period of seven weeks and included evaluation and compilation of all relevant documents.

Availability: June 2008 onwards.

Momentive Performance Materials

Momentive Performance Materials offers PBN for better thermal stability in CIGS manufacturing

Product Briefing Outline: Momentive Performance Materials, Inc. recently launched a new product line of Pyrolytic Boron Nitride (PBN) crucibles, heaters and coatings to consider for the enhancement of the production of CIGS solar cells.

Problem: Compared to other alternative ceramic materials, PBN potentially provides a higher level of chemical and thermal stability and a lower total cost of ownership. Due to the relatively low wetting of PBN by most molten metals, PBN typically withstands the high temperature and high-volume throughput demands of CIGS solar cell manufacturing with minimal deterioration.

Solution: Pyrolytic Boron Nitride (PBN) is an anistropic, high-temperature ceramic that exhibits a unique combination of high electrical resistance and good thermal conductivity. This non-toxic, non-porous compound is exceptionally pure by virtue of the synthesis process (high temperature/low press chemical vapor deposition). It can be deposited or easily machined into a wide variety of shapes, including crucibles, boats, tubes, bottles and machined plate products. As a coating on graphite, it may help protect heaters and evaporation sources from the corrosive effect of molten metals. PBN's directional thermal conductivity provides improved 'heat spreading' capability for improved temperature uniformity, according to the company. The combination of high strength, good thermal conductivity and a low coefficient of thermal expansion make the materials extremely resistant to thermal shock, the company claims.

Applications: CIGS solar cells.

Platform: Pyrolytic Boron Nitride and Pyrolytic Graphite Crucibles, heaters and coatings.

Availability: October 2007 onwards.

Isopad

ISOPAD Big Heating plates enable larger panel photovoltaic cells

Product Briefing Outline: Isopad has developed heating panels that offer equipment manufacturers of thin-film photovoltaic cells the chance to make significantly larger cells – and lower the cost per watt of energy generated. Recent expansion of manufacturing capacity means shorter lead times and reliable delivery for these key sub assemblies.

Problem: The restriction in silicon supplies and the subsequent fast ramp to volume capability for thin-film cells means capital equipment makers need to improve throughput, lower capital costs per watt and provide higher conversion efficiency cells. New techniques are required to move the thin-film manufacturing processes rapidly to full volume as this new industry comes on stream – and to do that whilst improving yields and cell output.

Solution: With decades of work in the high vacuum industry, Isopad has developed some of the largest 'all-metal' panels available for high temperature, PECVD and other deposition and subsequent lamination processes. Custom designed for each equipment manufacturer, Isopad's durable, high-quality heating solutions provide equipment manufacturers with a reliable heating solution. These large panels are used where nil outgassing, even heat, reliability in use and high throughput are required – at temperatures up to 1000°C. Isopad's designers call on decades of expertise to ensure the large panel heaters meet the needs of the customers needing solutions for large sized deposition or lamination equipment.

Applications: Big heating plates, heater, thin-film, vacuum deposition, flat panel display, photovoltaic solar cell manufacturing and lamination.

Platform: Isopad heating panels are key components of manufacturing equipment for thin film vacuum deposition and lamination. They are designed to help equipment makers provide high quality, high throughput solutions for solar panel assembly.

Availability: August 2008 onwards.

Fab & Facilities

Materials

Cell Processing

Thin Film

PV Modules

Power Generation

Market Watch

Plasma texturing and porous Si mirrors boost thin-film Si solar efficiency

Hanne Degans, **Izabela Kuzma**, **Guy Beaucarne** & **J. Poortmans**, IMEC, Belgium

ABSTRACT

Thin-film silicon solar cells are a potentially low-cost alternative to solar cells based on bulk silicon that are commonly used in the industry at the present time. However, a major drawback of the current epitaxial semi-industrial screen-printed cells is that they only achieve an efficiency of about 11-12%. By upgrading their efficiency, this kind of solar cell would become more attractive to the photovoltaic industry. The optimization of the front surface texture by dry texturing based on a fluorine plasma and the introduction of an intermediate porous silicon reflector at the epi/substrate interface (multiple Bragg reflector) has proven to result in an efficiency boost up to about 14%.

Introduction

Epitaxial thin-film silicon solar cells are cheaper compared to solar cells based on bulk silicon. However, the main drawback of the current epitaxial thin-film solar cells is their relatively low efficiency. Two techniques have been proven to upgrade the efficiency of this type of solar cell: the optimization of the front surface texture by plasma texturing based on halogen atoms, and the introduction of an intermediate reflector at the epi/substrate interface. The optimized front surface texture combines the requirements of uniform light diffusion (Lambertian refraction) and reduced reflection with very limited removal of silicon (since the epitaxial silicon layer is already quite thin). The introduction of the intermediate reflector (multiple Bragg reflector) prolongs the path length of the low energy photons by a factor of at least 7, ultimately boosting the efficiency of the solar cells.

Epitaxial thin-film solar cells

Silicon solar cells based on mono- or multicrystalline bulk silicon substrates dominate the photovoltaic market. However, being made entirely of high purity silicon, the production of this type of solar cell is very energy consuming and relatively expensive. To further promote the photovoltaic industry, the production cost of solar cells should drastically decrease by reducing the material cost.

Epitaxial thin-film silicon solar cells have the potential to be a low-cost alternative to bulk silicon solar cells. These screen-printed solar cells use a cheaper substrate and a thinner active silicon layer (20µm) compared to the current bulk silicon solar cells (200µm). The low-cost substrate consists of highly doped crystalline silicon wafers (impure silicon from metallurgical grade silicon or from scrap material) [1]. On this substrate, a thin epitaxial active silicon layer is deposited using the CVD process.

The production process of epitaxial thin-film silicon solar cells is very similar to that of conventional bulk silicon solar cells. Therefore, compared to any other thin-film technology, it will be relatively easy to implement it in the existing production lines. However, a major drawback for the industrial competitiveness of epitaxial thin-film silicon solar cells is their moderate efficiency compared to conventional bulk silicon solar cells. The open-circuit voltage and fill factor of these cells can reach similar values as bulk silicon solar cells but, due to the optically thin active layer (20µm compared to 200µm), light is lost in the low-quality substrate from the moment it is transmitted from the epi layer into the substrate, resulting in a loss of short-circuit current, which can amount to as much as 7mA/cm^2.

The challenge is to find the ideal trade-off between sufficient efficiency and reduced cost, particularly in regard to industrial large-scale production.

> The challenge is to find the ideal trade-off between sufficient efficiency and reduced cost, particularly in regard to industrial large-scale production.

This paper describes two developments that increase the optical path length and consequently positively influence the efficiency of epitaxial thin-film silicon solar cells: plasma texturing and the insertion of a porous silicon mirror at the interface between the low-cost silicon substrate and the active layer. It has been shown that these adaptations raise the efficiency of the epitaxial thin-film silicon solar cell to almost 14%.

Efficiency improvement by plasma texturing

By texturing the front surface of the active layer of a solar cell, surface light scattering changes, thereby influencing the performance of the solar cell. The purpose is to make an optimal front surface that is 100% diffusive (Lambertian Refraction, exhibiting complete scattering). In such a case, photons would move through the active layer at an average angle of 60°, resulting in an increase in pathlength by a factor of 2. In other words, an active layer of only 20µm would then optically behave as if it were 40µm thick.

Using plasma texturing based on fluorine, the optimal surface front end, exhibiting Lambertian Refraction, can be reached with only a very limited removal of silicon (only 1.75µm). This is very important in epitaxial thin-film silicon solar cells, as the active layer in this type of solar cells is already quite thin (20µm). Apart from the efficiency improvement due to optimized scattering, plasma texturing also lowers the reflection, achieves oblique light coupling and lowers contact resistance. This results in an additional improvement of the short-circuit current with 1.0 to 1.5 mA/cm^2 and an extra efficiency improvement of 0.5 to 1.0%.

Efficiency improvement by introducing porous silicon mirrors

A further adaptation that improves the efficiency of epitaxial thin-film silicon solar cells is the incorporation of a porous silicon mirror at the interface between the active layer and the low-cost substrate. This mirror decreases the transmittance of long wavelength light into the substrate.

In practice, the reflector is made by electrochemical growth of a porous silicon stack of alternating high- and low-porosity layers (a multiple Bragg reflector), defined by the quarter

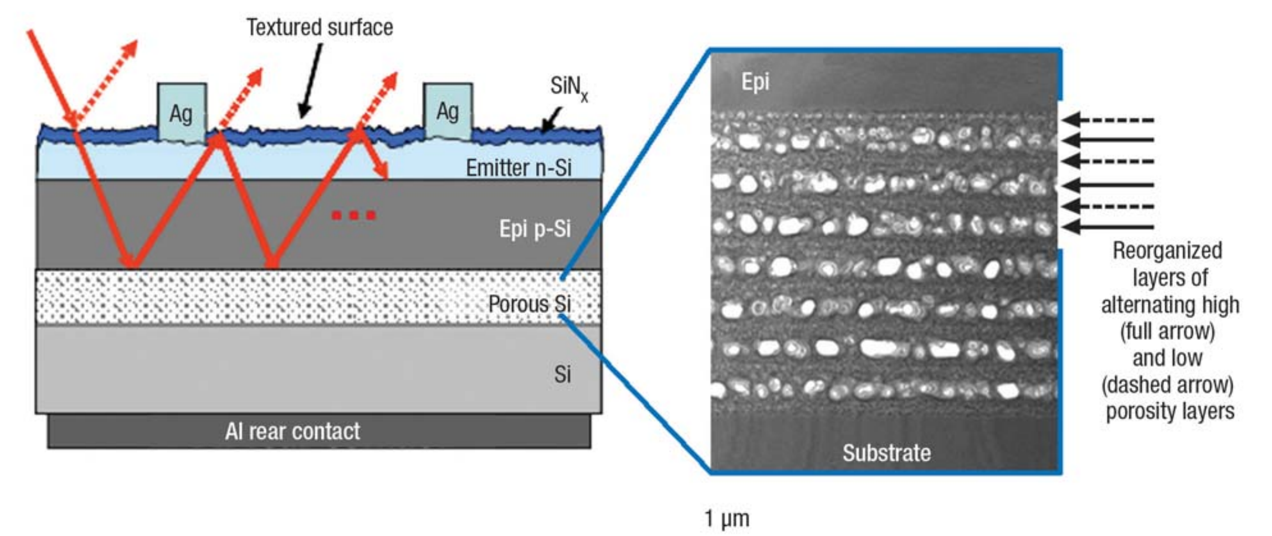


Figure 1. Porous silicon reflector – shows (left) an advanced epitaxial cell layout illustrating the concept of an intermediate reflector; (right) Transmission Electron Microscopy (TEM) picture of a reorganized porous silicon stack.

wavelength rule. During epitaxial growth of the active layer, the porous Si in the stack reorganizes into layers with small and large voids, but retains its original layout. This structure is a proven effective reflector. The mirror reflects the photons that reach the interface, either by the Bragg effect (for normal incidence on the mirror) or by total internal reflection (for light impinging obliquely onto the mirror at angles above the critical angle). As a result, they can pass a second time through the active layer. The reflected photons that reach the front surface of the active layer outside the escape angle – a large part of them, due to the diffusion of the light – will again be reflected. The introduction of the porous mirror will therefore cause multiple photon reflection. Consequently, the optical path length is enhanced, resulting in an increased efficiency of the solar cell. It was shown that, with a perfect Lambertian surface at the front end, a 15-layer porous silicon mirror resulted in a path-length enhancement of 14, meaning that an epitaxial thin-film silicon solar cell with a 15µm active layer would behave like a 210µm-thick bulk silicon solar cell [2].

The introduction of the porous silicon mirror resulted in an internal reflectance of 80-84%, of which 25% could be attributed to the Bragg effect itself (see Figure 2) [3]. The effect could even be improved by using an optimized reflector design in which the thicknesses of the low- and high-porosity layers vary with the depth (chirped porous silicon stacks), resulting in a substantial bandwidth enlargement of the reflector. With this chirped specialized structure, the path length enhancement of low energy photons could be increased much above the current value of 7 (with the effect of the reflector alone. Combined with a perfectly light diffusing top surface, it increases to above 14). Solar cells prepared on low-cost Si substrate with this reflector and screen-printed contacts reached an excellent efficiency of 13.9% and a J_{sc} of 29.6mA/cm^2 [4].

Conclusions

Both plasma texturing and the introduction of a porous silicon mirror at the interface between the epitaxial layer and the substrate have been shown to improve the efficiency of epitaxial thin-film silicon solar cells and pave the way

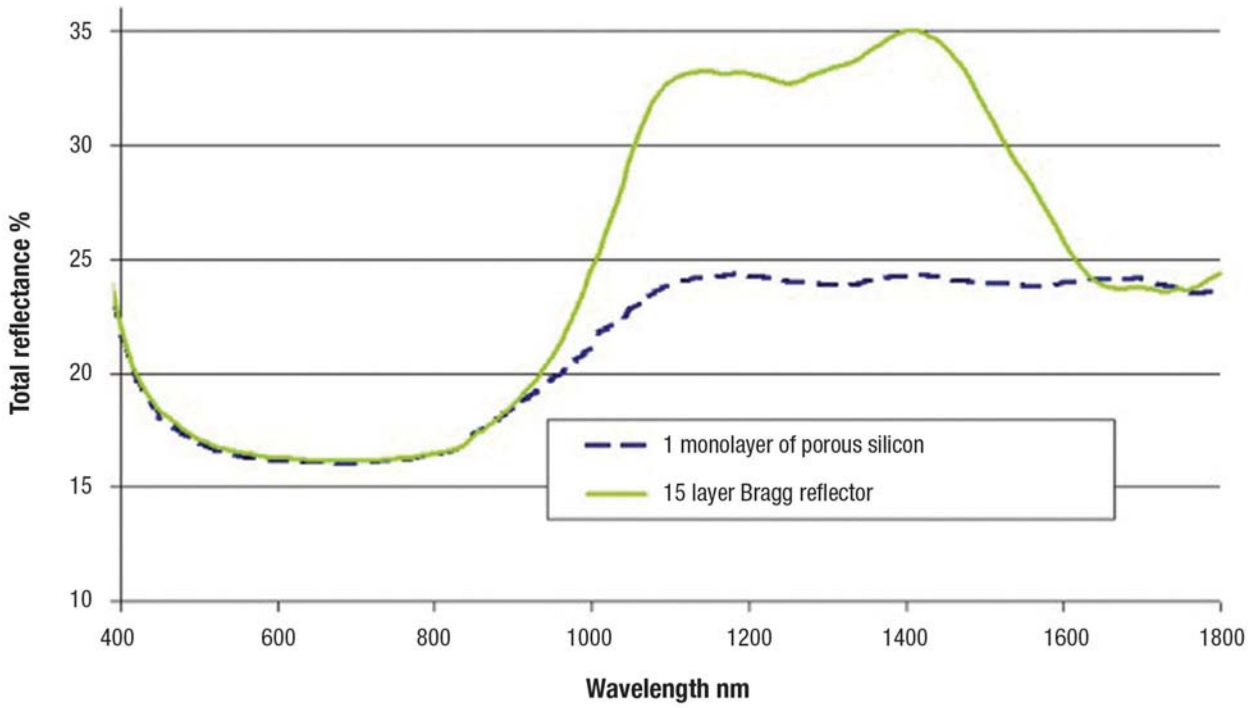


Figure 2. Reflectance comparison between 15-layer porous Bragg reflector and porous monolayer.

to low-cost industrial production of this type of solar cells as an alternative to bulk silicon solar cells.

Acknowledgements

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Hanne Degans, Scientific Editor at IMEC, received her Ph.D. in biology from the K.U. Leuven (Belgium) in 2002. She then worked at the VMM (Vlaamse Milieu Maatschappij). In 2008, she joined IMEC as Scientific Editor and Press Spokeswoman.

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Jef Poortmans, Department Director Solar & Organic for IMEC, received his Ph.D. in 1993, after which he joined IMEC's photovoltaics group, where he became responsible for the Advanced Solar Cells group. He began activity around thin-film crystalline Si solar cells and organic solar cells at IMEC and he has been coordinating several European Projects in this domain. At the moment he is Program Director of IMEC's Strategic Program SOLAR+. Dr. Poortmans has authored or co-authored close to 350 papers that have been published in Conference Proceedings, books and technical journals.

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Thin-film CIGS starts to come of age

Tom Cheyney, Senior Contributing Editor (USA), Photovoltaics International

ABSTRACT

The next two years will be crucial in determining the market viability and future of what many see as the most promising thin-film photovoltaics technology: copper indium gallium (di)selenide (CIGS) and its gallium-free cousin, CIS. With potential conversion efficiencies just below that of crystalline silicon PV, low-cost manufacturing strategies offering a chance to reach sub-dollar-per-watt manufacturing costs on both glass and flexible modules, and applications ranging from utility- and industrial-scale farms to building-integrated commercial and residential uses, the quaternary compound has a large grid-parity upside – if the very real challenges of scaling production to commercial volume can be met.

A handful of companies – Showa Shell, Honda Soltec, Wurth Solar, Global Solar, and Sulfurcell – have already produced megawatts of cells and modules and are adding manufacturing capacity. Dozens more firms are in various stages of development, attempting to fine-tune the process as well as fit out and qualify pilot lines and volume-production-scale facilities by 2009/2010 and ship product as soon as possible.

Large technology companies have also entered the CIGS arena, directly or indirectly through investment, as evidenced by IBM and TOK's wide-ranging materials/process/tooling joint-development effort and Intel Capital's investment of US$38 million (as part of a US$135 million equity funding) in Berlin-based Sulfurcell's manufacturing expansion. If all of the promised fab ramps take place successfully and come online by 2010/2011, nearly 2.2GW of CIGS capacity (including Showa's proposed 1GW plant) would be available, according to the most recent estimates from the U.S. National Renewable Energy Laboratory (NREL).

If all the promised fab ramps come online by 2010/2011, nearly 2.2GW of CIGS capacity would be available.

As for the markets, in its most recent report and forecast on thin-film PV, NanoMarkets foresees the total segment reaching US$8.9 billion in 2012 and US$22 billion in 2015 (a nearly 10x increase from 2008's US$2.4 billion), with the CIGS sector accounting for US$1.4 billion and US$4.9 billion (a more than 31x increase on 2008's US$152 million) in those respective years (see Figure 1).

Industry experts agree that several issues must be resolved in order for reliable, cost-competitive CIGS-based solar modules to be developed and proliferate:

- Module efficiencies must move beyond the low-double-digit range
- The toolset for growing the absorber films should be standardized and the manufacturing performance level improved
- The layers themselves should be thinned below a micron and columnar structures deposited by alternative methods need optimizing to achieve higher efficiencies
- A good, relatively cheap barrier layer to encapsulate flexible modules from moisture ingress must be perfected; and
- CIGS' absorber film uniformity and stoichiometry has to be improved over large-area substrates.

The U.S. connection

Nowhere have CIGS startups raised the hopes of investors and the solar-curious public more than in the United States, where TFPV (largely thanks to First Solar and Uni-Solar) accounts for more than 60% of solar production. Nanosolar, Miasolé, HelioVolt, Solyndra, SoloPower, Ascent Solar, and DayStar have raised (and burned through) hundreds of millions of dollars (largely via venture capital, private equity, initial public offerings, and government research awards), while others like ISET, RESI and Telio Solar have kept a lower profile.

These companies' proprietary CIGS absorber-layer deposition techniques, examples of which range from sputtering (Miasolé, DayStar) to electrochemical deposition/plating (SoloPower), and coevaporation on flexible polymer (Ascent) to nanoink printing combined with rapid thermal processing (Nanosolar), are unproven in terms of their ultimate scalability. None of these CIGS upstarts, whether they employ a discrete or monolithic approach to cells, has yet to truly demonstrate high-efficiency, high-yield, high-throughput multimegawatt-scale production capabilities remotely comparable to the thin-film sector's champion First Solar – despite the marketing hyperbole and assurances of great progress by some players.

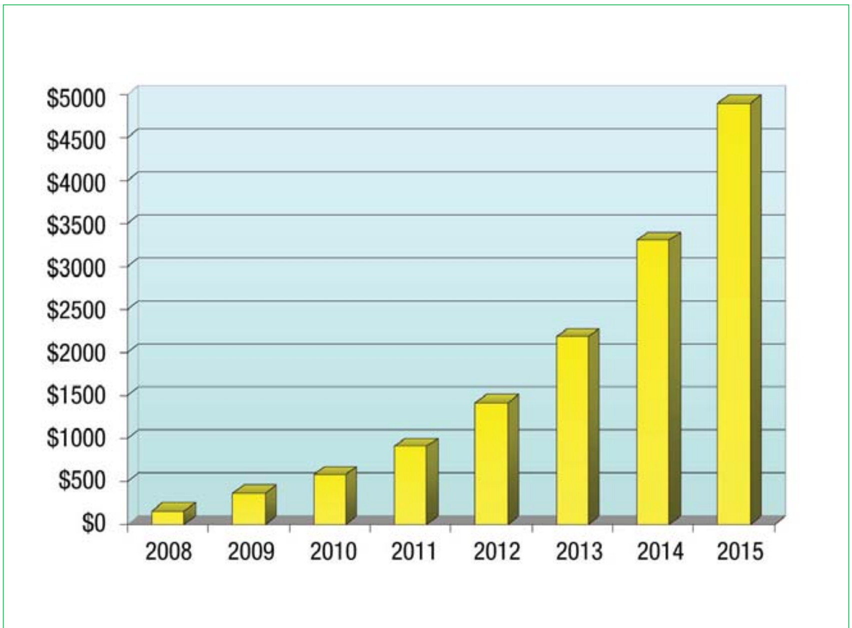

Figure 1. CIS/CIGS thin-film PV market, 2008-2015 (US$ in millions).

Source: NanoMarkets, LC

From Nanosolar's as-yet-unconfirmed claim of a 430MW manufacturing line to the stated goals of HelioVolt, SoloPower and the other aforementioned outfits of having 20, 25 or 40MW factories up and running by this year or next year at the latest, the pressure is mounting for CIGS companies in the United States and elsewhere to demonstrate their ability to make the scaling transition from the development line to the volume-production fab.

Solyndra, Miasolé making progress

According to Harin Ullal of NREL (where many of the thin-film technologies have been developed), of the 40 or so emerging and established CIGS companies that exist in the world that are actively developing and/or manufacturing CIGS worldwide, about 20 of those are located in the United States, including several operating in 'stealth mode.' Among the development-stage firms, he believes that Solyndra and Miasolé have 'made some real progress' lately in getting their TFPV to market.

Although Solyndra still refuses to publicly comment about its roadmap or core technology (which a patent search reveals as thermal coevaporation) – or much of anything else about itself, for that matter – two hefty five-year (2008-2012) module supply deals with Phoenix Solar and Solar Power, Inc. worth €450 million and US$325 million, respectively, were announced in July. This news suggests that the Fremont, CA-based company has made significant headway on ramping its manufacturing and may be moving close to product commercialization – or at least that the two customers believe it has.

> "For Miasolé, over the next 6 to 12 months, it's about execution."
> **Joe Laia, Miasolé**

Along with recently securing tens of millions of dollars in fresh funding from steelmaker/mining concern ArcelorMittal's new cleantech fund, Leaf Clean Energy, and other investor groups, Miasolé said in July that it had achieved a verifiable 10.2% conversion efficiency at NREL on its flexible cell-encapsulated glass modules that came off its nascent production lines in Santa Clara. (By comparison, the national lab's latest champion CIGS cell-on-glass recently reached 19.9% efficiency; Ullal says the ultimate theoretical efficiency for CIGS, regardless of substrate, might be as high as 27%.)

"This demonstrates our ability to consistently produce high-efficiency CIGS modules on production equipment," said President/CEO Joe Laia at the time of the announcement. "This is a critical step on our path to producing low-cost solar modules in high volume."

Photos courtesy: Global Solar.

Figure 2. Global's CIGS tools use a multisource coevaporation process.

Laia, a semiconductor capital equipment veteran who joined Miasolé in September 2007, told *Photovoltaics International* during a midsummer facility visit that the company has sharpened its focus in its drive to commercialization and unsubsidized 10-cents-per-kilowatt-hour grid-parity solar energy costs. "For Miasolé, over the next 6 to 12 months, it's about execution. I think you need to demonstrate the technology, that you can take the technology that you have and make a compelling product at a compelling price. There's no magic in any of this... For us, where we are in our development, we need to drive the efficiencies that we want and then go look for costs to take out."

Laia would not go on the record with many specifics of the company's manufacturing technologies, latest conversion efficiency distributions (tight as they are), factory ramp, or product shipment timelines. "We are in the process of demonstrating that we understand how to make material in a reproducible fashion that is commercially viable, but we aren't going to explain what those [details] are because I'd just be giving roadmaps to all the other guys in the space."

> Global Solar will have 175MW of capacity by 2010, if all goes according to plan.

During a tour of Miasolé's production floor, the activity level was high and the noise around the two U-shaped 20MW continuous roll-to-roll manufacturing lines was loud, largely because of an air-system connected to the handling system

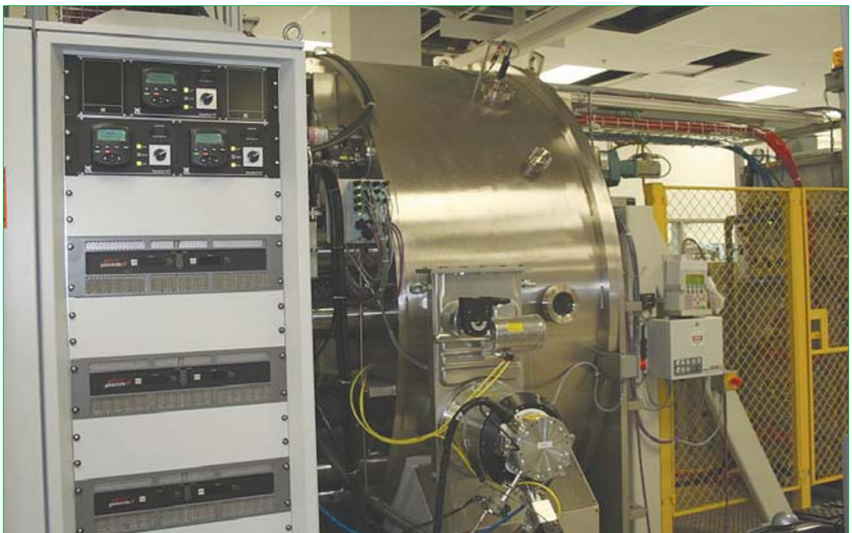

Figure 3. Large chambered systems sputter the TCO films.

on the toolsets. Kilometre-long spools of metre-wide steel foil are fed at a few feet per minute into the equipment, which are essentially multichamber cluster tools incorporating each of the steps required to process CIGS cells.

The flexible substrate, which is reoriented from a horizontal to a vertical position at the start of the run, rolls through the sequential process stages, including the standard molybdenum back-contact step, the proprietary 'cylindrical rotary magnetrons' sputtering the CIGS, and the deposition of the cadmium-sulfide buffer layer and then the transparent-conducting-oxide (TCO) front-electrode film.

"It's steel in and CIGS out," as Laia explained, a single-pass, "end-to-end manufacturing process." The material-laden foil is then laminated, cut into cell strips, tested, and binned for integration/encapsulation into glass PV modules being assembled elsewhere in the factory.

Global Solar ramps capacity

When NREL's Ullal speaks of "the established guys," that is, the companies employing one of the two working CIGS processes (thermal coevaporation and two-stage vacuum-coated precursor/selenization or sulfurization) and shipping commercial modules in relative volume with efficiencies ranging from 10-12%, the only U.S. company to make the senior project manager's short list is Global Solar.

> Global uses a batch serial process on its roll-to-roll production lines.

With 40MW of manufacturing capacity coming online at its new 110,000-square-foot factory in the desert south of Tucson, AZ, a 35MW plant ramping near Berlin, and another 100MW scheduled to fill out the main site by early- to mid-2010, the company will have 175MW within two years, if all goes according to plan.

Thousands of strings of flexible thin-film 210mm long x 100mm wide CIGS cells on foil from Global's new lines have been shipping down the road to Solon America's nearby assembly facility (itself in a ramp-up to an eventual capacity of 80-100MW), where they are packaged in 'tech-agnostic' glass modules alongside the units containing crystalline-silicon-based cells from other manufacturers.

Global is not exactly a newcomer to the space, with roots stretching back to Martin Marietta's early CIGS efforts in 1991 and an official birth year of 1996, when it was established as a joint venture between ITN Energy and Tucson Electric. For the first 10 years, the company worked on researching and developing flexible plastic CIGS panels, first for military and government use and then for Brunton and others in the commercial and consumer markets. It built a 4MW factory in the early 2000s, steadily improving efficiencies and yields, and driving down costs, while shipping large amounts of the portable power units.

Figure 4. One screen printer at Global can handle 40MW of capacity.

When Solon and a private European investor bought Global from then-owner UniSource in 2006, the resulting capital infusion allowed the company to start planning its first volume production facility and also optimizing a novel approach to engineering its CIGS cells into traditional glass panels – a process now in manufacturing at Solon.

Global's factory floor

During a late April tour of the Tucson facility, Global's Chief Technology Officer Jeff Britt walked around the floor and described the manufacturing flow. The factory floor was bustling with equipment in various stages of delivery, installation, characterization, and optimization, with plenty of floorspace still remaining for the later phases of expansion.

> "We have put our own IP stamp on how to control the selenium."
> **Jeff Britt, Global**

Although Global operates roll-to-roll production lines, the web material does not feed continuously through one, large multichamber vacuum process system, but rather the spools move from tool to tool in what Britt called a "batch serial process." Ceiling-mounted cranes lift the heavy foil rolls off the tools and place them on carts, which are then pushed to the next equipment set in the process flow.

By taking this not-exactly-continuous roll-to-roll approach, "it allows us to balance our production," explained Britt. "If you have to make an improvement in one process that allows you to speed the web up, all of a sudden everything else is a bottleneck. You can buy particular toolsets as you increase the capacity of each process; you can put in particular tools to even out and eliminate any bottlenecks in the production process. It frees you to do that kind of development that can be implemented immediately instead of having to wait for the next entire generation of tools to come out, offering flexibility in your capacity ramp."

Processing the CIGS

The two- to three-thousand-foot-long rolls of foot-wide, 1mm-thick stainless steel foil are loaded first onto a custom-designed sputtering tool, four of which will be part of the initial 40MW ramp. The process starts with the deposition of a thin chromium layer to promote better adhesion to the foil of the 300-400nm molybdenum films deposited by the same tool. Britt said the per-roll cycle time in the moly tool is about eight hours, including the pumpdown, deposition, venting, and cleaning steps.

The big rolls of foil then move the key process sequence – the multisource coevaporation tool used to deposit the 1.5-2.0μ-thick layer of copper, indium, gallium, and selenium, where the web is heated up to between 500 and 600°C. "We need more of these tools than the Moly tools," Britt noted. "We don't have exact matching, where one process matches another in terms of capacity, so we've got an unbalanced number of systems." Eventually, seven pieces of CIGS equipment will extend the length of the factory floor, separated by a pumphouse chase, according to Britt.

Regarding one of the trickiest pieces of taming the CIGS process – the control of selenium when the temperatures get too high – Britt said, "we have put our IP

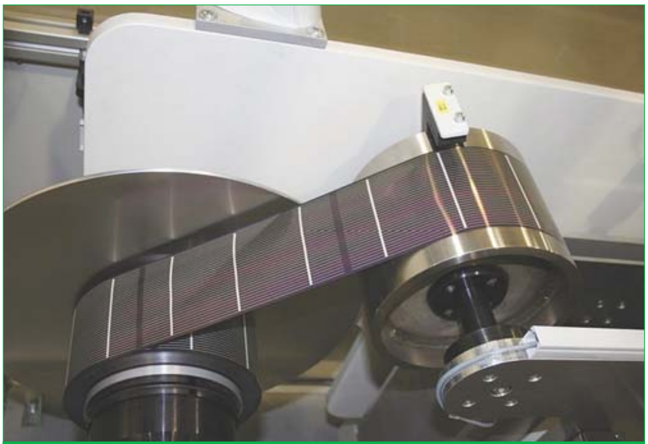

Figure 5. Up to 18 CIGS cells are strung together at a time at Global.

stamp on this on how to control the material. Because it has a high vapor pressure, it's difficult to supply selenium in the right way to lead to a high-quality, high-efficiency solar cell. You induce defects if you don't control the selenium properly."

After the CIGS films are deposited, the web moves over to the cadmium sulphide coating systems, which lay down the thinnest film (at 80nm thick) in the stack. The proprietary process tools are segregated inside an atmosphere-controlled room of their own, "because of some of the process by-products need to be controlled to remove hazardous materials," explained Britt. "The process generates some level of cadmium in liquid form. We have an entire waste-treatment facility behind the room, so that when this waste is treated it becomes entirely free of the heavy metal and we use the effluent from the abatement process to chill the towers of our air-conditioning system."

The rolls then are transported to the TCO sputtering equipment, which is a "relatively fast process," according to Britt. "We'll need only three tools of this type to round out our 40MW." However, he would not disclose the type of TCO film that is in use at Global.

'Looks a lot like a silicon cell'

With all of its thin-film layers deposited, the processed foil then moves to another part of the factory for screen printing. "This looks a lot like a silicon solar cell that has a screen-printed collection grid that is used to collect the majority of the current and funnel it out of the solar cell," he pointed out. "The rest of the room is one large curing furnace because this one printer services the entire 40MW plant."

> Global's Britt wants to see improvements in analysis and metrology tools.

As the oven for curing the silver ink laid down during the printing process needs to be very long, the unit goes to the end of the room, makes a turn, and winds back to the front of the room. Britt said they will add another system, with a similar layout, during the next expansion.

He held up a handful of printed cells on foil, showing how each pass prints a dozen of the cells. After printing, the next step is slotting the cells, where the roll of 12 is taken and "split it into three separate rolls. Now we're going to have a single roll of solar cells instead of three rolls wide. We do this so because that will be the input for the next system, which strings together those cells. You end up with something that looks like a roll of postage stamps." With the stringer, Global makes connected pieces of "up to 18 cells long, which, with wiring, is approximately 2 metres long."

From cell strings to module

The strung-up cells are then sent to be tested in the pulse simulator down at the other end of the area, "which measures efficiencies and power output characteristics of the string, and then lifts it up and places it into a bin. Depending on the power output, we have a number of bins and we'll sell those like-powered strings to one customer." More stringer tools will be installed, eventually stretching down the length of the building, Britt said.

Once the cells are tested, "we package them up and ship them out to whoever's going to make the modules," such as minority owner Solon. "Those modules will be subjected to very stringent reliability tests...we'll be qualifying them and making sure they'll live through that 20- or 25-year warranty that we're offering." One close-to-home, real-life test of Global modules will come from a 750KW solar field across the parking lot from the factory, scheduled to be activated in Q3 2008.

One area in which Britt would like to see some improvements is the available metrology and analysis gear. "We're always keeping our eyes open for new metrology tools that we can either integrate in-line or between processes, tools that will give us some early indicators. We feel right now that there's not enough information, we want to know more things about the morphology and the composition that we really don't know right now. You have to carry your yield losses around for a long time with this kind of process."

Figure 6. Global's PowerFlex strings can be integrated into standard modules.

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About the Author

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Empowering thin-film cells: how DC and RF generators impact high-quality coatings of thin-film solar cells

Dirk Ochs, HÜTTINGER Elektronik GmbH + Co KG, Freiburg, Germany

ABSTRACT

The rapidly-growing photovoltaic market has placed a strong demand on manufacturers to decrease solar cell production costs. For thin-film solar cells, this can be achieved by increasing substrate sizes to achieve a better productivity and by adding more advanced layer stack systems to enhance the solar cell's efficiency. Nearly all required layers of the prominent thin-film-based solar cell types (a-Si/μc-Si, CdTe and CI(G)S) can be deposited by using plasma processes. On the one hand, plasma-enhanced chemical vapor deposition (PECVD) is used for the deposition of a-Si and μc-Si layers. On the other hand, magnetron sputtering is used for coating with transparent conductive oxides as ITO (indium tin oxide) and ZAO (aluminium-doped zinc oxide), metallic back contact layers such as Ti, Al and Mo, or components of the compound semiconductor layers such as Cu and In. Magnetron sputter processes use direct current (DC) or pulsed DC, whereas radio frequency (RF) power is used for PECVD processes. Of utmost importance to get a reliable, high-efficiency solar cell is a good uniformity of the deposited layers and the need for the layer to be defect-free. Defects such as particles and splashes are created inside the plasma when an unwanted local discharge – a so-called arc – occurs. This arc can be eliminated by switching off the power supply. The faster this is done, and the less energy that is delivered into the arc, the smaller and more insignificant the defect creation will be. For this reason, as well as for precise control of electrical power, advanced, fast-reacting arc management is very important to attain high-quality solar cell coatings.

Introduction

Solar cells can be divided into two main groups. While wafer-based solar cells are the most commonly-produced type, thin-film solar cells will increase in popularity and importance over the next few years. The most prominent thin-film solar cell types are a-Si/μc-Si [1,2], CI(G)S [3] or CdTe [4]. The principal layer stack design of these cells is shown in Figure 1, while Table 1 shows the different materials used for these layers, most of which are deposited using plasma-based methods. Deposition of these layers can be divided into two main groups: PECVD deposition for Si-based layers, usually using RF power, and magnetron sputtering for coating with transparent conductive oxides (TCO). Magnetron sputtering processes mainly use DC power.

Transparent contact layer	AZO, ITO
Active layer	a-Si, μc-Si, CdS/CdTe, CdS/CIS
Metallic contact layer	Mo, Al, Ag
Substrate	Glass, polymer foil, metal strip

Table 1. Thin-film solar cell materials.

All DC and RF power supplies used for solar cell applications need a high precision process control and a supreme arc management with adaptable parameters to provide minimal disturbances in the plasma process and to obtain optimized results in terms of film quality, homogeneity and uniformity over the whole substrate. The principal function of a power supply is the power conversion from mains into different voltage and frequency levels, and the isolation between mains and load and the dynamic control of the process power. In particular, the dynamic range of the plasma impedance has to be considered in the design to cover the three states of the plasma and the transition between them: insulating gas, ignition, plasma, arc and arc quenching.

DC coating processes

Magnetron sputtering is used for the majority of thin-film solar cell layers. Figure 2 shows the principle set-up for

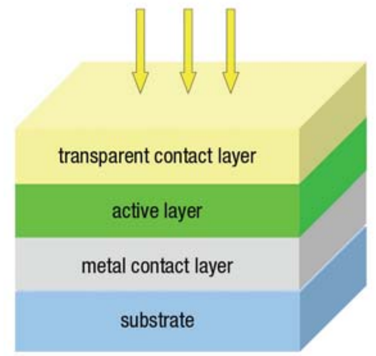

Figure 1. Principle design of thin-film solar cell layer stack.

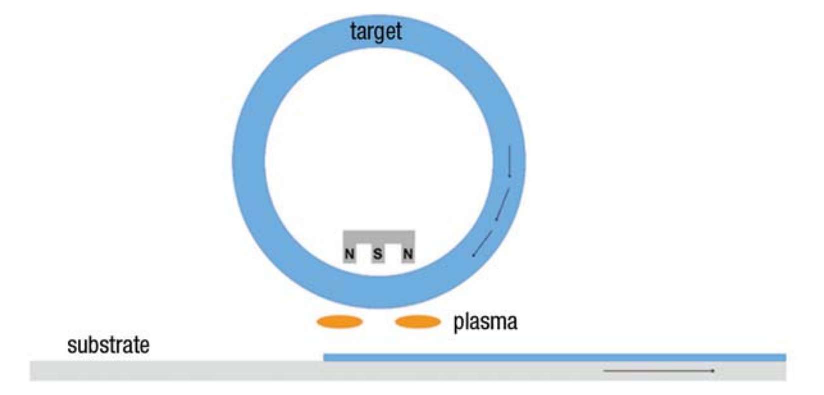

Figure 2. Principle set-up for rotatable magnetron sputtering.

Detection time	< 300ns
Switch off time	Ca. 1.5 µs
Break time	0-80ms
Ramp time	0-100ms

Table 2. Values noted during current-based detection sequence (see Figure 3).

rotatable magnetron sputtering. The rotatable tube target of the magnetron is connected to a high negative voltage. In this way, the plasma is ignited in front of the target locally fixed by the magnet array. The positive Ar ions are generated in the plasma and accelerated towards the target and remove target material by collision. A thin, uniform and compact layer with the desired structure and composition is built up on the substrate.

For all of these layers, a good thickness homogeneity of the deposited layers at high deposition rates is very important. The DC power supply (MP family) is designed for powering sputtering cathodes. The most important features of the power supply are a high-efficiency switched-mode power conversion technique, an operating output voltage up to 800V, full output power capability at output voltage down to 400V, a fast arc switch-off and recovery, an extremely low arc energy and a wide variety of user-adjustable parameters. All units are microprocessor controlled. The most important of the aforementioned features is the highly advanced arc management. Electric arcs that can occur inside the vacuum chamber may negatively affect the treated surface and for that reason arcs should be extinguished as quickly as possible. The arc detection system is equipped with three different arc detection criteria to ensure fast response to an arc occurrence. One of these criteria is a current-based detector that reacts when the output current I_{out} exceeds a user-defined current threshold value I_x (see Figure 3).

> Electric arcs that can occur inside the vacuum chamber may negatively affect the treated surface and for that reason arcs should be extinguished as quickly as possible.

The second detection criterion is the voltage drop during the arc occurrence. The voltage-based detector is armed when the output voltage exceeds a user-defined threshold A and triggers when the voltage drops below a user-defined threshold B.

The third detection method is a combined voltage and current-based detector, which reacts when the output

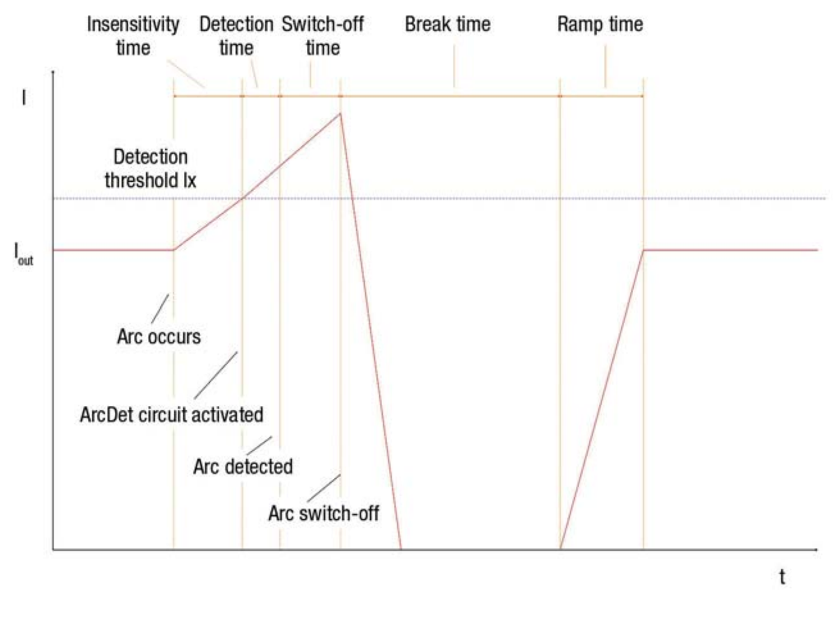

Figure 3. Current-based arc detection sequence.

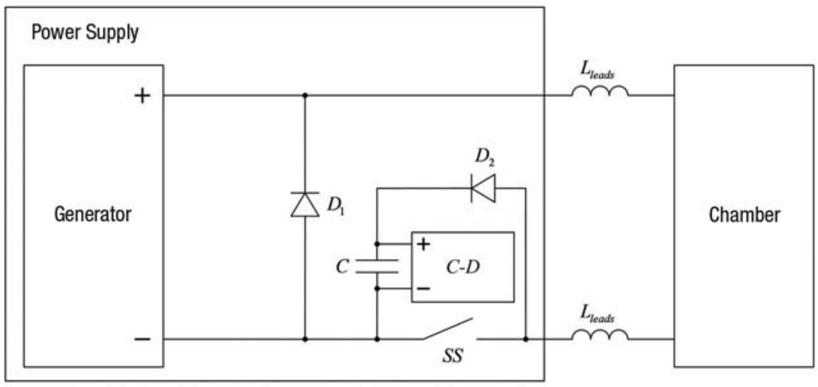

Figure 4. Principle of the cable length compensation.

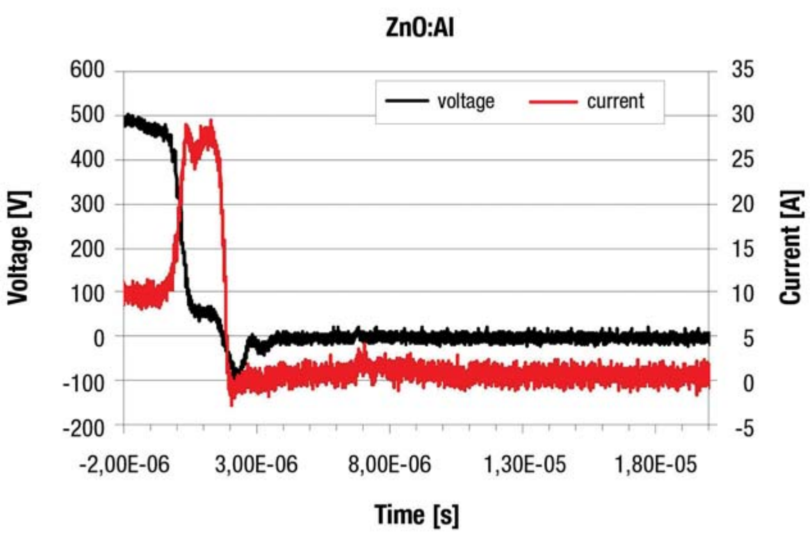

Figure 5. Current and voltage during an arc event using CLC.

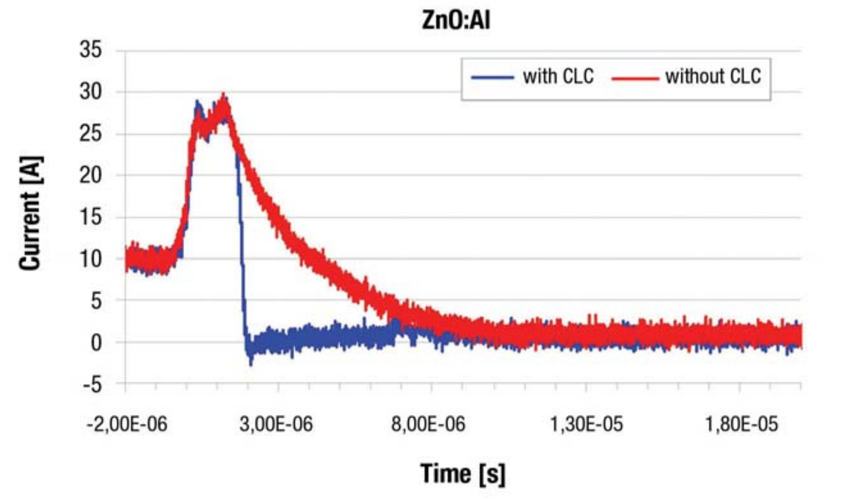

Figure 6. Current during an arc event with and without CLC.

voltage is lower than the user-defined voltage threshold and the current is higher than the user-defined current threshold. Table 2 shows the typical values for the time windows described in Figure 3.

In addition to this very fast arc detection, a so-called cable length compensation was implemented in the power supply. This is a positive voltage applied to the magnetron power cable after arc detection and power switch-off. Figure 4 shows the principle of this feature.

By applying the positive voltage, the negative potential of the cable is very quickly reduced. This results in a further decrease of the residual arc energy which is delivered to the cathode after arc detection. Figure 5 shows the current and voltage of an arc event at a ZnO:Al (AZO) target using a power supply with CLC. For comparison purposes, the current during the arc event is shown for a power supply with and without cable length compensation (Figure 6). The faster decrease of the current resulting from the CLC is clearly visible. This reduces the energy delivered into the arc significantly.

The improved arc management in combination with the cable length compensation feature realizes a very fast power switch-off with a residual arc energy significantly lower than 1 mJ/kW. DC power supplies of this type are available from 1 to 240kW maximum output power.

By applying the positive voltage, the negative potential of the cable is very quickly reduced. This results in a further decrease of the residual arc energy which is delivered to the cathode after arc detection.

RF coating processes

In additon to the DC power supplies, RF power is needed, especially in the case of Si layer deposition. PECVD deposition of layers as a-Si and μc-Si is performed using RF excited plasma processes [7, 8]. The typical RF operating frequency is 13.56MHz, but higher frequencies are also used. In order to have a cost-effective design for a high-power RF generator in the power range up to 50kW, an oscillator-amplifier concept has been chosen with a solid-state driver in combination with a tube type end stage amplifier (see Figure 7).

Starting from 1μW, the signal is modulated for power control and pulsing

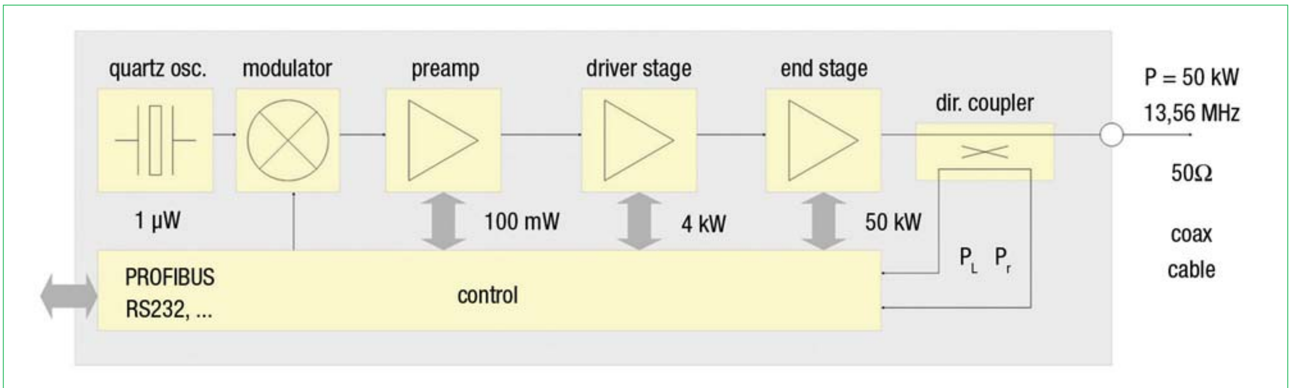

Figure 7. Principle design of the RF power supply.

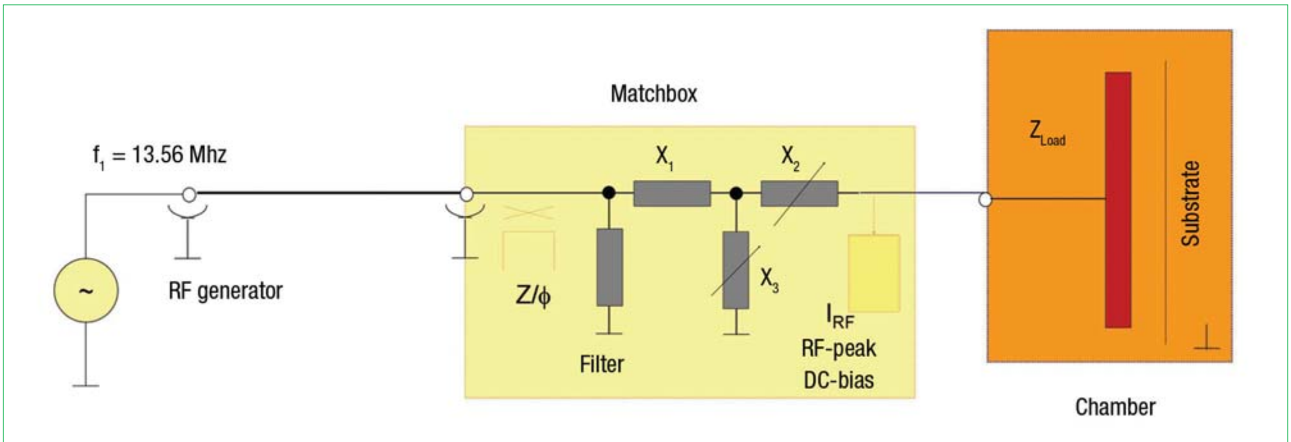

Figure 8. Principle of an impedance transformation network.

functionality before it reaches the chain of amplifiers where the power of the modulated signal is increased in the pre-amplifier to a level of 100mW and in the driver stage to a level of 4kW. Finally, the robust tube type end stage creates the output power level of up to 50kW. The output power that is delivered into the 50Ω coaxial cable is controlled and the incident and reflected part is measured by the directional coupler.

The impedance of the cathode varies with the process in the range of 1-5Ω with a strong capacitive part. In contrast, the output impedance of the generator has 50Ω. In order to deliver the maximum output power of the generator to the chamber, an impedance transformation network is required.

The impedance of the cathode is matched to the 50Ω via a network of three elements as shown in Figure 8. To compensate the varying impedance of the process, two of the three elements are variable by motor-controlled vacuum capacitors. The resulting impedance of the matchbox and process parameters – such as the RF peak voltage and the DC bias voltage – are measured and delivered to the controller inside the matchbox. These signals are also transferred to the generator which acts as a system controller.

By these means, even critical processes can be ignited and stabilized for long cycle times. Depending on the needs of the process, the system can operate in constant wave mode as well as in pulsed mode.

Summary

For wafer-based and thin-film solar cell applications, high power DC and RF power supplies are available that meet the specific process-related technical and economical requirements. These requirements are a high precision process control, and a supreme arc management with adaptable parameters to provide minimal disturbances in the plasma process and to obtain optimized results in terms of film quality, homogeneity and uniformity over the whole substrate. The better the quality of the deposited layers, the higher the efficiency of the solar cell.

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About the Author

Dirk Ochs joined HÜTTINGER Elektronik GmbH + Co KG in 2005 as Senior Application Engineer. He is responsible for all application-related items of the HÜTTINGER power supplies in the field of plasma deposition, etching and modification processes. He studied physics at the Justus Liebig University in Giessen and received his Ph.D. in surface science at the Technical University Clausthal-Zellerfeld in 1998. Prior to joining HÜTTINGER, he worked for seven years in the development departments of vacuum coating equipment manufacturers Oerlikon and Singulus consecutively, focusing on the development of new plasma coating and etching equipment as well as the development of related processes.

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PV Modules

SolFocus gets first CPV system running at ISFOC

This first 200 kilowatt (kW) phase of SolFocus' planned 3MW concentrator photovoltaic (CPV) solar power plant at the Institute of Concentration Photovoltaic Systems (ISFOC) in Spain is ready to operate. A further 300kW will be ready in a month, according to the company. ISFOC will own and operate the plant as part of its testing and evaluation goals for further CPV installations within Spain in the future.

"We chose SolFocus' CPV arrays as part of the ISFOC project because we believed their non-imaging optical design would provide efficient and reliable systems," said Dr. Pedro Banda, Director General of ISFOC. "We had confidence that they would be able to meet not just the design challenges, but the manufacturing challenges for volume deployment as well; we could not be more pleased with the results."

"Completing this first stage of the ISFOC project marks a major milestone for SolFocus, and for concentrator photovoltaics in general, on our way toward achieving grid parity for renewable energy," said Gary D. Conley, CEO of SolFocus. "Working with the ISFOC team in this collaborative project of commercial deployment and scale, we are proud to deliver on the immense promise and potential that CPV holds in scaling to meet the world's energy needs."

SolFocus claims that its CPV solar panels have the lowest carbon footprint in manufacturing, and are over 95 percent recyclable.

Trials and Certification News Focus

Opel International's CPV technology undergoes Korean trials

Opel International is to start trials of its CPV technology with Dass Tech Co. Ltd., and Taiho Solar Co., Ltd. of South Korea that could lead to a commercial order in excess of 10MW for the company. Dass Tech and Taiho Solar are planning solar grid field deployments in Asia and Europe.

"Opel is honored to be selected by Dass Tech and Taiho Solar following their extensive review and onsite meetings at Opel. This entry into the Korean market represents a significant step forward for Opel into the new, emerging Asian market for solar grid fields," said Watson S. Coverdale, Opel Executive in charge of Asia. "Not only are we promoting climate change in response to global warming, but together with Dass Tech and Taiho Solar, we are a catalyst for a reduction in Asia of oil dependence."

This 10kW order with Opel International is for its MK-I concentrating solar module system.

Underwriters Laboratories establishes North American PV testing and certification facility

Underwriters Laboratories (UL), a product safety testing and certification company, has opened North America's largest commercially focused PV testing and certification facility in San Jose, California. The 20,000 square-foot facility, dubbed the Photovoltaic Technology Center of Excellence, will provide both indoor and outdoor certification and testing services via its 14 test chambers and two solar simulators for PV modules and panels. It will also provide full pre-certification services including training and R&D.

"The opening of UL's PV testing facility is great news for the solar industry," said Tom Kimbis, Acting Program Manager for the U.S. Department of Energy's Solar Program. "Increased UL testing capacity should translate into shorter cycle-times for listing solar modules; a critical component in getting solar end-products to market faster."

Coupled to the growing PV manufacturing community based on the west coast, UL decided that California would be an ideal location for the new facility and that it would be capable of meeting the demand for testing services.

UL said that they were working with SolarTech, an initiative of the Silicon Valley Leadership Group, to help reach as many solar product manufacturers as possible. SolarTech provides the opportunity for introduction of a safety-related discipline during the early stages of product development in the PV supply chain and an end-to-end solution for PV companies.

Solar Semiconductor wins module certification from TÜV Rheinland

Solar Semiconductor has had its photovoltaic modules certified by TÜV Rheinland to IEC 61215 and IEC 61730 after stringent tests were conducted, the company said. According to Solar Semiconductor, it has become the first company in India to have certification for high power 295Wp modules.

"We have been growing rapidly and setting up multiple manufacturing facilities to meet our business goals. Having a strategic cooperative partnership with a certifying body like TÜV Rheinland is a tremendous asset for us as we continue to build the highest quality PV modules," said Ravi Surapaneni, Vice President of Solar Semiconductor Pvt. Ltd., India. "Our products were certified to the toughest performance and safety standards of the IEC 61215 and IEC 61730 after stringent tests were conducted by TÜV Rheinland. Solar Semiconductor is the first company in India, and amongst the few in the world, to have certification for high power 295Wp modules. The TÜV certifications further validate Solar Semiconductor's commitment of producing the highest quality solar panels on the market. Our pledge is to simply make the world's best Solar Photovoltaic modules."

TÜV Rheinland.

Billed as a 'strategic cooperative partnership' with TÜV Rheinland, Solar Semiconductor has now put in place the systems and processes it expects to enable the validation of its future products more quickly.

ersol's Nova-T thin-film module receives TÜV certification

TÜV Rheinland has awarded certification to standard IEC 61646 to ersol's Nova-T amorphous thin-film module following collaboration by ersol with Oerlikon Solar. The modules are produced using Oerlikon's fabrication equipment, and during the testing process underwent a variety of harsh stress tests to gain the sought-after certification.

Standard IEC 61646 tests for ageing of modules due to exposure to adverse conditions. ersol's Nova-T modules were put through tests to determine the degree of wear on the material when exposed to elements such as UV radiation, cold, heat, humidity, snow, wind pressure and wind suction. The modules were awarded the certification based on the absence of any visible damage or changes in their power and insulation properties.

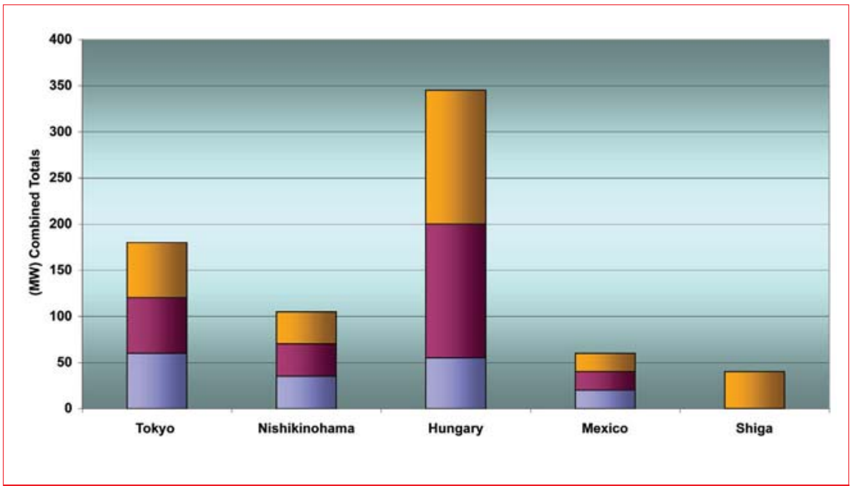
Module Production News Focus

Sanyo opens new 40MW module plant

Sanyo has officially opened its latest photovoltaic module assembly plant in Ohtsu City, Shiga Prefecture, Japan. The new 7000m^2, plant has an initial capacity of 40MW per annum with the capacity to expand production further, Sanyo said.

The new facility is part of Sanyo's latest investment strategy in solar, which is expected to be in the region of US$650 million over the next three years.

In 2007, Sanyo's PV production reached 260MW and is expected to reach 340MW in 2008. The company is currently considering further module expansion ramps at plants in Hungary and Mexico. The Hungary plant is Sanyo's largest with a capacity of 145MW per annum.



Sanyo module production forecast.

News

Day4 Energy ups production by 300%

Day4Energy, a PV module manufacturer, has added 35MW of production capacity to its Burnaby production facility in a greater-than-anticipated production expansion. The installation of Phase I production equipment in the facility has increased the company's output by 25% more than was originally planned to 47MW per annum. The Phase II expansion, which is currently in process, will add an extra 50MW of capacity.

"Day4 Energy embarked on an ambitious growth strategy for 2008, and I am pleased to report our progress is on schedule," said Neil Lang, Day4Energy's COO. "With our Phase I expansion now complete, our immediate focus is on production ramp-up. We have already initiated production on the first part of the line and are looking to bring the rest of the equipment on-line in short order."

Module Sales News Focus

SunPower adds to direct distribution model with Solar Sales acquisition

A former distributor and large-scale installer of photovoltaic modules in Australia has been acquired by SunPower Corporation as part of the PV manufacturer's evolving direct sales business model. For an undisclosed sum, Solar Sales Pty. Ltd. will become a unit of the Silicon Valley-based company.

"Solar Sales has been a valued SunPower customer and partner for several years," said Howard Wenger, Senior Vice President of global business units at SunPower Corp. "The strength of its management team, coupled with its market understanding and momentum, will help to form an ideal platform from which we can succeed in both the commercial and residential markets."

Solar Sales offers solar panels and inverters via a national network of 30 dealers throughout Australia, and designs, builds and commissions large-scale commercial systems.


A Perfect Fit.
komax xcell 3400

EPV SOLAR enters 250MW thin-film module agreement with City Solar

City Solar Kraftwerke AG has entered into a five-year supply agreement with EPV SOLAR for the delivery of 250MW of amorphous silicon modules to City Solar. The agreement will see the initial delivery of 2MW of modules for installation at City Solar's site in Germany by the end of 2008. EPV has begun shipments of modules from its New Jersey manufacturing facility to serve this contract.

EPV's 30MW manufacturing facility in Senftenberg, Germany will then provide the remaining 248MW from the conclusion of the 2MW project for the remainder of the five-year period. The Senftenberg facility is expected to begin production in the third quarter of 2008.

Yingli to supply 64MW via four new contracts

Yingli Green Energy has announced its receipt of four new sales contracts for provision of 64MW of PV modules in total. The four contracts are composed of twin orders from two companies, namely, Conergy AG and GeckoLogic GmbH, and were entered into at the Intersolar Trade Fair in Munich in June 2008.

The agreements with Conergy will see Yingli provide 7MW of modules in 2008 on a fixed-price basis and 50MW in 2009, the price of which will be determined in the fourth quarter of 2008.

GeckoLogic has also ordered two shipments of modules and under the terms of the contract will receive 4MW of modules between September and December 2008 for a fixed price. The price of the further 3MW delivery will be determined in the third quarter of 2008.

"We have been developing our relationship with these two well-regarded companies for the past few years, and have won the trust from an increasing number of major industry players with our product quality and customer service," said Mr. Liansheng Miao, Chairman and CEO of Yingli Green Energy. "We look forward to further strengthening our relationship with them in the future. Demand in Germany remains strong and the region continues to be an area in which we plan to further strengthen our presence."

Italian energy firm places 30MW order with Suntech

Suntech has said that it has signed a two-year deal with Enel.si, a subsidiary of Enel, Italy's largest power company, to supply 30MW of photovoltaic modules, starting in late 2008. Suntech said that this was part of a strong pipeline of orders building for 2009, across all major demand regions.

"Suntech has an excellent reputation for delivering premium quality, high power output solar modules and we are pleased to enter this partnership with them," commented Riccardo Felicioli, Enel.si Managing Director. "Renewable energy solutions will no doubt play an increasingly important role in the total energy mix, and Enel.si is committed to supporting broader adoption of these technologies."

"With its substantial solar irradiation, relatively high cost of grid electricity, and favorable solar subsidies, Italy is set to embrace solar as part of its renewable energy portfolio, commented Dr. Zhengrong Shi, Suntech's Chairman and CEO.

Trina Solar also wins module supply deal with Enel

Trina Solar is to supply Enel.si, a subsidiary of Enel SpA, Italy's largest power company, with a total of 17MW of PV modules starting in 2008. 15MW are scheduled for delivery in 2009 at fixed prices, Trina Solar said.

"We are very pleased to sign this agreement with Trina Solar. The new contract adds products to our portfolio that becomes day by day larger and more diversified," says Paolo Riccardo Felicioli, Managing Director of Enel.si.

Suntech has also recently announced a module supply deal with Enel.si for 30MW over the same two-year period.

Solarfun garners one year 30MW module deal with Martifer Solar

Portugal based PV installer; Martifer Solar Sistemas Solares SA has signed a 30MW one year module deal with Solarfun Power Holdings. The fixed price deal runs from January to December 2009.

"This agreement is one of our largest new contracts to date," noted Solarfun CEO Harold Hoskens. "This project is particularly important as it will further enhance our presence in regions outside of the mainstream developed solar markets in Europe. We plan to continue to geographically diversify our business to these and other regions in the coming years."

"We are very happy to be working with Solarfun for the installation of their PV modules in various projects throughout Portugal, Italy, Greece, and other countries in Southern Europe," commented Henrique Rodrigues, Martifer Solar CEO.

Tool Order News Focus

Trina Solar places multi-year, multi-system solar simulation order with Spire

Trina Solar has placed a multi-year, multi-system contract for Spire's 'Spi-Sun' Simulator 4600 Single Long Pulse (4600 SLP) systems. The 4600 SLP has recently been purchased by the National Renewable Energy Laboratory and Underwriters Laboratories.

"From our years of experience in the PV module industry, we recognize the importance of having advanced equipment in our line to produce high quality PV modules to compete globally," noted Jifan Gao, Chairman and CEO of Trina Solar. "We have developed a beneficial relationship with Spire and hope to continue using their high quality products to help us achieve our goals."

"We are proud of our simulation systems. They are the standard of the industry. We have invested heavily into the spectral quality and uniformity of the Spi-Sun Simulator. Only Spire has the profound history of research built into production ready systems." said, Roger G. Little, Chairman and CEO of Spire Corporation. "Spire's business in China continues to grow rapidly. Trina is a leader not only in China but in the world market and we are very excited to work with them on expanding their capability."

India's PLG Power places 25MW turnkey module line order with Spire

PLG Power Limited, the Energy and Power division of PLG Group, Mumbai, India, has placed a 25MW turnkey photovoltaic (PV) module production line order with Spire Corporation. This is PLG Power's first operation in the PV industry.

Spire will provide PLG Power Limited with a high performance, semi-automated crystalline cell module manufacturing line that integrates Spire's key interconnect, lamination, and testing machines, along with intermediate tooling stations.

Spire wins another PV module line order from Russia

Spire Corporation has received a contract from Bogoroditsk Plant of Techno-Chemical Products (BTCP), a chemical company, to provide a photovoltaic module assembly line for the company's operations in Russia. The semi-automated crystalline silicon module manufacturing line will be capable of producing up to 12MW of solar modules per year, according to Spire. Located in the Tula region of Russia, this will be BTCP's first PV operation.

Spire will supply the process technology and training to operate the factory, as well as assistance in qualifying the factory's modules to international standards and certification. The line is designed to be easily expandable at a later date.

In November 2007, Spire received an order from Ryazan Metal Ceramics Instrumentation Plant Joint Stock Company (RMCIP JSC) of Ryazan in Russia to provide them with a turnkey 12MW module manufacturing line.

Product Briefings

Enerize Corporation

Transparent polymer protective covering from Enerize boosts PV module conversion efficiencies

Product Briefing Outline: Enerize Corporation has developed a new design for photovoltaic (PV) modules using a proprietary transparent polymer material that is claimed to outperform glass conventionally used as a protective covering. The proprietary polymer material is highly transparent, and stable under UV and ionizing radiation exposure. The new highly transparent polymer material can be applied directly to the PV module surface at low temperatures, eliminating the need for the adhesives required with glass and some other polymers.

Problem: Conventional glass has several disadvantages as a protective covering for photovoltaic modules. Glass is relatively heavy, brittle and reflective. Light reflected from the glass surfaces (both exterior and interior) does not reach the solar cell underneath, and glass tends to block ultraviolet light, thus reducing the energy that can be obtained from this part of the spectrum.

Solution: In conventional designs using glass, the efficiency of the PV module can be decreased by 7% or more as compared with a PV module without a glass covering, according to Enerize. Compared to PV modules laminated with glass, those coated with Enerize polymer coating materials exhibit an increase in efficiency of as much as 25% or more. Applications: Enerize transparent polymer materials and coating technologies can be used to improve conversion efficiencies and overall performance of mono-crystalline, multi-crystalline, amorphous silicon photovoltaic and non-silicon based PV modules such as CIGS (copper indium gallium selenide).

Platform: The new highly transparent polymer material can be applied directly to the PV module surface at low temperatures, eliminating the need for the adhesives required with glass and some other polymers. This eliminates the multi-layer structure including the reflective surfaces present with glass. No glass is used with this polymer coating.

Availability: May 2008 onwards.

Coveme SpA

Coveme backsheet 'dyMat PYE' has a 5x lifetime extension over traditional polyester materials

Product Briefing Outline: Coveme SpA's new 'dyMat PYE' backsheet material is used to prevent electrical hazards and to grant high vapour barrier, thus avoiding power loss during the expected lifetime of the solar module. Coveme, in co-operation with DuPont Teijin Films, has developed a high grade PET inner layer with a lifetime five times longer than traditional polyester.

Problem: Due to water permeation of the outer layer, the inner PET layer suffers from hydrolysis losing its original properties. Therefore the traditional backsheets is, to a certain extent, unbalanced, having a long lasting outer layer and the inner layer suffering from early aging. This phenomenon cannot be detected with the naked eye but is only visible through deeper analysis. The problem analysis shows that improving the hydrolysis resistance of polyester is the key for a better performing backsheet.

Solution: 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. The laminate thickness has been designed to provide the best combination of properties in terms of electrical insulation and weatherability. It also forms a strong barrier to oxygen and humidity.

Application: dyMat PYE is available in unlimited quantity and suitable for thin film and mono-/ polycrystalline solar modules.

Platform: dyMat PYE is certified by TUV to be resistant to Partial Discharge in the range 680 – 1220 VDC. It complies with Partial Discharge Test according to IEC 60664-1. Solar modules with dyMat backsheets are certified as per IEC 61215 and 61730. Master roll: 1.9 m x 3500 m. Customized reels: from 100 m length. Inner core: 3" or 6." Cut sheets on request. Sizes and drills according to customer's drawings. Different thickness and colour combination on request.

Availability: September 2008 onwards.

Honeywell

Honeywell's PowerShield PV325 backing material protects PV modules from harsh conditions

Product Briefing Outline: Honeywell has developed a new material called 'PowerShield' PV325, which is designed to provide greater levels of protection to photovoltaic (PV) solar cells and modules that are located more hostile environments. The material is UV-, moisture- and weather-resistant, and designed to also withstand the electrical load produced by the modules, which can operate at up to 1,000 volts of electricity. The material was developed primarily for rigid PV modules, which are specifically designed to feed power into a utility or local power grid.

Problem: Back sheet material performance is impacted by a variety of factors. The true validation of overall backsheet performance and value can only be confirmed via testing within specific modules themselves. Honeywell believes that by providing the backing system as well as the critical barrier component, photovoltaic module producers have one source to address their needs relative to the backing material, optimizing performance and value while providing a more integrated backing solution.

Solution: The reflective white material is based on Honeywell's high-performance barrier film technology. The dielectric, or insulator material, has a traditional five-layer design that includes two outer protective layers based on ethylene-chlorotrifluoroethylene (ECTFE) fluoropolymer film and a core polyethylene terephthalate (PET) layer, as well as two inner bonding layers of proprietary adhesive material. The design is an alternative to traditional backing systems based on poly-vinyl fluoride (PVF).

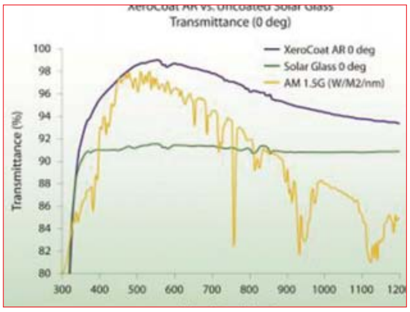
Applications: Rigid PV modules used for utility or local power grids that experience harsher or humid conditions.

Platform: Nominal 325µm (13.0 mil) semi-gloss white opaque composite specifically designed as a durable dielectric backsheet for crystalline Si photovoltaic modules rated for 1000 VDC.

Availability: May 2008 onwards.

Product Briefings

XeroCoat Technology



XeroCoat launches single-layer low-refractive index coating boosting module power conversion

Product Briefing Outline: XeroCoat Technology has entered the solar energy market targeting the solar thermal and solar photovoltaic segments with its anti-reflective coatings. The XeroCoat anti-reflective coatings are claimed increase conversion efficiency and, consequently, the power output of solar systems, while being of low cost.

Problem: Photovoltaic modules suffer from reduced conversion efficiency even before the sun's light reaches the solar cells. This is because the solar module's protective cover glass reflects some of the incident light. For typical glass panels, depending on the time of day, 4% to 15% and more of the incoming light is lost from reflections and, thus, is not available to generate electricity. Applying an anti-reflective coating to the cover glass of the module will reduce these reflections and increase the module's output power. Current commercial PV technologies convert 10%-20% of the incoming light to electricity. The same module with a suitable anti-reflective coating can deliver an additional 0.3%-0.6% power conversion. A product achieving higher conversion efficiency in a cost-effective manner can make solar modules more affordable.

Solution: By using the XeroCoat anti-reflective coating on a photovoltaic module, the solar energy reaching the solar cells is claimed to increase by as much as 3% at noon and by as much as 6% at early morning and evening hours. Module makers can expect a 3% increase in power output on a peak watt (Wp) basis, and a 4% increase in energy produced on a kilowatt-hour (kWhr) basis, resulting in the equivalent of a solar cell efficiency gain of approximately 0.5-0.75% points, without modification.

Applications: Applicable across all solar energy technologies including crystalline, thin film, concentrating solar thermal

Platform: Uses non-toxic, recyclable coating materials and a low energy manufacturing process. Meets IEC 61215 module test standards and exceeds current industry standards for abrasion resistance.

Availability: July 2008 onwards.

Bürkle GmbH

Bürkle's 'Ypsator' laminator has five openings for high-throughput

Product Briefing Outline: Bürkle GmbH has introduced its multi-opening module laminator that can process both crystalline and thin film photovoltaic cells. The 'Ypsator' system laminates up to 20 modules per cycle. On a surface area of 3.5m^2 per opening and five openings, manufacturers can produce ten photovoltaic modules per batch at the same time. The total annual capacity is with around 500,000 modules. This corresponds to an annual power capacity of 40 megawatts.

Problem: The weakness of normal single-opening laminators is within the process guiding and reproducibility and they are limited in their production capacity. A large assembly space would therefore be required because the lamination only takes place on one opening.

Solution: Due to its structure and the homogeneous temperature distribution that are reached by the heating of the heating platens via thermal oil, the process times are reduced considerably. The 'Ypsolar' technology is also new. The lamination process is separated in order to make the processes more flexible and increases productivity. In a first step, the modules are prelaminated. This means that the moisture and the air pockets are removed from the sandwich in the vacuum and thus a vacuum-tight compound is created. The lamination is finished in a subsequent press. In a third step, the Ypsator cools down the solar module from 150°C to hand warmth. Due to the structure of the three lamination steps, the glass modules can be laminated with less stress which produces less glass breakage.

Applications: Crystalline and thin-film module lamination for high-volume production.

Platform: Bürkle supplies the entire backend for the manufacture of thin-film modules.

Availability: November 2007 onwards.

Dow Corning

Dow Corning adds three new performance-based solar module materials to portfolio

Product Briefing Outline: Dow Corning's Solar Solutions Group has developed an encapsulant and two potting agents that have been tested and qualified for photovoltaic module applications: the PV 6010 Cell Encapsulant and the PV 7010 and PV 7020 Potting Agents.

Problem: Given the vast amounts of products available on the market, a key challenge is being able to evaluate correctly which actually work best for demanding solar energy applications, while providing target life-time parameters and the required overall performance levels.

Solution: Dow Corning's PV 6010 Cell Encapsulant forms a clear, durable protective laminate layer over the surface of photovoltaic (PV) solar energy cells, providing tested corrosion and delamination protection. The company claims that the new encapsulant provides electrical, high-temperature and ultraviolet stability with no discoloration. Dow Corning's PV 7010 and PV 7020 Potting Agents are designed to insulate PV cells' electrical junction boxes, providing excellent, cost-effective electrical insulation and long-lasting protection from moisture, heat and other environmental conditions, the company claims. These materials remain flexible and stable over wide temperature variations (-40° to 150°C) and offer easy reparability and global availability. The PV 7010 offers a faster cure rate, while the PV 7020 has greater viscosity and thermal conductivity, according to the company.

Applications: Photovoltaic modules.

Platform: The clear PV 6010 Cell Encapsulant has a viscosity/cps or mPa-sec of 925 and a refractive index of 1.41 @633nm. It is repairable and employs a moderate temperature cure and is a self priming elastomer. The PV 7010 is translucent green, a viscosity/cps or mPa-sec of 430, a Thermal Conductivity (W/m·K) of 0.18. The PV 7020 potting agent is grey in color, a viscosity/cps or mPa-sec of 14000, a Thermal Conductivity (W/m·K) of 1.34 and certified to UL94 – V1, V10.

Availability: September 2007 onwards.

Snapshot of spot market for PV modules – quarterly report Q2 2008

Continuous monitoring with pvXchange trade statistics

pvXchange, Berlin, Germany

ABSTRACT

Solar enterprises will each be faced with the occasional surplus or lack of solar modules in their lifetimes. In these instances, it is useful to adjust these stock levels at short notice, thus creating a spot market. Spot markets serve the short-term trade of different products, where the seller is able to permanently or temporarily off-set surplus, while buyers are able to access attractive offers on surplus stocks and supplement existing supply arrangements as a last resort.

A spot market always shows the up-to-date prices of solar modules, because it does not consider the long-term delivery contracts of the producers. These days, the spot market for PV modules is global, because the short-term satisfaction of local supply deficits is possible with short transportation times and relatively low logistics costs.

pvXchange provides a closed online trading platform for sellers going 'public' with a short-term offer. Other participants of the market can decide if they want to buy the goods at that price, while potential buyers may post their interest and in turn be contacted by interested sellers.

Each issue of *Photovoltaics International* will enable the tracking of spot prices of modules through statistics provided by the pvXchange trading platform.

Executive summary

Module supply shortages are leading to increased prices. This growth trend, noticed during the first quarter of the year, has been enforced further in recent months. The trend affects all product groups including Chinese manufacturers, and is the result of high demand and short supply, which is expected to continue until the end of Q3 2008.

The continuous and even increasing scarcity of modules creates general market instability. Price trends and availability are being dominated by the Spanish power generation market, with project developers buying the available world supply for Spanish solar parks, essentially rendering the desired 5% tariff reduction in Germany impossible. German project developers that do not capitalise on long-term supply agreements are incapable of covering their materials needs via the spot market in a profitable way.

A lightening of the current situation is not expected before the fourth quarter of 2008. The market will remain uncertain, in a large part due to the possible developments in the Italian and U.S. markets, as it remains unclear whether the demand in these two regions will compensate for the sagging demand in the Spanish market.

There is an exception to this gloomy outlook. Building in the thin-film sector still yields profits, where there remain high hopes for the performance of the German market. Due to the general shortage, the demand for thin-film modules – especially from market leader First Solar – has increased to such an extent that the spot market prices of 2007 have been topped.

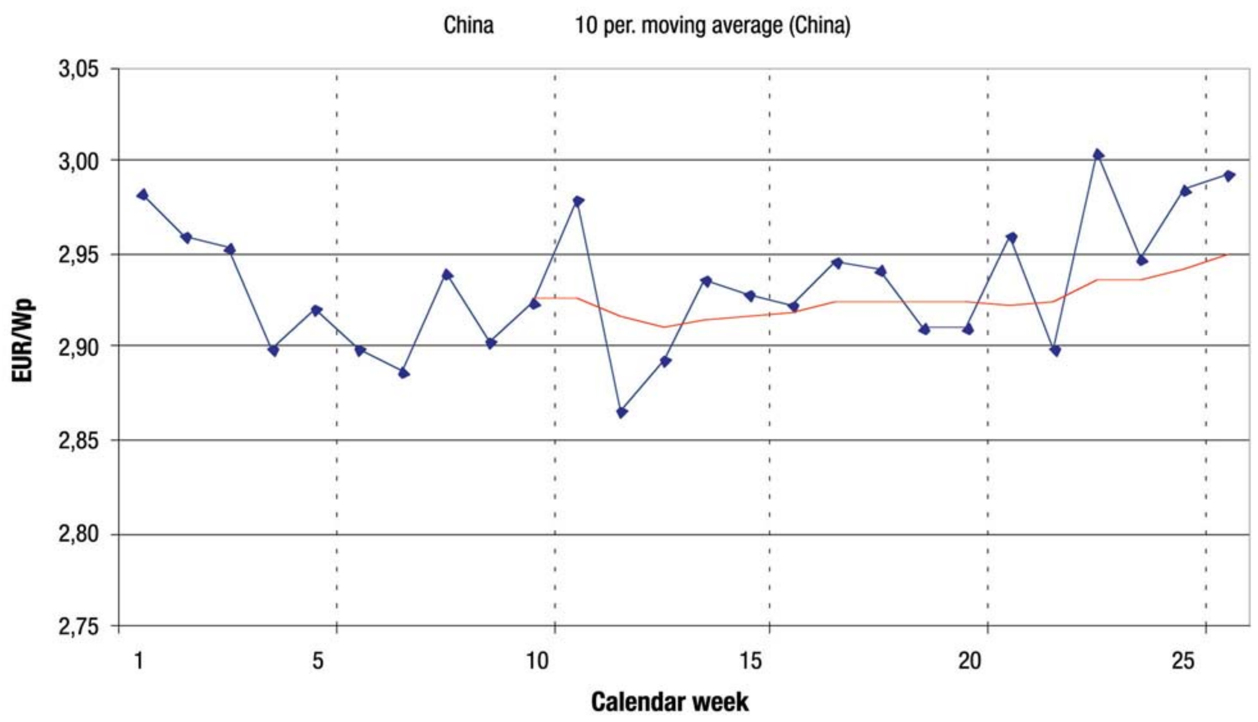


Figure 1. Development of market prices for crystalline modules produced by Chinese manufacturers in the first half of 2008 (in €/Wp).

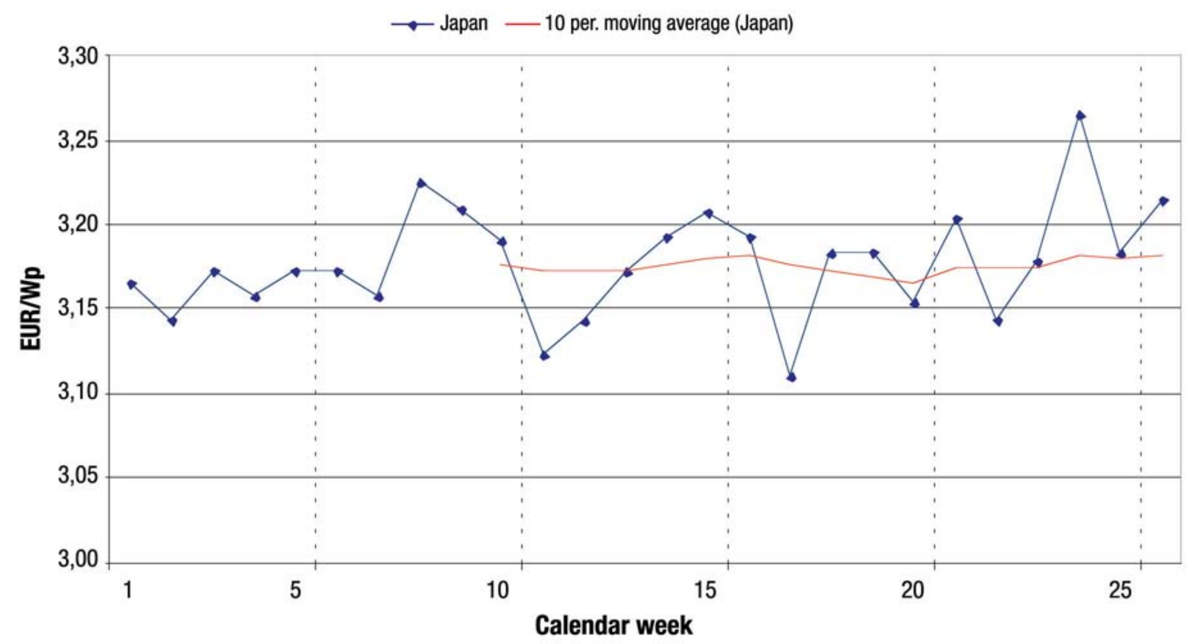


Figure 2. Development of market prices for crystalline modules produced by Japanese manufacturers in the first half of 2008 (in €/Wp).

As a result, a paradox emerges. Due to the increasing price pressure caused by the policy framework in Germany on the one hand, and the high demand for PV modules from Spain in particular on the other hand, the highest price increases happen in the most profitable business sector of highly efficient thin-film modules.

pvXchange market trader trends

Manufacturers from all regions of the industry trade on pvXchange. Trends for the first half of 2008 suggest the following:

Chinese manufacturers like SuntechPower, Yingli, Chaori and Trina Solar are still gaining ground. A product certification is always a pre-requisite, but new brands like ET Solar, Wuxi, Guofei, Solarfun and Jetion are definitely progressing. The profitability pressure in the German PV market and supply shortages make it easy for these new suppliers to place their products. The spot market offers less- to well-known brands, while relatively unknown brands and module types were a lot more predominant in June in particular.

With the exception of Sharp and Sanyo, Japanese manufacturers such as Kyocera and Kaneka are showing slightly less of a transaction volume on pvXchange. First Solar has again strengthened its position as No. 1 product; other U.S. products do not appear in the larger manufacturing scale.

As always, German manufacturers are seldom traded via pvXchange,

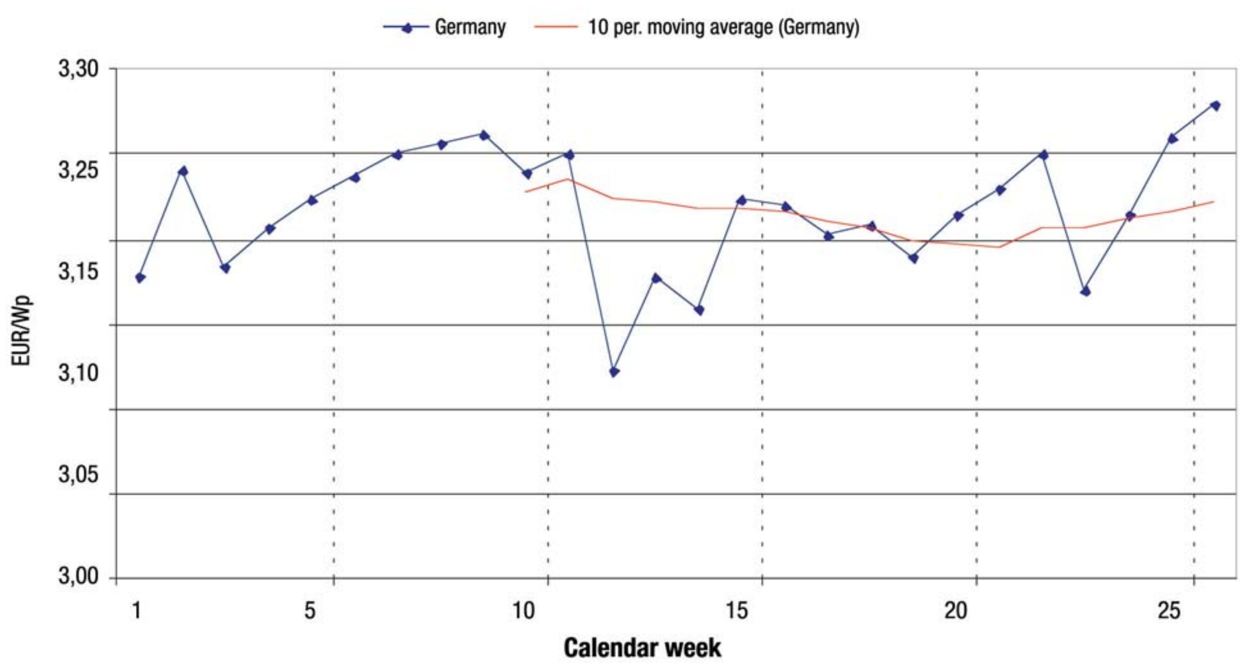


Figure 3. Development of market prices for crystalline modules produced by German manufacturers in the first half of 2008 (in €/Wp).

except for the modules produced by Solar-Fabrik and Schott Solar. The spot market is influenced not only by German manufacturers; these companies tend to assign large-scale projects to their long-existing customers rather than to manufacturers in the Far East. For this reason, German modules often do not even appear on the free market (Solon would be an excellent example).

Data analysis: January - June 2008

In this section we provide information on the data basis underlying the analyses presented in the Figures. All results are based on an analysis of procurement statistics selected from the pvXchange.de trade platform. In the six-month period from January to June 2008, more than 31MWp of PV modules were sold on the pvXchange trading platform and are included in this volume analysis. This figure does not correspond to the entire transaction volume on the platform, but to the revenues actually realised by the end of each month.

A complete analysis of the transaction volume is only possible after a certain period of time. The year's analysis is usually undertaken after completion of the first quarter of the following year. Given the current growth trend, we forecast that total trading volume realised on the platform will exceed 100MWp in 2008.

Price development by country of origin

This section will present the price development in different selected countries or regions of origins from June 2008 onwards. The module supply shortage trend that has already been noted has lead to a broad increase in prices, a trend that has been strengthened in June 2008.

It can be expected that this high price level for crystalline modules cannot be maintained in the German market. The drop-off in volume of crystalline modules could be attributed to the high growth rate of thin-film module volumes and the possibility of recession in the German market.

The Spanish market will need to be watched closely as the expected cool-down of the Spanish PV market will lead to a price decrease later in the year.

The global market is currently dominated by the policy frameworks of the two major sales markets of Germany and Spain. In Germany, low profitability expectations are combined with a high investment security due to very reliable framework conditions. Currently, the spot market prices are mainly determined by the Spanish market, but this should change as soon the conditions of feed-in tariff systems deteriorate. This situation has an impact on the contracts closed by manufacturers for the coming year.

At the moment, a certain hesitance towards long-term supply and price agreements can currently be noticed.

*The module spot prices report is brought to you in conjunction with **pvXchange** and will form a regular feature in **Photovoltaics International**.*

About the Authors: pvXchange

With the idea of an independent procurement of photovoltaic products, pvXchange has gained the market-leading position in the business customer segment. The customer base of pvXchange currently includes more than 2,000 companies from the solar industry. pvXchange is a proven online trading place, where suppliers and prospective buyers meet directly and face-to-face. pvXchange offers no goods in itself, but rather provides a professional mediation between the participants of a trade.

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Large-area solar simulators: critical tools for module manufacturing

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ABSTRACT

The importance of rapid and accurate measurement of the electrical power output and related characteristics of photovoltaic (PV) modules or panels concluding the manufacturing process cannot be overemphasized. Even though these modules will likely be deployed under a variety of outdoor solar illumination conditions, they must be tested under a set of standard conditions to assure consistency of results demanded by both the manufacturer and the customer. The ability to provide a measurement tool for this critical manufacturing step that possesses the proper specifications and qualities, ranging from spectral accuracy to ease-of-use, is imperative.

Introduction

Solar simulators used in the production testing of PV modules must exhibit several basic, but important properties:

- They must accommodate the most common modules being tested, be easy to use and maintain, and be sufficiently rugged and reliable for daily use in a manufacturing environment.
- They must fit conveniently into high volume production and factory automation.
- Their output spectrum must be sufficiently close to that produced by natural sunlight to give accurate performance results.
- Variations in optical output (irradiance), both spatially over the area of the test plane and temporally during a given test and from test-to-test, must be sufficiently small to not impact the test results.
- They should be traceable to known and accepted standards.

Most solar simulators used for large-area PV module testing possess two common characteristics. First, they generally employ one or more appropriately filtered xenon-filled gas discharge lamps as their light source. Second, they are usually operated in a pulsed optical mode (as opposed to continuous or cw mode) to minimize electrical power consumption, minimize module heating during test, and maximize the time between required lamp changes.

The two basic types of large-area simulators that Spire currently provides are (short) multipulse and single long pulse (SLP). The company also currently offers two different test plane sizes; the smaller Model, Spi-Sun Simulator 3500, is 102cm x 162cm (40" x 64") and the larger Model 4600 is 137cm x 200cm (54" x 79"). On the multipulse machines, a single data point of the I-V curve is obtained during each pulse, typically ~1 ms in duration. A full I-V curve typically requires 100 data points and, hence, 100 flashes. With the SLP machines that generate light pulses ~50-100ms long, the entire I-V curve is obtained in a single pulse. The industry trend is moving toward SLP rather than multipulse for several reasons, including faster test time, higher throughput, the use of very high efficiency Si solar cells, and reduced sensitivity to various solar cell physical phenomena that are most common in thin-film cells such as a-Si, CdTe, or CIGS.

Spectral performance standardization

The need to standardize the three most critical parameters related to the optical output (irradiance) of large-area solar simulators used to test PV modules has been long recognized by two leading standards organizations, ASTM International and the International Electrotechnical Commission (IEC). To address this important need, each agency has issued standards over the past several years that define the spectral output, the spatial uniformity, and the temporal (time) stability of solar simulators that are used to test terrestrial PV modules. Specifically, ASTM's version is defined in their E927-05 standard [1] and IEC's in their 60904-9 standard [2]. While there are some subtle differences between these two standards, they are essentially similar. Both standards specifically address what the spectrum of the light emitted from the simulator must be, how the intensity of this light can vary spatially over the test area, and how the intensity can vary with time during both an individual pulse and from pulse-to-pulse.

Of these three parameters, the one that has traditionally been the hardest to address, both in terms of ability to achieve and ability to measure, is the irradiance spectrum. Nearly all PV modules are designed to work best under solar illumination conditions that correspond to sunlight impinging at an angle above the horizon (the elevation) that results in the light rays effectively going through 1.5 atmospheres and having both direct and diffuse (scattered) components. This illumination is commonly referred to as AM1.5 Global (or AM1.5G) and is described in more detail in ASTM Standard G-173.

> The industry trend is moving toward SLP rather than multipulse for several reasons, including faster test time, higher throughput, the use of very high efficiency Si solar cells, and reduced sensitivity to various solar cell physical phenomena.

Realizing that precise simulation of an AM1.5G spectrum using artificial light could be extremely difficult, both ASTM and IEC set up three classifications for the spectral accuracy of large-area simulators. These classifications define what fraction of the total spectral irradiance should lie within six distinct wavelength ranges (Table 1). For a spectral Class A designation, the irradiance fraction must be within +/-25% of AM1.5G for each wavelength interval or bin; for Class B, it must be within +/-40%; and for Class C, within +100 to –60% (Figure 1 shows regions and classifications). For a simulator to be classified as Class A (spectrally), its measured output points must *all* fall within the green region. Similarly, Class B must fall within the yellow region and Class C must fall with the brown region. The worst data point defines the classification; e.g., if all the data points from a single measurement are green but one is brown, then the classification must be Class C.

Instrumentation development

For many years, the National Renewable Energy Laboratory (NREL) in Golden, Colorado, USA has recognized the need for accurate measurement of the spectral irradiance from solar simulators. Over the years they have developed a sophisticated instrument, the PASS (Pulse Analysis Spectroradiometer System), which is able to give accurate and repeatable, NIST-traceable measurements of pulsed solar simulator output spectra [3,4]. Their system consists of an integrating sphere attached to a single stepping monochromator, appropriate optical detectors, switchable gratings and filters, and control and data analysis hardware and software. Traceable to NIST calibrations, the system measures the 400 to 1100nm spectrum in 5nm increments, with a single optical pulse required for the measurement of a single wavelength increment. This requires a minimum of 140 pulses; consequently, measurement of an SLP simulator having typical cycle times of 15 to 30 seconds can take up to an hour or more. Measurement of multiple points on a single simulator can thus be very impractical. Since it is also a relatively sophisticated instrument, it requires a highly-trained and knowledgeable individual to use it properly.

Despite the shortcomings of the NREL PASS, Spire realized the benefits that ownership of such an instrument would have. Contracting with NREL, Spire procured the only copy of their instrument with software that exists outside of NREL in February 2008. A photograph showing this instrument in use at Spire is shown in Figure 2. Despite the relative complexity of its operation, we utilize it to measure selected simulators and to periodically verify the calibration of a simpler, easier-to-use, Spire-developed dual-spectrometer spectral analyzer (described below).

Based on several of the key features of the NREL PASS, Spire undertook a task to develop an easier-to-use instrument to perform routine spectral measurements of our simulators at the conclusion of the manufacturing cycle. Figure 3 shows a block diagram of the dual-spectrometer instrument, while Figure 4 shows the instrument itself, which affords much faster spectral measurement than the PASS – an important consideration when performing multiple measurements on the same simulator. Using the same type of optical collector on the test plane as the PASS, fiber optics are used to distribute the optical signal to two separate grating spectrometers. Gratings and filters in each of the spectrometers are chosen to optimize the performance of each within its respective wavelength band. Both utilize TE-cooled Si detectors to assure optimum sensitivity over their entire wavelength ranges. Response of the two units overlaps in the 800 to

Wavelength Range (nm)	AM1.5G Standard	Irradiance Fraction					
		Class A		Class B		Class C	
		Min	Max	Min	Max	Min	Max
400-500	0.184	0.138	0.230	0.110	0.258	0.074	0.368
500-600	0.199	0.149	0.249	0.119	0.279	0.080	0.398
600-700	0.184	0.138	0.230	0.110	0.258	0.074	0.368
700-800	0.149	0.112	0.186	0.089	0.209	0.060	0.298
800-900	0.125	0.094	0.156	0.075	0.175	0.050	0.250
900-1100	0.159	0.119	0.199	0.095	0.223	0.064	0.318
Total	1.000	–	–	–	–	–	–

Table 1. ASTM and IEC definition of spectral classification by assigning specific irradiance fractions to the six most important wavelength ranges from 400 to 1100nm.

PV Modules

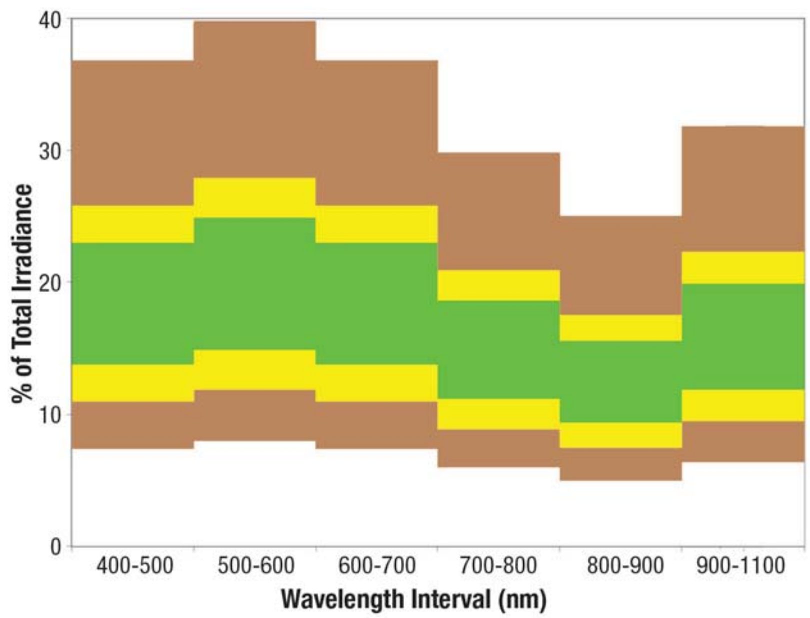

Figure 1. Graphical representation of the three ASTM and IEC spectral classification definitions. The wavelength region of interest, 400 to 1100nm, is divided into six wavelength intervals or bins of either 100 or 200nm width. For Class A, *all* irradiance values must fall in the green region; Class B corresponds to the yellow region, and Class C to the brown region. Outside of the brown region, the simulator is considered unclassified. A simulator's classification is based on its worst bin.

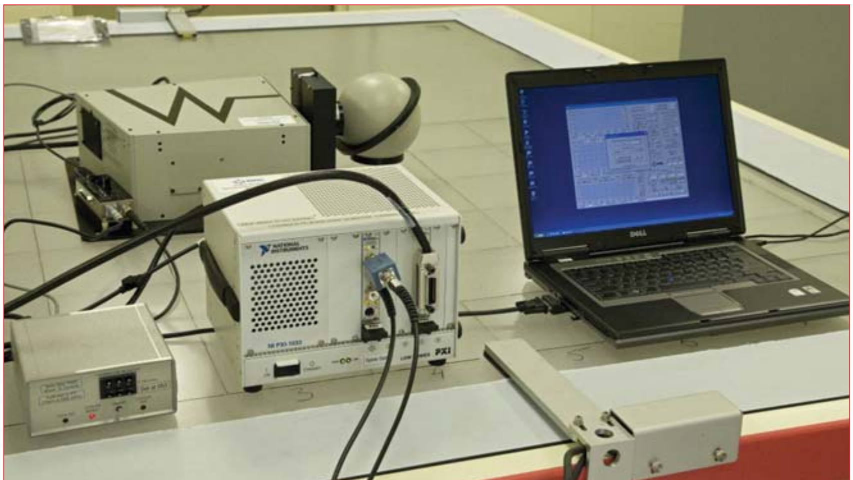

Figure 2. The NREL-designed and built Pulse Analysis Spectroradiometer System (PASS). This critical instrument exists only at Spire and NREL.

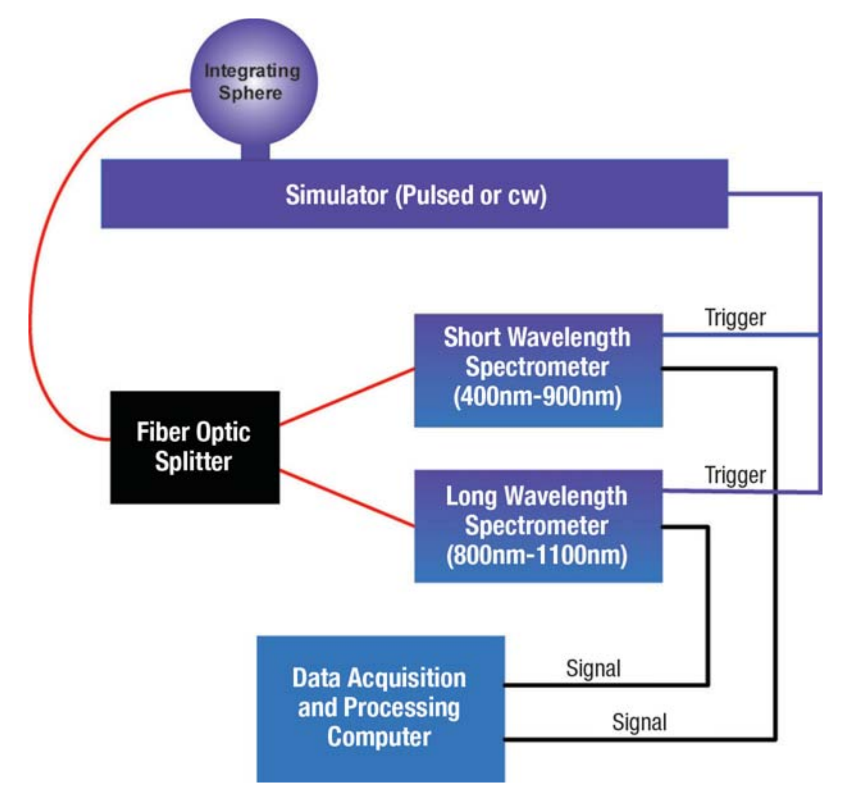

Figure 3. Block diagram of the dual-spectrometer, pulsed solar simulator spectral analyzer. The intensity calibration lamp used to check the system prior to each use is not shown.

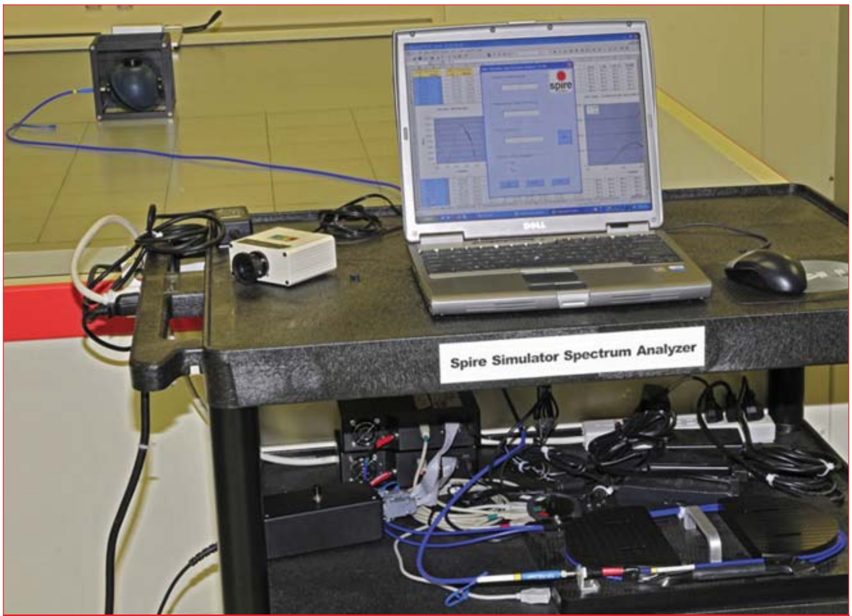

Figure 4. Spire-designed dual-spectrometer spectral analyzer measuring a Spi-Sun Simulator 4600. The sphere sits on the simulator test plane and is connected by a fiber optic cable. The principal spectrometer components are on the shelf below the laptop computer.

900nm interval; since the outputs of the two must obviously agree in this region, this feature is used as a double-check of proper operation and calibration during each use (Figure 5 illustrates the level of agreement between measurements taken with this dual spectrometer system and the two PASS units).

Data acquisition triggering is provided by a trigger signal from the simulator to the two spectrometers. Unlike the PASS, the entire spectrum can be obtained from a single optical pulse (although multiple pulses – typically ~30-50 – are preferred when measuring a multipulse simulator to give better statistics). Finally, calibration of the unit is checked daily using a cw calibration lamp that is periodically checked against a NIST-traceable lamp.

Measurement of simulator spectra

Using the dual-wavelength spectral analyzer, we have studied the irradiance spectra of numerous simulators, both multipulse and long pulse. As discussed earlier, a major benefit of our dual-wavelength analyzer is the rapid measurement time that allows relatively easy mapping of spectra with spatial position. Figure 6 shows results of one such study, in which a total of eleven points distributed over the full test plane of a Spi-Sun Simulator 3500SLP were examined. It is apparent that all eleven points are Class A. This performance actually exceeds that required by both the ASTM and IEC standards; these two standards require that the spectrum meet the given classification only at a single point in the test plane.

In simulator utilization, the stability and lifetime of the xenon flash lamps and other optical components that affect or contribute to the irradiance spectrum and total intensity are also important. With use, there is the possibility of lamp failure, change in output spectrum as the lamp ages, and change in optical characteristics of all the internal reflecting and transmitting surfaces. With this in mind, we undertook a study of simulator output as a function of cumulative flashes, the results of which are shown in Figure 7. During the course of the study, which lasted over 100,000 flashes – the expected lamp lifetime under long-pulse conditions – we monitored the short-circuit current of a 75W PV module and two portions of the irradiance spectrum. The shortest wavelength region was from 400 to 500nm, and the longest from 900 to 1100nm. During this study, no changes or adjustments were made to any of the simulator settings. Figure 7 demonstrates the long-term stability of the lamp and of all other components in terms of both total output, as exemplified by the flat I_{sc} curve for the module, and of the spectrum, as indicated by the lack of changes in either the long or short wavelength portions of the spectrum.

Summary and conclusions

As solar simulators find increasing use in the PV module manufacturing industry, the need for spectral accuracy has become more apparent. Realizing this, Spire undertook a major effort to develop its own spectral measurement capability rather than to constantly rely on outside services. Using this capability, we now routinely measure every simulator that we manufacture. Through careful design and manufacturing control, our simulators have been demonstrated to routinely produce Class A spectra both at system installation and after 100,000 pulses of use. We plan to continue using this unique capability in the design and manufacture of future, even larger-area and more versatile solar simulators.

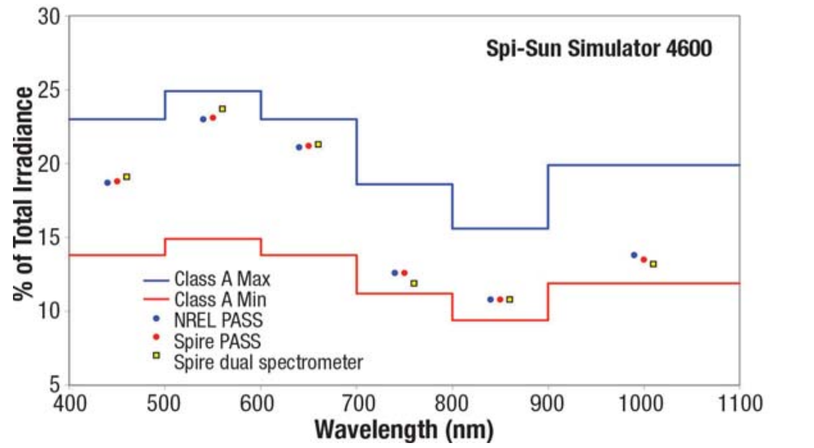

Figure 5. Spectral measurement results taken at the same single point on a Spi-Sun Simulator 4600 using NREL's PASS, Spire's PASS, and Spire's dual-spectrometer analyzer (each data point set is intentionally spread out horizontally to facilitate viewing). In contrast with Figure 1, the upper and lower boundaries only for the Class A region are shown. The agreement between the three instruments is apparent.

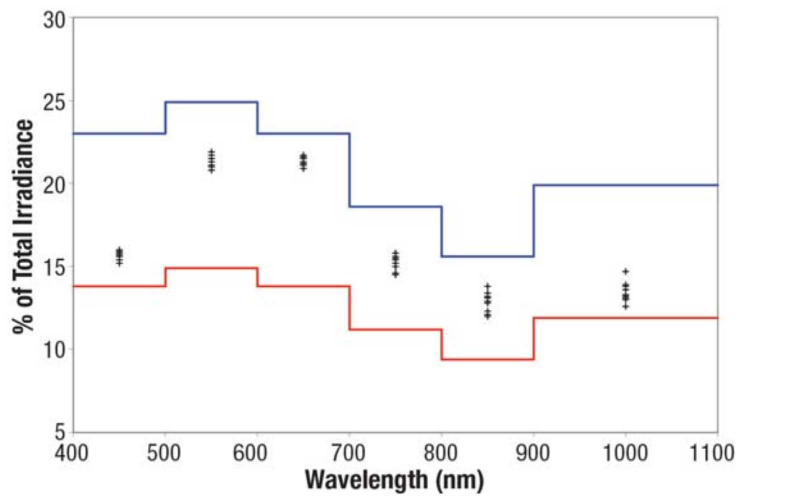

Figure 6. Spectral measurement results taken with Spire's dual-spectrometer analyzer at eleven different test points distributed over the entire test plane of a Spi-Sun Simulator 3500SLP. The spatial uniformity of the Class A spectrum is apparent.

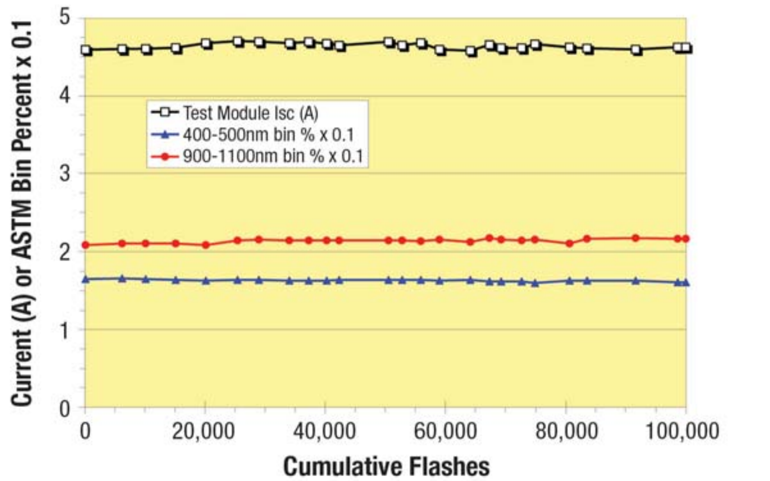

Figure 7. Long-term stability of a long-pulse Spi-Sun Simulator 3500SLP. Each lamp pulse was approximately 100ms in duration and pulse repetition rate was approximately 2/min. Shown is the short-circuit current for a 75W test module placed on the simulator and the fractional amounts of irradiance in the 400-500 and 900-1100nm wavelength intervals (bins). No significant changes in any of the parameters occurred during the rated 100,000 flash lifetime of the xenon lamp.

Acknowledgements

The authors are indebted to numerous individuals who contributed to this work. In particular, ***W. Neal*** and ***H. Sobhie*** supplied major technical guidance and input, ***S. Sutherland*** and ***S. Moore*** set a lot of the early groundwork, ***S. Hogan*** provided much-needed encouragement and support, and ***A. Andreas*** of NREL gave significant technical assistance.

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About the Authors

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Roger G. Little received his B.A. in physics from Colgate University in 1962 and his M.Sc. in physics from the Massachusetts Institute of Technology in 1964. Mr. Little founded Spire Corporation in 1969. Since then, he has guided the commercialization of Spire's technology and directed Spire's growth to a diversified solar energy company with 250+ employees, and now holds the roles of Chairman of the Board of Directors, Chief Executive Officer and President of the Company.

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PV Modules

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Market Watch

Failure analysis of design qualification testing: 2007 vs. 2005

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ABSTRACT

Design and performance qualification testing of PV modules consists of a set of well-defined accelerated stress tests with strict pass/fail criteria. ASU-PTL is an ISO 17025-accredited testing laboratory and has been providing photovoltaic testing services since 1992. This paper presents a failure analysis on the design qualification testing of both crystalline silicon (c-Si) and thin-film technologies for two consecutive periods: 1997-2005 and 2005-2007. In the first period, the industry was growing at a slower rate with traditional manufacturers, with qualification testing of c-Si technologies being primarily conducted per Edition 1 of the IEC 61215 standard. In the second period, the industry was growing at an explosive rate with new manufacturers joining the traditional manufacturers, while qualification testing of c-Si was primarily conducted per Edition 2 of IEC 61215. Similar failure analysis according to IEC 61646 has also been carried out for thin-film technologies. The failure analysis of the test results presented in this paper indicates a large increase in the failure rates for both c-Si and thin-film technologies during the period of 2005-2007.

Introduction

The design qualification certification (per IEC 61215/1646 or IEEE 1262 standard) is a market-driven requirement and the safety certification (per IEC 61730 or ANSI/UL 1703 standard) is a regulatory-driven requirement. The design qualification testing is a set of well-defined accelerated stress tests – including irradiation, environmental, mechanical and electrical tests – with strict pass/fail criteria. The qualification testing does not, as anticipated, identify all the possible reliability issues in the actual field; however, it does identify the major/catastrophic design quality issues. The qualification testing may be considered as the minimum requirement for the reliability testing. The type, extent, limits and sequence of the accelerated stress tests of the qualification standards have been stipulated with two goals in mind. The goals are to accelerate the same failure mechanisms observed in the field without causing failures that do not occur in the field, and to induce these failure mechanisms in a reasonably short period of time, usually 70-120 days.

ASU-PTL has issued more than 300 design qualification and type approval certificates for manufacturers worldwide. Studies have been carried out in relation to accelerated qualification testing for crystalline silicon technologies per IEC 61215 standard [1,2,3]; accelerated reliability testing (for example, prolonged accelerated stress testing until failures are induced) for crystalline silicon (c-Si) technologies [4]; and accelerated reliability testing for thin-film technologies [5].

In the case of thin-film technologies, the qualification testing was conducted per IEC 61646 in both periods under discussion in this paper. Since there was no second edition of IEC 61646 at the time of this study, the change in failure rates for the second period relate only to the combined influence of new and traditional manufacturers.

Figure 1. The ANSI/UL 1703 Temperature test is performed in ASU-PTL's test field.

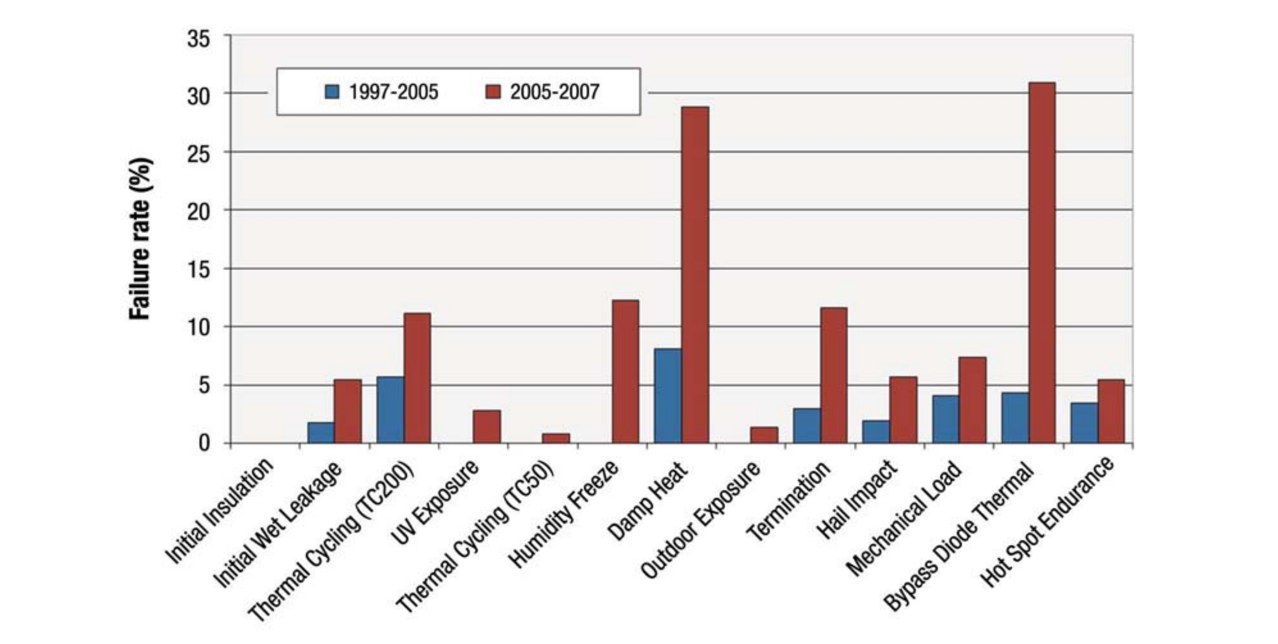

Figure 2. Failure rate comparison of crystalline silicon modules for the 1997-2005 and 2005-2007 periods.

Methodology

In the 1997-2005 period, approximately 1200 modules were tested, while the 2005-2007 period saw the testing of approximately 1000 modules. About 90% of the modules tested were crystalline silicon modules and were tested according to the IEC 61215 and IEEE 1262 standards (mostly according to the IEC 61215 standard as the IEEE 1262 standard was withdrawn in 2000). About 10% of the modules in question were thin-film (amorphous-silicon, cadmium telluride and copper indium selenide) modules and they were tested according to the IEC 61646 standard. The results are presented and discussed in the following two sections.

Results and discussion

Failure rates: 2005-2007 vs. 1997-2005

The failure rates of crystalline silicon modules and thin-film modules in various accelerated and non-accelerated tests of the qualification standards are presented in Figures 2 and 3 respectively. As shown in these two figures, the failure rate has dramatically increased in the 2005-2007 period as compared to the 1997-2005 period. For example, in crystalline silicon technology, the failure rates of the key tests are (2005-2007 vs. 1997-2005): initial wet resistance (5% vs. 2%); diode thermal (31% vs. 4%); damp heat (29% vs. 8%); humidity freeze (12% vs. 0%); and 200 thermal cycles (11% vs. 6%). In the thin-film technology, the failure rates of the key tests are (2005-2007 vs. 1997-2005): initial wet resistance (20% vs. 1%); damp heat (70% vs. 28%); humidity freeze (17% vs. 6%); and 200 thermal cycles (20% vs. 0%).

A disturbing find is that the modules fail at an alarming rate (5% for c-Si and 20% for thin-films) even in the initial, out-of-the-box wet resistance test. These out-of-the-box, non-accelerated test failures can be easily avoided by the manufacturers via inline- or spot-checking of the production modules. Another major observation is that the failure rate for the major accelerated tests such as damp heat, thermal cycling and humidity freeze tests has more than doubled or tripled for the current modules. On one hand, for c-Si, the majority of the damp heat or humidity freeze failure is related to the post-wet resistance test (an additional post-test in Edition 2) rather than post-visual and post-performance tests combined.

The failure rate has dramatically increased in the 2005-2007 period as compared to the 1997-2005 period.

On the other hand, for c-Si, the majority of the thermal cycling test failure is related to the post-visual and post-performance tests rather than the post-wet resistance test. The post-wet resistance test failure occurs primarily around the junction boxes. The post-performance failures in the thermal-cycling and ultraviolet chamber tests are significantly influenced by the shorting problems related to the bypass diodes. The shorting problems of the bypass diodes appear to be associated with the prolonged thermal stresses of the diodes in the chambers. The diode failures, even in the ultraviolet chamber maintained at 60°C over a few weeks, warrant a pre-screening or pre-qualification of the diodes before they are installed in the modules. Because of this diode problem, the module manufacturers are penalized by having to repeat the entire test sequence or the entire test program with new diodes.

The proposed pre-qualification of diodes is expected to reduce the testing time and cost for the module manufacturers. The most severe test for the thin-film modules is the damp heat test at a failure rate of 70%. About 86% of this failure is related to the post-wet resistance test rather than the post-visual and post-performance tests.

Failure rates: IEC 61215 (edition 1) vs. IEC 61215 (edition 2)

The major differences between Editions 1 and 2 of the accelerated tests of the IEC 61215 standard lie in the thermal cycling (200 cycles) test and bypass diode thermal test.

Thermal cycling test

The purpose of the thermal cycling test is to determine the ability of the module to withstand thermal mismatch, fatigue and other stresses caused by repeated changes in temperature. The test in Edition 2 of the standard is the same as that in Edition 1 except that the new edition requires application of peak power current during thermal cycling when the module temperature is above 25°C. For a set of manufacturers, ASU-PTL had conducted tests according to both Editions 1 and 2 of the standard. Table 1 compares the Edition 1 and Edition 2 thermal cycling test results obtained for nine different manufacturers. All of the thermal cycling failures presented in Table 1 are related to the post-performance test. Out of nine manufacturers' modules, four manufacturers' modules failed in the Edition 1 thermal cycling test, whereas only one manufacturer's modules failed the Edition 2 thermal cycling test. Interestingly, it appears that almost all of the traditional manufacturers had effectively addressed the thermal cycling failure issue during the first period itself. This analysis indicates

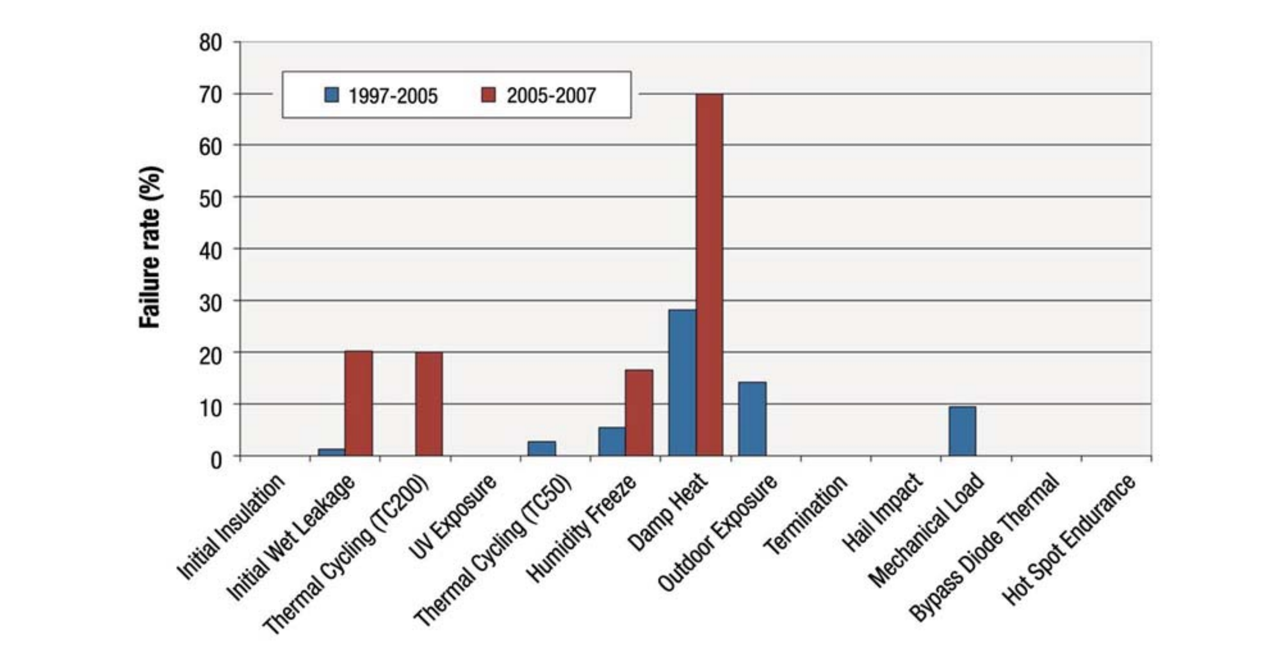

Figure 3. Failure rate comparison of thin-film modules for the 1997-2005 and 2005-2007 periods.

that the Edition 2 thermal cycling test is not more stringent than Edition 1 test for eight out of nine manufacturers' modules investigated in this study.

Bypass diode thermal test

The purpose of the bypass diode thermal test is to assess the adequacy of the thermal design for the hot-spot susceptibility. This test was not required in Edition 1 whereas it is required in Edition 2. The diode failure is caused by overrating of the diode (diode manufacturer issue), and/or by inappropriate electrical configuration and short circuit current of the module (module manufacturer issue).

The proposed pre-qualification of diodes is expected to reduce the testing time and cost for the module manufacturers.

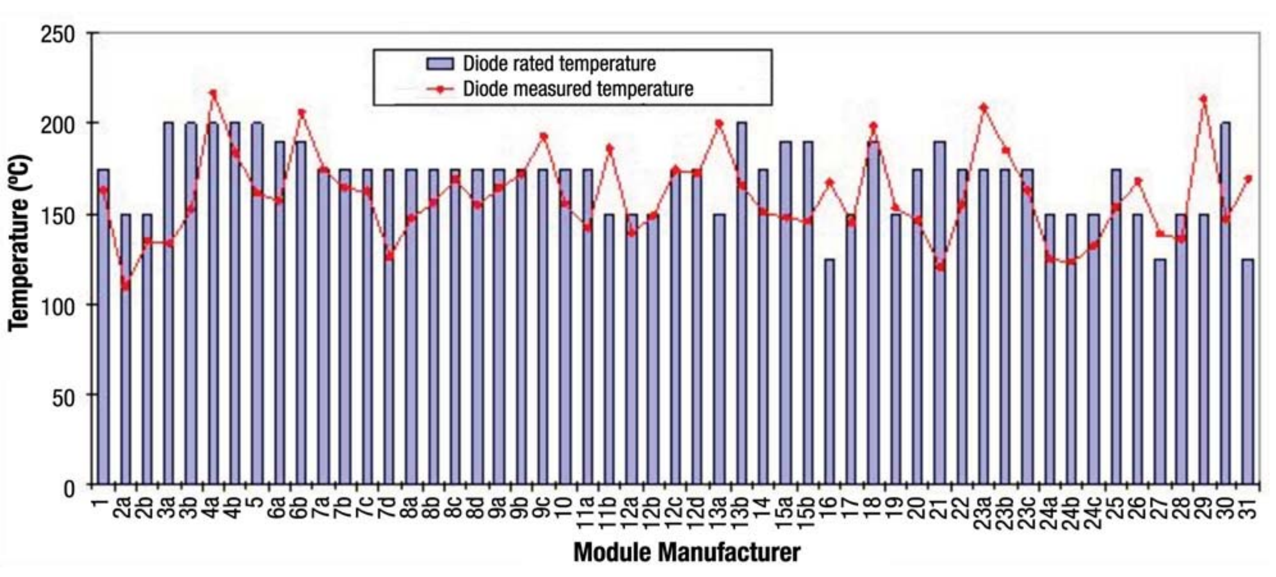

Figure 4. Diode thermal test failure: red dot above the blue column indicates failure.

Manuf. Code	Number of Ed. 1 Modules	Number of Ed. 2 Modules	Post-TC200 Perf. Failure Rate in Ed.1	Post-TC200 Perf. Failure Rate in Ed.2
2	68	8	7%	0%
29	14	4	7%	50%
4	14	4	21%	0%
7	14	12	14%	0%
9	16	6	0%	0%
15	12	4	0%	0%
24	4	4	0%	0%
32	22	2	0%	0%
25	12	8	0%	0%

Table 1. Thermal cycling test failure rate comparison between Editions 1 and 2 of IEC 61215.

Surprisingly, the highest failure rate (31%) for the crystalline silicon modules is related to the bypass diode test (see Figure 2). More than 90% of these bypass diode thermal test failures were related to the higher measured/calculated temperatures of the diodes as compared to the rated temperatures. Less than 10% of the diode failures were related to either the post-visual inspection test (diode touching and melting the junction box casing) or the post-performance test (diode short circuiting). As shown in Figure 4, all the diodes with 125°C rating failed in this test. Out of 31 different manufacturers' modules tested (Figure 4), 19 manufacturers' modules consistently passed the diode test (61%) and the other 12 manufacturers' modules consistently or randomly failed the diode test (39%).

Conclusions

The failure analysis of the qualification test results of ASU-PTL indicates a large increase in the failure rates for the 2005-2007 period as compared to the 1997-2005 period. In both crystalline silicon and thin-film modules, the higher percentage of failure observed in the 2005-2007 period is primarily attributed to the market entry of a large number of new manufacturers, the wet resistance test after damp heat and humidity freeze tests, and the performance test after thermal cycling test. The Edition 2 thermal cycling test of the IEC 61215 standard does not seem to be more stringent than the Edition 1 test. A large fraction of the modules fails due to the bypass diode failures in the chamber and diode thermal tests, suggesting that a pre-qualification of bypass diodes may be warranted.

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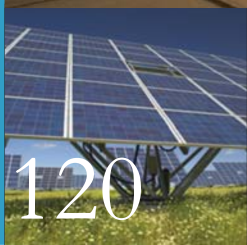
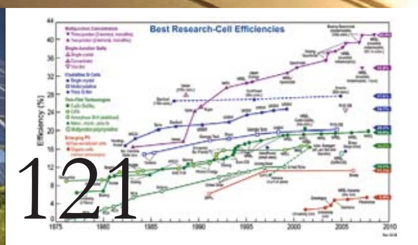
Power Generation





SEPA reveals top 10 U.S. solar utilities

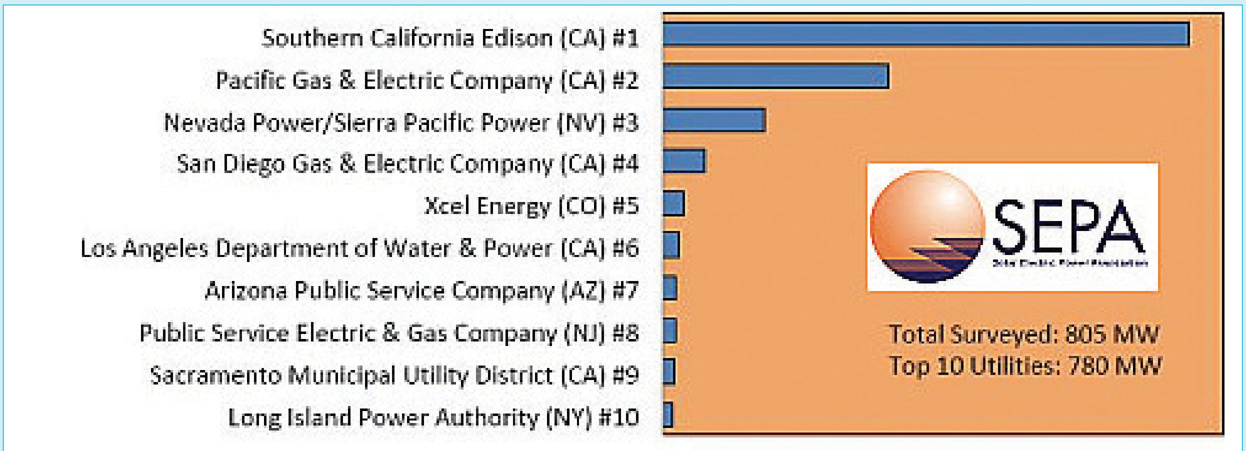
The Solar Electric Power Association (SEPA) has for the first time compiled the Top 10 energy utilities that use solar power as part of its energy mix. It may be a short-term position due to the recent scale of newly-announced solar plants but, according to the SEPA figures that were compiled through to the end of 2007, Southern California Edison (CA) took top honors as the most solar-integrated utility with the most overall solar capacity (MW) and solar capacity per customer (MW/customer).

"Based on recent announcements and internal discussions with utilities, SEPA anticipates that utilities will quickly become the largest and one of the most important customers for the solar industry," said Julia Hamm, SEPA Executive Director. "Whether solar electric systems are developed by utilities, their customers, or solar companies, the utilities' proactive engagement with emerging solar technologies is important to the solar industry as a whole. This market survey and resulting rankings provide a baseline against which increased utility activity can be measured in the future."

Top 10 lists were also released based on the amount of solar electricity interconnected to the utility in two different configurations: customer side of the meter and utility side of the meter.

On the customer side of the meter, Pacific Gas & Electric (CA) took the honors for both the largest amount of overall solar capacity and the highest MW per customer. On the utility side of the meter, Southern California Edison is the highest-ranked utility both for overall MW as well as MW per customer, which drove its number one total ranking.

"These top ten rankings highlight solar-leading utilities that have put significant efforts into facilitating what have traditionally been customer-based solar solutions," says Mike Taylor, SEPA Director of Research. "What has become apparent however is that over the next few years, there will be an unprecedented level of new utility engagement in the solar industry that develops both centralized and distributed systems in new and unique ways. Several U.S. utilities, some of whom aren't in these rankings yet, are positioning themselves to be the solar industries largest and most innovative customers."



Ranking 1A: Top Ten Utilities ranked by Total Solar Electric Capacity (MW) – All Utilities.

Abengoa Solar secures funding for next 50MW energy plant

Abengoa Solar has said that its new Solnova 4 Concentrating Solar Power plant, using parabolic trough technology will begin construction in September, 2008 with a 50MW power output capacity. Abengoa Solar said that it has finalized the funding for the new plant planned in Saville from 14 banks in its latest funding round.

"More than half of the 300 megawatts planned for our Solúcar platform are under construction," said Santiago Seage, Chairman of Abengoa Solar. "The PS10 is already operational and with Solnova 4 we will have 170 megawatts under construction".

Amando Sánchez Falcón, Abengoa CFO, stated that, "this deal is just another example of Abengoa's ability to continue financing operations in a difficult environment. The confidence that the financial institutions place in the combination of Abengoa Solar's technology and operational leadership and Abengoa's construction capabilities is one of the keys to the success of this deal".

The institutions involved in the financing are Banesto, Caja Madrid, Calyon, Dexia Sabadell, ING, Kfw, Ladesbank, Natixis, Santander, Société Générale and Ubibanca for the construction and start-up of Solnova 4, and La Caixa, Sumitomo and West LB for the photovoltaic plants.


Abengoa Solar uses parabolic trough technology

First Solar wins 10MW turnkey installation in U.S.

Sempra Generation has selected First Solar to provide a 10MW turnkey thin-film PV energy plant near Boulder City, Nevada. The project started in July and is expected to be completed by the end of 2008. The modules to be used at this ground-mount project will come from First Solar's manufacturing facility in Perrysburg, Ohio, the company said.

"Sempra Generation has a proven track record for successful energy resource development and we are pleased to work with them to bring additional renewable electric generation to the region," said Mike Ahearn, CEO of First Solar. "The 10MW PV power plant will be adjacent to Sempra Generation's existing El Dorado combined cycle natural gas plant. By co-locating this new PV power plant with existing infrastructure and the associated interconnection and transmission facilities, Sempra Generation will maximize their land and transmission."

First Solar will design, engineer and construct the turnkey PV power plant and will provide monitoring and maintenance services for the plant over its lifetime

First Solar embarks on two solar projects in California

In a dual project announcement, First Solar has announced that it is to provide all engineering and installation services for the construction of a 2MW rooftop solar PV power project in Fontana, California for Southern California Edison (SCE). The second announcement is for a 20-year power purchase agreement for energy generated by a further planned Blythe-based power plant. First Solar's construction of the Blythe facility, which will have a minimum output of 7.5MW with an optional maximum of 21MW, is expected to begin in 2009.

The rooftop plant will be the first step in SCE's plan to install 250MW of solar generating capacity on large commercial rooftops in the Southern California area over the next five years. Connection to the supply grid is anticipated in September 2008.

The planned project in Blythe, California, will be the largest ground-based PV power plant in the state. First Solar will take responsibility for all the engineering, procurement and construction of plant, and will also provide maintenance services for the plant's lifetime.

"These projects represent significant steps towards the deployment of low cost, solar electric generation resources for California," said Mike Ahearn, CEO of First Solar. "First Solar looks forward to developing these and other projects which will move California closer to its renewable energy and greenhouse gas reduction goals."

FPL gets go-ahead for three solar energy centers

Florida Power & Light Company (FPL) has received approval from the Florida Public Service Commission (PSC) to start construction on three separate utility-scale solar power projects in the state. The construction of these projects will make Florida the second largest supplier of utility-generated solar power in the U.S.

The planned projects are as follows:

The DeSoto Next Generation Solar Energy Center, which will be constructed on FPL's land in DeSoto County. This 25MW project will become the world's largest photovoltaic solar facility and is expected to be in operation by December 2009.

The Martin Next Generation Solar Energy Center, the world's first project to integrate solar thermal steam generation into a combined-cycle steam turbine. The hybrid design will produce up to 75MW of solar thermal capacity at FPL's Martin Plant site, coming on-line at the end of 2009, with completion planned for 2010.

The Space Coast Next Generation Solar Energy Center will be located at the Kennedy Space Center and will be in operation by the first quarter of 2010. The facility will provide 10MW of photovoltaic solar capacity.

"[The] decision by the PSC represents a major step forward in making Florida a leader in solar power generation," said Armando J. Olivera, President, FPL. "At a time of record-setting fossil fuel prices and concern over global climate change, solar power helps to meet the goals of protecting the environment and enhancing Florida's energy security."

SunPower to construct largest power plant in the U.S. for Florida Power & Light Company

Florida Power & Light Company has selected SunPower Corporation to build the largest solar photovoltaic power plant in the United States at a location at DeSoto County, and a second plant at the Kennedy Space Center. The DeSoto County plant will have a 25MW capacity and is expected to be completed in 2009, while the 10MW plant is scheduled for completion in 2010.

SunPower will design and build the facilities using its SunPower panels at both sites and installing its SunPower Tracker system at the DeSoto plant. FPL will own, operate and maintain the systems, construction of which is subject to approval by the Florida Public Service Commission.

"These agreements confirm the growing trend in the U.S. to build solar power plants at a scale rivaling those in market-leading countries such as Germany and Spain," said Howard Wenger, Senior Vice President of global business units for SunPower. "With these agreements totaling approximately 35 megawatts, we applaud Florida Power & Light's commitment and leadership in renewable energy."

Unisolar approves transformerless inverters from Sputnik Engineering for its thin-film modules

Unisolar has officially approved transformerless inverters from Sputnik Engineering for use with its products. With immediate effect, all amorphous thin-film modules from Unisolar – both branded and OEM products – can be combined with SolarMax products from Swiss inverter manufacturer Sputnik Engineering without further approval procedures.

The question of whether transformerless inverters are suitable for combination with thin-film modules has long been the subject of discussion. In addition, solar modules made from amorphous silicon tend to degrade over the first few months, with output and voltage initially increasing. The system must be designed in such a way as to ensure that the increased initial voltage does not damage the inverter.

Sputnik Engineering AG has been able to evaluate the effect of this voltage increase using its MaxDesign system visualisation software. The software offers the option of calculating limit values with stabilised end values or initial voltages.

"Transformerless inverters from Sputnik Engineering AG have been operating successfully with Unisolar's amorphous silicon modules since 2005," reports Stefan Burri, Sputnik's Head of Technical Sales Support. However, installers have until now had to combine the products at their own risk as Unisolar had not officially approved this practice. "Their official approval offers clarity and safety," adds Burri. Galvanically-separated central inverters from Sputnik Engineering AG have been approved for use with Unisolar modules for several years.

Sputnik Engineering AG focuses on the development, sales and maintenance of inverters for grid-connected PV systems.

EDF Energies Nouvelles to build 7MWp solar farm in southern France

EDF Energies Nouvelles has begun construction on one of France's largest solar power farms in the Malvezy industrial zone of Narbonne, France. The plant, which will have a capacity of 7MWp, will be constructed using 95,000 thin-film modules supplied by First Solar, which will be delivered to the site in late July.

The company is currently installing the panel supports and inverters, while completion expected by the end of 2008. The 7MWp capacity will provide enough electricity to meet the power needs of over 4,200 people.

Product Briefings

Siemens AG

SINVERT PV inverters from Siemens offer field-proven performance and reliability

Product Briefing Outline: Siemens AG has developed and manufactured inverters for photovoltaic applications since 1987. The latest products of this development are the SINVERT PV inverters, a family of three phase grid connected inverters in the range of 60kVA up to 1700kVA. They already serve as central inverters in a large number of PV power plants. In Siemens' SINVERT 1700 MS, four units of 420 kVA act as a single 1.7 MVA, PV inverter. The combination of up to four single inverters working together to maximize performance, yield and availability.

Problem: Operators, investors and poroject planners need a PV power plant which requires a minimum of maintenance care. Less service labour and down-times mean less cost reduction in the return on investment. Only the most reliable and field-proven components, such as modules and their mounting structures, cabling and combiner boxes as well as the inverters with their containers and the whole medium voltage equipment are desired. To control these complex power plants, an industrial grade supervision system is necessary.

Solution: Equipped with features like master slave operation, symmetry monitoring and VAr control, Siemens' SINVERT covers the current and future recommendations of a reliable and almost maintenance-free operation. Providing superior performance ratio, SINVERT makes the best of the power the solar panel can generate.

Applications: Grid-connected PV installations, such as fixed and tracking field installations and BIPV installations.

Platform: Standard Siemens drive inverters from the MASTERDRIVES and SINAMICS series which are certified by all applicable standards. Using these high performance drives, Siemens delivers PV inverters in cabinets of two sizes, 2000 x 2700 x 800mm and 1902 x 918 x 834mm. Transportation is easy due to the separate transformer cabinet. Pre- configured concrete containers are also available.

Availability: July 2008 onwards.

Kaco

Kaco offers Powador XP 100-HV inverter for solar power generation up to 100kW

Product Briefing Outline: Kaco now offers a new generation of central inverters that optimize yield from solar modules configured for large-scale power generation. The Powador XP100-HV central inverter uses DSP-based technology that is intended to offer the highest performance, reliability and efficiency.

Problem: Wattage output from modules varies greatly according to solar radiation during the day and inverters can affect overall efficiencies by being unable to flexibly process/handle varying loads on the system. Uptime (i.e. continuous feed-in) is a constant concern for power generation operating in isolated areas where it can be costly to replace broken inverters leading to lost energy.

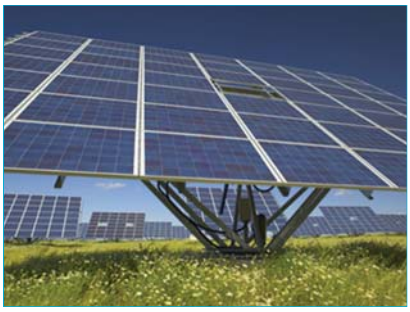
Solution: The patented pulse width modulation algorithm (PWM) and load-adaptive clock frequency reduce IGBT switching losses by more than 30%. Depending on the load cycle, the switching frequency is optimised in order to achieve higher degrees of efficiency and better energy yields for the PV plant. Reliability and maintainability are significantly enhanced by redundant power supplies for crucial systems/components, a refined IGBT stack design with laminated DC bus bar, extremely low stray inductance and gate drive interfacing with differential signalling. Depending on the load and environmental temperature, the cooling fans are monitored and controlled in an intelligent way.

Applications: Large-scale power generation facilities segmenting generation areas of up to 100kW in size.

Platform: The XP100-HV central inverters feature fully digital control technology compared to traditional analog electronic designs with the benefit of a reduced number of components. MPP range 450V – 800V; maximum voltage 950V; maximum current 235A. Ripple voltage <3%.

Availability: June 2008 onwards.

Mecasolar



Mecasolar's dual axis trackers increase module performance

Product Briefing Outline: Mecasolar is a company dedicated to the design, manufacture and distribution of dual axis, azimuth and vertical solar trackers, MS Tracker 10 in its two versions MS Tracker 10 and MS Tracker 10 +. The trackers come with a 10-year guarantee on parts and workmanship and displacement.

Problem: The MS TRACKER 10 and 10 PLUS trackers perform solar tracking through astronomical programming. The PLC incorporated into the system controls actuation of the two gear motors, which position the photovoltaic surface perpendicular to the sun's rays, thus maximizing electrical energy generation; the tracker may also be placed in a night position and may assume the evening position in order to being the daily work cycle.

Solution: Accordingly, with the Mecasolar tracking system, increased performance is offered for photovoltaic installations as compared to installations on fixed structures. Said increases are greater than 35%, and vary depending upon the geographic location at which the plant is located, and can even reach as high as 45% for some regions in Spain, according to the company.

Applications: Dual axis, azimuth and vertical solar trackers.

Platform: The MS TRACKER sits on a foundation or concrete footing reinforced with corrugated wire mesh. It is anchored to the footing by securing nuts and locknuts on steel stud bolts. The solar tracker is comprised of two metal profile substructures made of hot dipped galvanised steel, which give the structure a robust resistance. The tracker's central body is comprised of a 'V-shaped' structure on which the frame rests in which the photovoltaic modules are mounted. Mecasolar has the ISO 9001:2000 certificate, CE Certification for conformity with European Directives 98/37/CE, 73/23/CEE and 2004/108/CE. The tracker has been designed according the following standards: DIN 1055-4 (8.86), DIN 1056 (10.84) and MV-103 Building Standard.

Availability: July 2008 onwards.

Current status of the concentrating photovoltaic power industry

Sarah Kurtz, National Renewable Energy Laboratory (NREL), Golden, Colorado, USA

ABSTRACT

Today's PV industry is growing at a rapid rate, but the industry would grow even faster if costs could be reduced for both the final products and the capital investment required for scale-up. One strategy for reducing module cost is to reduce the amount of semiconductor material needed (the cost of the silicon solar cells typically comprises more than half of the module cost). Many companies are thinning the silicon wafers to reduce costs incrementally; others use thin-film coatings on low-cost substrates (such as amorphous/microcrystalline silicon, cadmium telluride, or copper indium gallium (di)selenide on glass or other substrates). Concentrating photovoltaics (CPV) follows a complementary approach and uses concentrating optics, which may be designed for low or high concentration, to focus the light onto small cells. Low-concentration concepts use silicon or other low-cost cells; high-concentration optics may use more expensive, higher-efficiency cells. The higher-efficiency cells can reduce the cost-per-watt if the cost of the small cells is minimal.

Introduction

Concentrator cells have recently been reaching increasingly impressive efficiencies, inspiring new interest in the high-efficiency, high-concentration approach. The current record efficiency is 40.8% for a three-junction GaInP/GaInAs (1.3eV)/GaInAs (0.9eV) cell [1]. A historical summary of champion cell efficiencies is shown in Figure 1. Multijunction concentrator cells have achieved much higher efficiencies than any other approach. This is not surprising for two reasons: (i) the highest efficiencies may be achieved if multiple semiconductor materials (with a range of bandgaps) are chosen to match the spectral distribution of the sun, and (ii) the compound semiconductors used in these cells are direct-gap materials and can be grown with near-perfect quality. The multijunction approach has been described extensively in the literature [2-11].

When compared with solar thermal approaches, CPV provides a qualitatively different approach, typically with lower water usage, greater flexibility in size of installation, and the ability to respond more quickly when the sun returns on a cloudy day. The tracking used for CPV also implies relatively higher electricity production per installed kilowatt, compared with fixed flat plate.

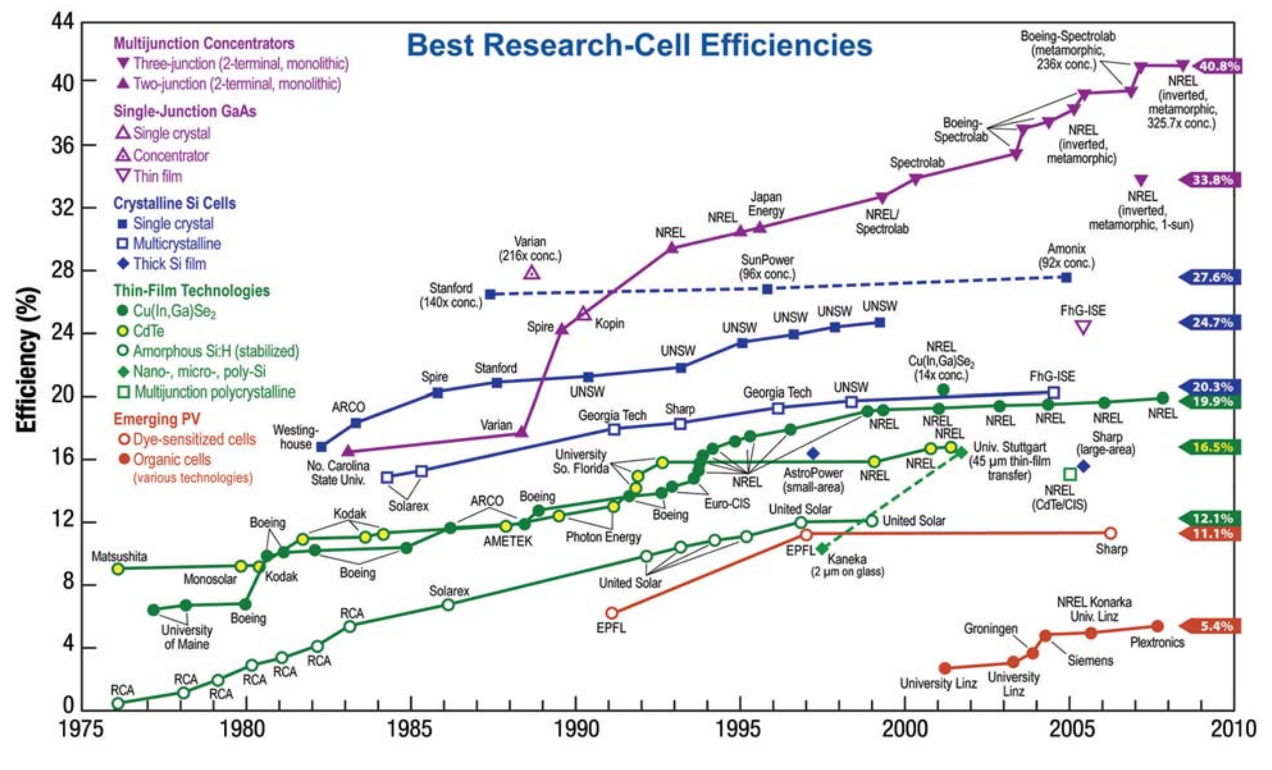


Figure 1. Historic summary of champion cell efficiencies for various photovoltaic technologies. The highest efficiencies have been achieved for multijunction solar cells, increasing at a rate of almost 1% per year in recent years. Multijunction cell efficiencies have the potential to approach 50% in the coming years.

Company	Type of System	Location	On-sun in 2007
Abengoa Solar	Multiple designs	Spain, USA	
American CPV		Orange, CA, USA	
Amonix	Lens, pedestal	Torrance, CA, USA	>100kW (Si-based)
Arima Ecoenergy	Lens, pedestal	Taiwan	
Boeing		USA	
Concentracion Solar La Mancha	Lens, pedestal	Ciudad Real, Spain	
Concentrating Technologies	Small mirror, pedestal	Alabama	>1kW
Concentrix Solar	Lens, pedestal	Freiburg, Germany	~100kW
Cool Earth Solar	Inflated mirrors	Livermore, CA, USA	>1kW
Daido Steel	Lens, pedestal	Nagoya, Japan	
Emcore	Lens, pedestal	Albuquerque, NM, USA	>10kW
Energy Innovations	Lens, carousel	Pasadena, CA, USA	
Enfocus Engineering	Lens, flat pivot	Sunnyvale, CA, USA	
ENTECH	Lens, pedestal	Keller, TX, USA	>1kW since 2003; >100kW (Si based)
EVERPHOTON Energy	Lens, pedestal	Taipei, Taiwan	
Green and Gold	Lens, pedestal	South Australia	
GreenVolts	Small mirrors, carousel	San Francisco, CA, USA	>1kW
Guascor Foton	Lens, pedestal	Ortuella, Spain	~10MW (Si-based)
Isofoton	Lens, pedestal	Malaga, Spain	
Menova	Modified trough	Ottawa, Ontario, Canada	
OPEL International	Lens, pedestal	Shelton, CT, USA	
Pyron	Lens, carousel	San Diego, CA, USA	>1kW
Sharp	Lens, pedestal	Japan	
Sol3g	Lens, pedestal	Cerdanyola, Spain	>10kW
Solar Systems	Dish, pedestal	Victoria, Australia	>100kW
Solar*Tec AG	Lens, pedestal	Munich, Germany	
SolarTech	Lens, pedestal	Phoenix, AZ, USA	
SolFocus	Small mirror, pedestal	Mountain View, CA, USA	>10kW
Soliant Energy	Lens, flat pivot	Pasadena, CA, USA	

Table 1. Summary of CPV companies.

Ten years ago, there was little commercial interest in CPV for the following reasons:

- The PV market was dominated by building-integrated or rooftop applications, whereas most CPV products are better suited to solar farms.
- The champion concentrator cell was only ~30% efficient, compared with ~40% today.
- The total size of the industry was about one-tenth of what it is today, making near-term, high-volume CPV deployment unlikely (i.e., CPV achieves low cost only when the volume of manufacturing is large).

In the last 10 years, the solar industry has mushroomed, and the CPV industry is now growing rapidly. Cumulative investment in CPV is now on the order of US$1 billion. Solar fields, which often use tracked systems, are becoming more common, providing a potentially huge

Company Name	Comment
Spectrolab	Datasheet describes minimum average 36% cells and cell assemblies at 50 W/cm^2
Emcore	Datasheet describes typical 36% cells and receivers at 470 suns
Spire (Bandwidth)	Datasheet describes typical 35% cells at 500 suns
Cyrium	North America
Microlink Devices	North America
Azur Space (RWE)	Europe
CESI	Europe
Energies Nouvelles et Environnement (ENE)	Europe
IQE	Europe
Arima	Asia
Epistar	Asia
Sharp	Asia
VPEC	Asia

* List does not include a number of other companies in R&D or stealth modes.

Table 2. Summary of companies with capability for epitaxial growth of multijunction cells.*

market for CPV products. With the overall PV market growing in the gigawatt range, CPV has an opportunity to enter the market with production of tens or hundreds of megawatts per year. This is significant because CPV is unlikely to achieve low costs when manufacturing at less than tens of megawatts per year. Ten years ago it would have been difficult for companies to have confidence that they could find markets for the needed volume. The growth of the market, and especially growth of the market segment that uses trackers, is an important contributor to the increased interest in CPV. The potential for CPV industry growth has been widely discussed in recent years [4-6]. The Bosi review (reference 4) includes almost 100 references.

Some cost analyses have predicted that using high-efficiency concentrator cells can lead to very low costs for solar electricity [5,6,12]. These studies imply that there is a potential for cost-effective implementation of high-concentration systems even in locations such as Boston, Massachusetts [6]. The energy payback of some CPV systems has also been studied [13]. Demonstration that these cost structures can be achieved will require development of a reliable CPV product followed by large-scale deployment. Many are watching for the success of this demonstration.

Current status of the CPV industry

Table 1 provides a partial list of today's CPV companies. This list has grown substantially in the last five years. Perhaps more important than the length of the list is the level of investment in the industry and the movement toward large-scale production. A company that might have attracted a US$1 million investment 10 years ago may hope to attract US$100 million today. Not surprisingly, the larger investment rates are enabling faster progress in the development, with multiple companies now reporting stable on-sun operation for months or years [12]. Reliable operation on-sun is the primary milestone that must be reached before CPV companies can begin the sort of rapid expansion that First Solar has demonstrated to be possible for a new technology. Recent reports of stable on-sun operation are an indication that rapid expansion could occur within the coming years.

Cell supply

A key concern of all of the CPV companies has been the availability of concentrator cells. Spectrolab and Emcore are currently shipping concentrator cells to multiple CPV companies. A significant number of new companies have recently demonstrated the capability for epitaxial (single-crystal) growth of multijunction cells. These are summarized in Table 2. Multiple start-up companies are developing recipes and are supplying samples in small volumes.

A quick review of the companies in Table 2 implies that the supply of cells is increasing. The efficiencies from the new companies are expected to be inferior to those from Emcore and Spectrolab, but may be acceptable to some CPV companies. A number of companies are fabricating cells with efficiencies greater than 30%; some have demonstrated efficiencies in the range of 35%. Although all of the companies on this list have some capability for growing multijunction cells, not all of them have demonstrated a capability for high-yield manufacturing.

The most immediate concern about the concentrator cells expressed by CPV representatives is whether the reliability testing is adequate. Both Spectrolab and Emcore report that they have tested the cells and are confident of their stability and performance, but most CPV representatives were not satisfied with the detail of the test data. Emcore bases its 20-year cell (and receiver) warranty on (i) years of experience with space cells manufactured for operation at up to 250°C; (ii) a firm understanding of both the physical-degradation mechanisms and the design/manufacturing methodologies needed to ensure long-term reliability of its CPV products; and (iii) a year (and counting) of stable on-sun terrestrial operation at 500 suns. Spectrolab has a similar space heritage and has tested its CPV

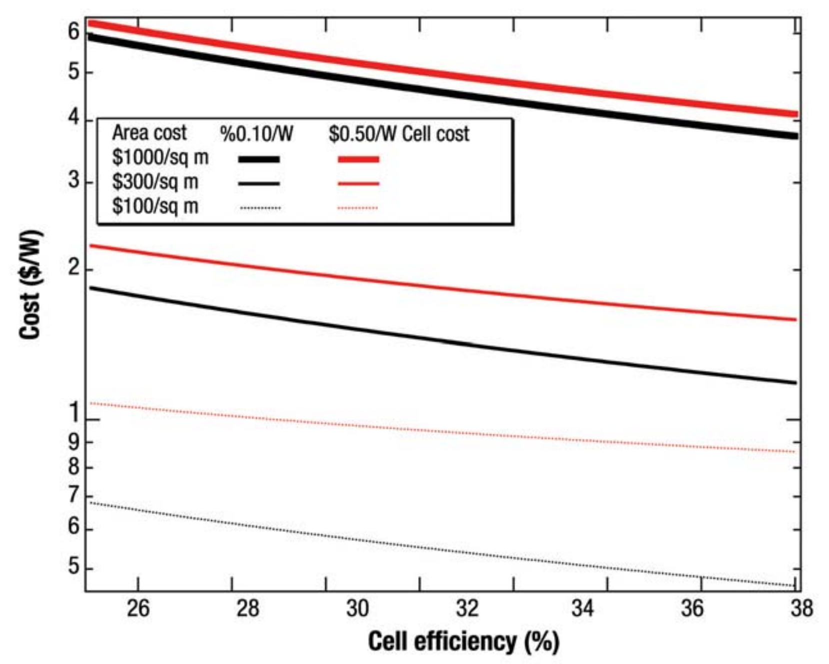


Figure 2. System cost as a function of cell cost and non-cell costs. The power was decreased from 850 to 690W/m^2 to account for optical and thermal losses. The equation used to calculate these data was Cost ($/W) = Area cost ($/m^2)/Efficiency x 690 (W/m^2) + Cell cost ($/W). The definition of cell cost in US$/W has 20%–35% uncertainty because it may or may not account for optical and/or thermal losses.

cells using the thermal-cycling, humidity, and humidity-freeze tests described in IEEE 1513-2001.

Emcore's current production capacity is ~350MW/yr at 1000 suns. Spectrolab has plans for capacity in a similar range. Both Emcore and Spectrolab report that their primary barrier to expansion is confidence in future sales. Just as some silicon PV companies are moving toward vertical integration, many of the CPV companies are considering vertical integration with cell companies to ensure adequate cell supply. In contrast, the cell companies are trying to avoid vertical integration in order to retain their ability to supply many CPV companies. The situation may become particularly complex as companies attempt to define whether to merge or separate these efforts.

Expansion of the manufacturing volumes should allow reduction in cost because of economies of scale. This consideration would tend to associate lower cell costs with a small number of cell companies. In 2007, cell supply was a primary concern among CPV representatives. With the growing number of companies with cell capability, this concern is substantially reduced.

Cell efficiencies

Cell efficiencies have been increasing at a rate of about 1% per year in recent years, and are expected to continue to increase toward 45%–50%. Spectrolab has reported an efficiency of 40.7% [2]; Emcore claims an efficiency of 39%; and NREL has described a new inverted structure at a record 40.8% [1]. Although a 50% solar cell should be achievable, the addition of multiple junctions may add cost and may have marginal benefit in terms of additional energy production in the field.

The trade-off between cell cost and cell efficiency is highly dependent on the relative costs of the cells and the systems. A simplistic analysis is shown in Figure 2. The cell cost in US$/W is strongly dependent on concentration. The cell costs of US$0.50/W and US$0.10/W represent, respectively, what is achievable today and what may be achieved in the future [12]. The US$1,000/m^2 area cost potentially includes not only the module costs, but also installation and land-use costs, and may approximate an entry-level system today. Lower costs will need to be achieved to be competitive in the marketplace; the US$100/m^2 target is aggressive, but demonstrates how the role of cell efficiency changes when the system cost becomes dominated by the cell cost. For US$1,000/m^2 systems, efficiency is clearly a strong cost driver. But if the system cost can be reduced to US$100/m^2 without further increase in cell cost, then efficiency becomes unimportant. The evaluation of the importance of cell efficiency and cost is fairly straightforward once the system design (especially the concentration) is fixed and the relative costs are known. An example equation is included in the Figure 2 caption.

Substrate supply

The manufacture of multijunction space cells in the last decade has been based primarily on germanium wafers supplied by a single company: Umicore (Brussels, Belgium). Multiple companies are now developing a germanium wafer capability, including AXT (Fremont, California); Sylarus (St. George, Utah); and PBT (Zurich, Switzerland). In addition, if the inverted method [11] of fabricating the multijunction cells becomes popular, the substrates may be reused or the material recycled. Although it is possible that the industry could be so successful as to create a shortage of wafers, this is not currently on the horizon. The current availability of germanium should support industry growth up to ~4GW/yr [12].

Conclusion

The use of concentrated sunlight on very small, but highly efficient (~40%) solar cells has the potential to provide cost-effective, large-scale, solar-electricity generation, especially in sunny locations. More than a dozen companies have learned to fabricate multijunction concentrator cells, positioning themselves to respond to the growing demand for these cells. About 30 companies are developing concentrator photovoltaic systems, and many have already deployed 1-100kW in the field. This industry is showing signs of being poised for substantial growth in the next years as the world enthusiastically embraces solar energy.

Acknowledgments

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The creation of large-scale photovoltaic power plants: the move to thin-film modules

David Owen, Publisher, Photovoltaics International

ABSTRACT

Every day, mankind consumes as much energy as it took the earth 1,370 years to store. The International Energy Agency estimates that by the year 2030, worldwide electricity consumption will have increased annually by approximately 2.4%. City Solar AG is seeking to increase renewable energy stocks through grid-connected solar power utilities. As one of the leading producers of large-scale photovoltaic plants, City Solar is uniquely placed to give us a better understanding of how these plants are put together.

Reserves of fossil fuels cannot cover our energy needs in the long term. Furthermore, price increases must be expected. It will be increasingly necessary to exploit deposits that are more difficult to mine, or that must be transported over longer distances. A worst-case scenario shows an increase in the number of political or even violent conflicts over control of remaining resources.

A world that uses solar energy solves important, central questions for mankind: less air pollution, less climate-changing CO_2, fewer political and violent conflicts over fossil fuels and a multitude of new, permanent work places.

City Solar is making great strides in delivering cost-effective power to the masses through their ambitious and aggressive power-plant building projects. To date, City Solar has connected to the grid projects with capacity of more than 81MW, including a 20MW installation in Beneixama (Spain), one of the world's largest photovoltaic power plants.

The resources and skills required to get a successful solar power plant up and running include securing the site, development and site management, excavation and foundation work, sourcing and testing solar modules, assembly of support frames and solar modules, installation of electrical equipment and ongoing technical operations management. Solar power plants produce approximately 410MWp worldwide, the majority of which are currently ground-mounted installations.

In order to install a power plant with a nominal power of 1MWp, an area of some 20,000 to 25,000m² is needed, depending on the site. The solar modules are mounted on metal supports, the heights of which vary between 1.8 and 2.5 metres. To avoid shading, a distance must be maintained between the rows of supports. Depending on the geographical degree of latitude, the incline of the site and the height of the supports, this distance is between 5 and 10 metres.

City Solar develops and constructs solar power plants independent of any manufacturer. With a proven track record of 21 installations in Germany and Spain using modern, top quality technology from producers of renown, they are able to achieve optimum operational availability for their power plants. This is vital to create high and continuous electricity yields with low operating costs and attractive returns for owners.

Figure 1. A Siemens engineer installing modules at a City Solar facility.

Grid Sub-Application	1997 MWp	2002 MWp	2007 MWp	2012 Conservative MWp	2012 Accelerated MWp	CAGR 1997-2002	CAGR 2002-2007	CAGR 2007-2012 Conserv.	CAGR 2007-2012 ACC.
Grid-Residential	28.5	296.4	856.5	3936.5	6904.5	60%	24%	36%	52%
Grid-Commercial	7.0	32.5	1519.6	6150.8	10788.3	36%	116%	32%	48%
Grid-Utility	**3.5**	**9.5**	**386.8**	**2214.3**	**3883.8**	**22%**	**110%**	**42%**	**59%**
Total Grid	39.1	338.3	2762.9	12301.6	21576.7	54%	52%	35%	51%
Total Demand	114.1	504.9	3073.0	12844.0	22142.9	35%	44%	33%	48%
Grid % Total	34%	67%	90%	96%	97%				

Table 1. Grid connected forecast.

(Courtesy of Paula Mints, Principal Analyst, Navigant Consulting, Inc. PV Services Program).

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SIEMENS

Figure 2. The Solar Park in Beneixama, Spain. In an area of 500,000m^2, 30 million kilowatt hours of clean energy are produced annually.

Without the financial support of government tariffs and the move by large utilities into the solar space, it is clear that the solar power plant market would not be growing at the triple digit growth it has enjoyed over the past five years. The recent Southern California Edison rooftops project is a great example of a large-scale energy provider jumping head-first into the solar energy market. In March 2008, SoCal Edison announced an ambitious project designed to generate 250MWp upon completion in five years. Funded partially by national and state government grants, this project will introduce a new scale for power generation projects.

I caught up with Stephan Brust of City Solar, and asked him a few questions regarding the company's technology and plans for the future.

Who supplies you with the volume of modules required for your projects?

"We use multiple suppliers like Q-Cells, aleo solar, SOLON, Canadian Solar, EPV, and Suntech. They were selected based on long-term experience in the market, high quality, reliability, large capacities, price-performance ratio and, of course, the strength of their warranties. Quality is paramount to everything we do and so we cannot afford any risks when putting together a 20MWp installation."

> Steffen Kammler, CEO of City Solar, commented: "We have selected EPV SOLAR as our commercial partner because of their reliable, low-cost amorphous silicon technology. We are confident that EPV SOLAR's PV modules will deliver exceptional performance and value for our customers."

What are the key criteria for selecting different brands of modules?

"We focus on characteristics such as efficiency rates, durability, ease of installation and how the modules work with different inverters. The modules need a max voltage of 1,000V. We only work together with manufacturers who are able to ensure warranty. Furthermore, the modules must fit to our mounting system. The most important advantages of our patented mounting system are its simple and quick assembly and its uncomplicated installation. This means a significant saving on material and time – savings of up to 50 percent. Particularly in the case of large-scale projects, these savings play an important role."

What are the characteristics of industrial strength inverters for solar power installations and how important are they to the running of a plant?

"They are very important for the running of a solar power plant. We work together with Siemens – in 2003, when our first power plant was built up at Saarbrücken's airport, Siemens was permanently involved in the construction. Siemens supplies invertors, transformers, substations, and takes care of the engineering as well as the electrical fittings. The example of our transformers demonstrates our strategy: we use dry-type transformers (Geafol), as, even though they are more expensive to buy than oil transformers, they do not need servicing, operate more efficiently and are environmentally friendly."

Is there anything particularly unique about the way you put together a plant?

"Yes. City Solar has an inbuilt facilty for research and development that works on cost reduction or efficiency improvement strategies throughout the supply chain. An example is our new tracker system that is 40% cheaper to make and has a 22% higher yield than other ground-mounted systems. Two projects in Spain's Albacete are using these systems; one 15MWp system in Mahora goes live in July 2008."

Figure 2. The Solar Park in Beneixama, Spain. In an area of 500,000m^2, 30 million kilowatt hours of clean energy are produced annually.

Without the financial support of government tariffs and the move by large utilities into the solar space, it is clear that the solar power plant market would not be growing at the triple digit growth it has enjoyed over the past five years. The recent Southern California Edison rooftops project is a great example of a large-scale energy provider jumping head-first into the solar energy market. In March 2008, SoCal Edison announced an ambitious project designed to generate 250MWp upon completion in five years. Funded partially by national and state government grants, this project will introduce a new scale for power generation projects.

I caught up with Stephan Brust of City Solar, and asked him a few questions regarding the company's technology and plans for the future.

Who supplies you with the volume of modules required for your projects?

"We use multiple suppliers like Q-Cells, aleo solar, SOLON, Canadian Solar, EPV, and Suntech. They were selected based on long-term experience in the market, high quality, reliability, large capacities, price-performance ratio and, of course, the strength of their warranties. Quality is paramount to everything we do and so we cannot afford any risks when putting together a 20MWp installation."

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Location: Beneixama (Alicante Province)
Nominal power: 200 x 100kWp (20MWp)
Global radiation: 1,934kWh/m^2 per annum at module level
Ground area: Approx. 500,000m^2 (approx. 71 football pitches)
Solar modules: Approx. 100,000 pieces
Manufacturer: City Solar (PQ 200)
Module surface: Approx. 160,000m^2
Electricity production: Approx. 30,000,000kWh per annum (requirement of more than 12,000 average households)
CO_2 avoidance: Approx. 30,000 tons per annum (over 25 years: approx. 750,000 tons)
Completion date: August 2007

Location: Mahora (Province Albacete, Spain)
Nominal power: 15MWp (Tracker)
Global radiation: 2,311kWh/m^2 per annum at module level
Tracker: Approx. 7,000
Type: City Solar system
Ground area: Approx. 1,000,000m^2 (approx. 142 football pitches)
Solar modules: Approx. 70,000 pieces
Manufacturer: Canadian Solar, Inc.
Electricity production: Approx. 28,000,000kWh per annum (requirement of more than 11,200 average households)
CO_2 avoidance: Approx. 22,400 tons per annum (over 25 years: approx. 560,000 tons)
Completion date: July 2008

Location: Alconchel (Province Badajoz, Spain)
Nominal power: 10MWp
Global radiation: 1,937kWh/m^2 per annum at module level
Ground area: Approx. 250,000m^2 (approx. 35 football pitches)
Solar modules: Approx. 59,530 pieces
Manufacturer: Conergy AG
Electricity production: Approx. 15,500,000kWh per annum (requirement of more than 6,200 average households)
CO_2 avoidance: Approx. 12,400 tons per annum (over 25 years: approx. 310,000 tons)
Completion date: June 2008

Are thin-film modules an obvious choice over Si modules?

"Absolutely. Recently, we entered into a long-term solar module supply agreement with EPV Solar, Inc., a leading thin-film solar module manufacturer and photovoltaic systems provider headquartered in New Jersey, USA. The framework agreement allows us to purchase 250MW of amorphous silicon modules over a period of five years. We use EPV modules to further execute our profitable growth strategy in Europe. A first 2MW project with EPV modules will be realized in Germany by the end of 2008."

What is next for City Solar?

"At the moment we are in the final phase of the big 15MWp Tracker project in Mahora (Spain), which will be finished in July. Moreover, we realized another two big ground-level power plants in Spain (7.5MWp in Yecla and 10MWp in Alconchel). So currently, City Solar has connected to the grid projects with capacity of more than 81MWp. Further markets are Italy and Greece: in Italy, we will build two projects by the end of this year; Greece will start in 2009."

With City Solar moving into thin-film modules and large players like juwi already using CdTe thin-film modules from First Solar, it seems clear that the future of the power generation segment of the solar industry will become increasingly about scale.

Outlook for Solar power generation

In Spain, more power was installed during the first six months of 2008 than in the entire 12 months of 2007. 2008 has also marked a milestone with the first MW PV plants being put into service in Greece and the Czech Republic.

The average growth rate for large PV installations over the past two years has been 100%. Significant growth is expected in the use of thin-film technologies and the French, Greek and Italian market sizes for power generation. The remainder of 2008 and the first half of 2009 will form another vital step in the adoption of solar power for energy generation.

Acknowledgements

The contributions of Denis Lenardic of PV Resources, Stephan Brust of City Solar AG, and Paula Mints, Navigant Consulting Inc. PV Services Program are greatly appreciated. Photos courtesy of City Solar AG.

Figures for the size of the power generation market are drawn from data provided by Denis Lenardic at www.pvresources.com. All information based on statistics of approximately 1150 PV plants with 200KWp or greater capacity.

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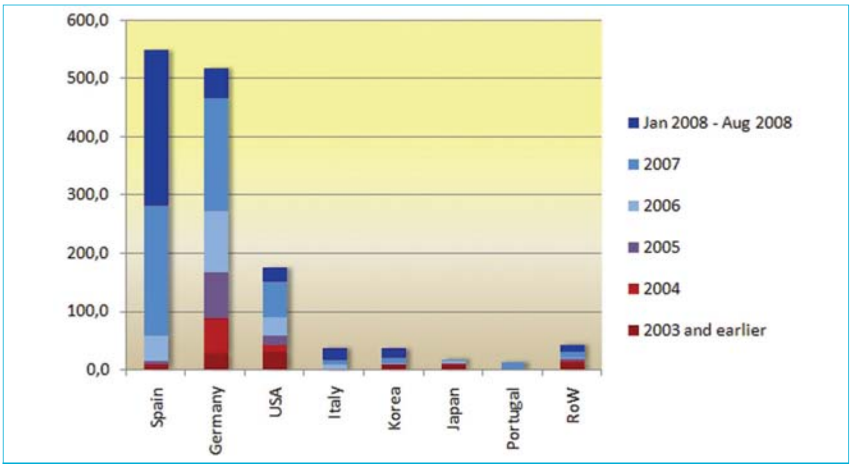


Courtesy of Denis Lenardic, www.pvresources.com.

Figure 3. Cumulative installed power by region.

Crystalline silicon technology	Thin-film technology
• Crystalline silicon cells are made from thin slices cut from a single crystal of silicon (monocrystalline) or from a block of silicon crystals (polycrystalline).	• Thin-film modules are constructed by depositing extremely thin layers of photosensitive materials onto a low-cost backing such as glass, stainless steel or plastic.
• Efficiency ranges between 12% and 17%. This is the most common technology representing about 90% of the market today.	• Thin-film manufacturing processes result in lower production costs compared to the more material-intensive crystalline technology, a price advantage that is currently counterbalanced by substantially lower efficiency rates (from 5% to 13%).
• Cost of running power plants with crystalline technology: 73% modules, 27% BOS (DC-Cables, engineering, substructure, installation, inverters).	• Cost of running power plants with thin-film technology: 52% modules, 48% BOS (DC-Cables, engineering, substructure, installation, inverters).

Competing technologies for PV power generation.

Market Watch

News

Photovoltaics industry to produce 12GW by 2010, says iSuppli

With the photovoltaic industry growing at a compound annual growth rate of 40 percent through 2010, iSuppli Corp. is projecting that the global production of PV cells will reach 12GW by 2010, up from 3.5GW in 2007. To reach that figure, as many as 400 production lines with at least 1MW of PV cell production per year will be established, a four-fold increase from about 90 to 100 production lines in existence at the end of 2007, iSuppli said. Importantly, iSuppli sees the number of 1GW scale fabs to grow as part of the photovoltaic industry's cost reduction strategies.

"The market for PV cells is estimated to grow by 40 percent annually until 2010, and 20 percent beyond," said Dr. Henning Wicht, Senior Director and Principal Analyst, MEMS and photovoltaics, for iSuppli. "Nearly all market participants plan to increase their sales by a Compound Annual Growth Rate of 40 to 50 percent during the next few years."

The need for a four-fold increase in the number of production facilities will require PV manufacturers to spend an average of US$500 million or more on each facility. The result will be the need for as many as 1,000 employees per facility. Annual revenues per fab will top US$1 billion, according to Dr. Wicht.

He noted that at this level of capacity expansion and fab investment through 2010, the photovoltaic industry will be on par with the semiconductor industry in that timeframe. The semiconductor industry is widely noted as a heavy investor in fabrication facilities and in the technology sector in general.

Constant cost reductions in the PV industry will see grid parity reached in 2012 for regions with high levels of sunshine and in areas of medium sun exposure, grid parity is projected in 2018, iSuppli said.

Industry Trends and Forecasts News Focus

North America-based PV equipment sales to reach US$1.2 billion in 2014

North America-based solar cell equipment manufacturers are projected to see sales top US$1.2 billion by 2014, up from US$260.2 million in 2007, according to a new report from Frost & Sullivan. The high cost of polysilicon has dampened PV manufacturers' capacity expansion plans in recent years, which has reduced the potential value of equipment sales, Frost & Sullivan said.

"Polysilicon prices are as high as US$200 per kilogram since silicon, which forms the base substrate for most solar modules, is currently experiencing heavy shortage," notes a Research Analyst with Frost & Sullivan. "The dearth of raw materials is preventing many manufacturing plants from operating at 100 percent capacity, driving up the prices of solar modules and hence, deterring potential investors."

The rapid increase in the number of thin film manufacturers, especially based in North America, means that equipment sales should grow rapidly in the coming years. Frost & Sullivan noted that 1W of power currently costs approximately US$1.75 to US$5, while thin-film substrates will help bring down the prices to a more acceptable US$1.3/W by 2012.

Thin-film PV revenues to exceed US$12 billion in 2013

A new NanoMarkets report projects significant revenue growth for thin-film photovoltaics manufacturers over the next seven years. According to the market research firm, the thin-film photovoltaics market will grow from US$2.4 billion in revenues projected for 2008 to over US$12 billion in 2013. The market is set to almost double by 2015, reaching US$22 billion, according to NanoMarkets.

US$20 billion could be invested in CSP energy through 2012

Market researchers at EER believe that the global Concentrated Solar Power (CSP) market is undergoing a renaissance that could see investments reach US$20 billion over the next five years.

According to EER, 2007 was a pivotal year for solar CSP development as both Acciona and Abengoa have inaugurated 65MW of parabolic trough and 11MW of central receiver technologies, respectively.

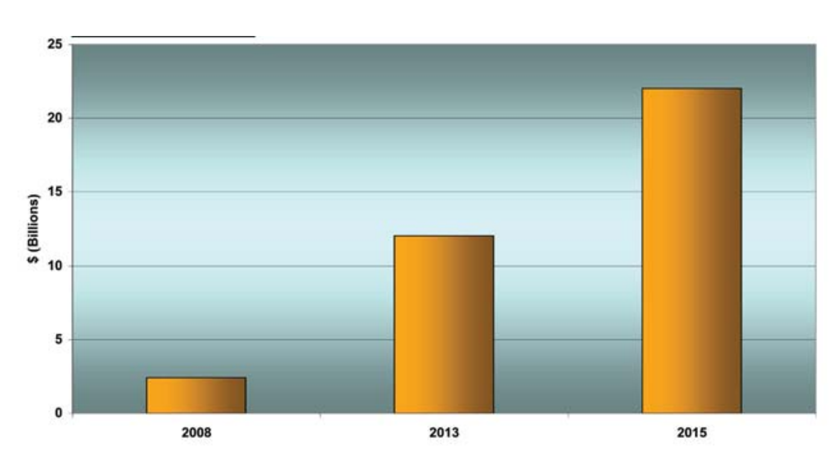
EER claims that there are currently over 5,800MW of solar CSP projects in the planning stages worldwide. Significantly, EER estimates that there is almost 6GW in the project pipeline for the use of parabolic trough technology through 2012.

IMS Research anticipates 40% growth in solar inverter market in 2008

IMS Research, a market research company for the electronics industry, has claimed that its figures indicate a more than 40% growth rate in the solar inverter market. The growth is being driven primarily by demand from Germany and Spain, but a slowdown in these two countries could contribute to a slowdown in growth for 2009. Data for this study were obtained from sales figures of leading solar inverter suppliers.

Estimated revenue of more than US$2 billion is expected in the industry by 2010, with the three-phase central inverter market expected to perform well over the next five years. This expansion will be a result of installation of an increasing number of large-scale PV plants, and the continued popularity of domestic and small-scale commercial systems.

"By the end of 2008, the global PV inverter market will have more than doubled from its 2006 size," said Research Director, Ash Sharma. "Demand is still very high for solar inverters, however with cuts in tariffs in Germany already agreed and uncertainty in Spain, market growth in 2009 will be very much dependent upon what happens to module pricing."



NanoMarkets: revenue growth for thin-film photovoltaics manufacturers.

BIPV market grew 33 percent in 2007

Frost & Sullivan believes that the Building Integrated Photovoltaics (BIPV) market is set for continued growth in the coming years but will need to resolve issues over aesthetics and finance and overall ownership. The market research firm said that the whole photovoltaics market saw sales of €6.24 billion in 2007, resulting in a growth rate of 46 percent. The emerging BIPV market saw sales of €149 million, an annual growth rate of 33 percent.

With Europe at the forefront of solar energy adoption, Sivanandan believes that the BIPV market will continue to grow in that region using both conventional crystalline solar cells as well as thin-film technologies.

Global thin-film production output to reach 3.5GW in 2010

In a new market research report from EuPD Research, global thin-film production output will reach 3.5GW in 2010. According to EuPD Research, only 20 percent of the 120 thin-film entrants will be able to start commercial PV thin-film production before 2010, while less than 50 percent of the 60 companies that have announced their intention to start commercial thin-film production by 2010 will actually meet their schedules.

An increase in the number of thin-film manufacturers will lead to tougher competition, especially as some markets will be maturing in the coming years. The report claims that thin-film technologies could reach grid parity in Europe between 2012 and 2016.

Solar to provide 10% of U.S. electricity by 2025 – study

A new study by clean tech research publisher Clean Edge and Co-op America, a non-profit green-economy organization, has suggested that the U.S. could attain production of 10% of its electricity requirements via solar power by the year 2025. The Utility Solar Assessment (USA) study provides a roadmap for use by utilities and regulators, as well as solar power companies, which outlines the necessity for involvement of utilities in scaling solar power in order to reach the 10% goal.

The study claims that solar power should be viewed as a cost-effective measure of electricity generation that can rival current electricity costs while steering away from the use of fossil fuels that are becoming more and more costly every day. The data in the study were compiled based on interviews with more than 30 solar, utility, financial, and policy experts.

Projections for solar energy prices are expected to decline from an average US$5.50-$7.00 peak watt (15-32 cents kWh) today to US$3.02-$3.82 peak watt (8-18 cents kWh) in 2015. A further decrease in cost to US$1.43-$1.82 peak watt (4-8 cents kWh) is anticipated by 2025, according to the study.

A comprehensive 'to-do' list was provided for each of the players (utilities, solar companies, regulators), outlining the steps that need to be taken by each in order to contribute to the combined effort and thereby to achieve the 10% goal by 2025.

Fab & Facilities

Materials

Cell Processing

Thin Film

PV Modules

Power Generation

Market Watch

The photovoltaics industry: against all odds, strong growth continues

Paula Mints, Navigant Consulting, Inc., Palo Alto, California, USA

ABSTRACT

The photovoltaic industry was once, and for quite some time, the unappreciated renewable technology. Perceived as too expensive without subsidies to reduce the price of ownership, and sometimes as an energy choice primarily for environmental zealots, the industry has continued, nonetheless, to grow at a compound annual rate of 34% over the past 30 years. Growth at this rate would be envied by any industry, and certainly deserves recognition, particularly as it has come with significant problems and has been extremely difficult to achieve. Now, with worldwide consensus on global warming along with sufficient evidence that fossil fuels are rapidly depleting, solar electricity is finally earning some respect – but the industry still has perception problems to solve.

Introduction

There are some who hold the view that the technology is too expensive – and, considering the price of a system to the end user (i.e., its capital cost), it is difficult to argue this point. Solar systems are expensive. However, when the rising cost of energy and the cost of environmental damage are factored into the system price, it becomes more reasonable.

The PV industry indeed enjoys strong growth, but there are obstacles to overcome. To render systems more affordable, the PV industry continues to require incentives (direct subsidies, capacity and production rebates, feed-in tariffs and tax incentives). The industry also needs manufacturing and research subsidies and incentives, in much the same way as do all industries and technologies. In this regard, it is important to remember that all utility electricity (even that produced with fossil fuels) is subsidized at some point in its chain. Further, solar electricity is clean, renewable energy, whereas conventional energy carries a carbon cost that remains unaccounted for.

Growth in the PV industry

Table 1 offers the compound annual growth rates (CAGR) for the PV industry for the past 30 years, 20 years, 10 years and the last five years.

In the case of PV industry growth, the CAGRs correctly indicate that the industry has experienced extraordinarily strong growth over 30 years. However, compound annual growth ignores yearly changes, and so, fails in the end to tell a complete story.

30-Year CAGR 1977-2007	34%
20-Year CAGR 1987-2007	27%
10-Year CAGR 1997-2007	39%
5-Year CAGR 2002-2007	44%

Table 1. PV industry compound annual growth rates.

Table 2 offers an insight into PV industry growth on an annual basis.

The industry saw 100% growth in 1978 over 1977, but from a very small base – 500kW in 1977 to 1MWp in 1978.

> Despite the odds against strong growth, PV industry demand continues climbing an extremely steep upward demand curve.

In 1983, the industry grew by 88% over 1982, with growth slowing to 21% in 1984. Strong growth in 1997, the year that industry demand grew by 38% to top 100MWp for the first time, was followed by 18% growth in 1998. Since 2000, however, annual industry growth has consistently been >30%.

Figure 1 offers a picture of industry growth from 1977 through 2007. The industry long expected a 'hockey puck' demand curve and has achieved its aim. Despite the odds against strong growth, PV industry demand continues climbing an extremely steep upward demand curve.

Recently, the PV industry's strong growth has attracted significant investment and media attention. Much of this attention is good; the industry needs continuing R&D investment as it works on continuing technology and manufacturing developments. Industry success is also inviting professionals from other industries such as software and semiconductor to join the solar industry. New business models are emerging that remove the paradigm of buying a solar system to buy electricity. Not all electricity customers will want to own their own means of production, but, as they all understand renting electricity, it begs the question: why not rent it from a clean source? Volume and success have

Year	MWp	% Annual Change	Year	MWp	% Annual Change
1977	0.5		1993	55.7	3%
1978	1.0	100%	1994	61.0	10%
1979	1.5	50%	1995	71.5	17%
1980	3.3	120%	1996	82.6	16%
1981	5.3	61%	1997	114.1	38%
1982	7.7	45%	1998	134.8	18%
1983	14.5	88%	1999	175.5	30%
1984	17.5	21%	2000	252.0	44%
1985	19.4	11%	2001	352.9	40%
1986	21.0	8%	2002	504.9	43%
1987	24.9	19%	2003	675.3	34%
1988	31.5	27%	2004	1049.8	55%
1989	37.9	20%	2005	1407.7	34%
1990	42.7	13%	2006	1984.6	41%
1991	48.2	13%	2007	3073.0	55%
1992	54.1	12%			

Table 2. PV industry annual growth rates (1977–2007).

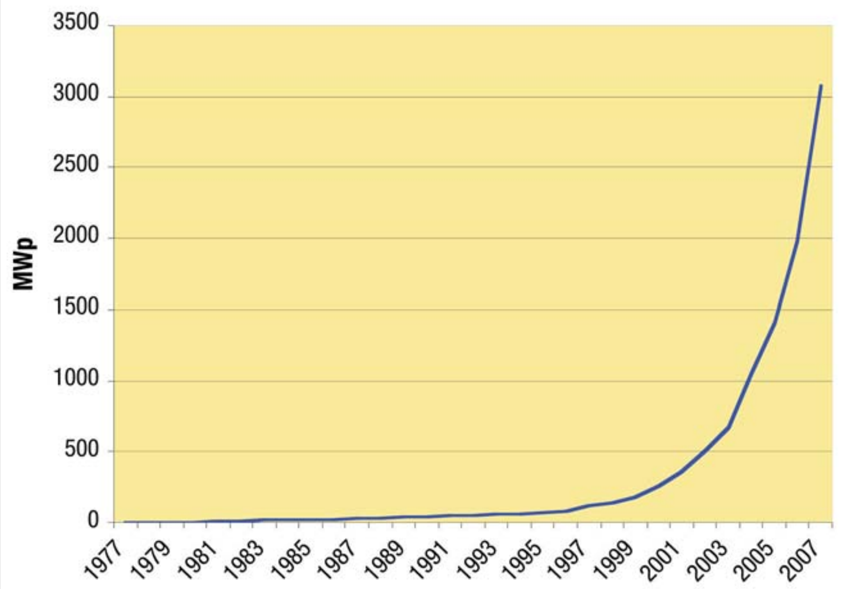


Figure 1. PV industry growth (1977-2007).

brought with them creative business ideas that may someday match the creativity of the technology itself.

Steep upward growth is expected to continue. Figure 2 presents a conservative and an accelerated forecast for PV industry growth from 2007 through 2012. For the conservative scenario, the CAGR for the five-year forecast is expected to be 35%. The CAGR for the accelerated forecast is expected to be 51%.

Since 1970, 10326.6MWp (10GW) of solar electricity has been installed globally into all applications and for all customer types. Ninety percent of this was installed from 2000 to 2007, and 73% was installed from 2004 to 2007. The situation in 2004 saw most technology manufacturers break even for the first time, and in some cases, make profit for the first time. The terrestrial PV industry is more than 30 years old, and has been profitable for about four years. Europe and its mighty feed-in tariff is the driving force behind the industry's success.

The role of incentives and the future of solar electricity

There is no doubt that the feed-in tariff model, which provides a pure economic incentive to buy a solar system, has proven to be the most successful market stimulus for the PV industry. Japan's capacity-based incentive stimulated a strong market until its cessation, but Germany's feed-in tariff kick-started industry demand, resulting in unexpected volumes of demand. The feed-in tariff incentive model, in its pure (and currently changing) form, allows the system owner (or system investors) to profit from ownership in what amounts to a two-year annuity payment.

From 2002 through 2007, Germany experienced a phenomenal 61% compound annual growth in demand for PV products. Without a doubt, it can be said that in 2004, 2005, 2006 and 2007, demand in Germany drove the global market for PV products. Other countries in Europe have patterned programs on the German model. At this juncture in PV industry history, Europe represents more than 70% of total industry demand. Figure 3 presents regional PV industry growth from 2002 through 2007.

Europe's successful feed-in tariff programs are expensive, and need controls to render them manageable. Otherwise, the very programs that are stimulating demand threaten to become too expensive to continue in the long term. In this regard, Spain is a perfect example. Spain is the strongest global market in 2008, but its program ends this September and the government is considering the implementation of an annual cap. Given that demand in Spain for 2008 is ~1500MWp, a 500MWp cap for 2009 and beyond would come as a blow to the industry. Regardless, Europe will continue to be the strongest global market for solar products for quite a few years.

Programs must be put in place to help build an economically sustainable PV market, while enabling the manufacturing sector to develop needed efficiencies and cost-cutting techniques.

At this point in U.S. PV market development, incentive programs, net metering and clear interconnection standards are necessary for the U.S. grid-connected market to thrive and, frankly, to survive. These programs (and in particular, the federal tax incentive) are also necessary for the power purchase agreement model (PPA) to function profitably and at lower risk for investors. Programs must be put in place to help build an economically sustainable PV market, while enabling the manufacturing sector to develop needed efficiencies and cost-cutting techniques. In the future, the net-metering penalty (whereby the system owner is not permitted to profit from the excess electricity fed into the grid, but can only zero out an electricity bill) needs to be changed to encourage larger systems, and more system ownership. Incentives for manufacturing must also be put in place to strengthen the U.S. manufacturing sector. Finally, the utility exemption must be amended or repealed to allow investor-owned utilities (IOUs) and publicly-owned utilities (POUs) to take advantage of the federal tax incentive.

The future of renewable energy credits (RECs) as a system-financing tool in the U.S. cannot be ignored.

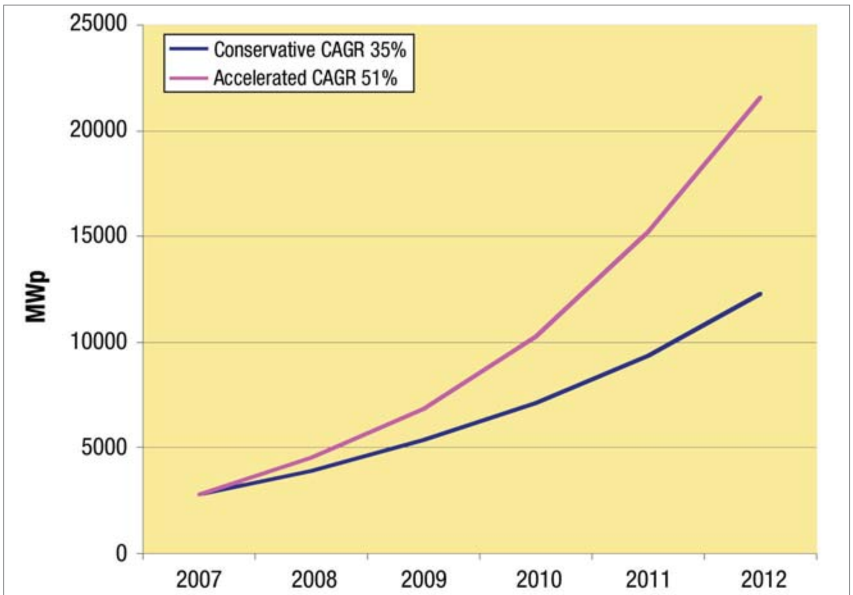


Figure 2. Conservative and accelerated PV industry forecast (2007-2012).

Renewable energy credits can function on their own or as a compliance tool. They are more lucrative as a compliance tool, operating in that regard almost as a performance incentive. As RECs become more common, their usefulness in the incentive mix will become more apparent. At some point, a state could us e RECs to fund its rebates. Many investment groups, some of whom are hoping to profit from a future market for selling solar-generated electricity, are counting on an explosive REC market to help drive profits. However, there is no consistent system in place in the U.S. towards the use of RECs and use of this vehicle remains in the formative stages.

In Japan, the cessation of that country's subsidy program has slowed the market considerably, and the government is considering a new incentive scheme to restart demand.

The market in South Korea is emerging, but remains beset with bureaucratic problems that slow sales of systems to that country. Recent changes to the country's feed-in tariff may limit demand. After October 2008, the feed-in rates change significantly, and in 2012, the country's solar incentive switches to an RPS (renewable portfolio standard)-driven plan that currently does not favour solar electricity. One likely reason for the changes through 2009, the lag, and then the significant change to RPS focus in 2012 is that system and component prices have risen instead of falling. Markets with high demand will tend to drive up prices, a problem for an industry with downward price pressure from governments.

China and India have strong potential to emerge as significant markets, but have yet to exercise this potential because solar electric technologies remain expensive to implement, coal is cheap, and both countries have affordability problems.

In developing countries, the need for photovoltaic technologies to provide electricity to remote houses and villages is great, while the ability of remote populations to afford the technology remains poor.

Solar modules – where are they going?

Solar modules are eventually installed in systems. Systems, however, are sold into applications, to regions, to countries and to end users within all of these sectors. Table 3 provides a brief overview of the applications.

More than 70% of solar modules go to Europe. In the near term, this will continue to be the case. Other markets, including the U.S. market, are still emerging, and will take time to do so. The market in Japan needs to re-emerge. The remainder of solar product goes into the grid-connected application. In 2007, 90% of demand was for grid-connected products. In the near term, this too will continue to be the case. The pie charts in Figure 4 provide an overview of global demand in 2007, by application and by region.

The industrialized and developing world markets for photovoltaic products require financing mechanisms to ensure current and future market growth. In the developing world, unstable economies, poverty, and lack of credit (among other problems) continue to dampen growth prospects. Photovoltaic products are still primarily used for off-grid applications in developing countries, though there is new interest in extending the grid (where possible) to some rural communities. In industrialized countries, subsidies and incentives for the grid-connected application are the primary drivers.

In developing countries, the need for photovoltaic technologies to provide electricity to remote houses and villages is great, while the ability of remote populations to afford the technology remains poor. Problems with supplying these remote areas with PV systems include the inability to afford a system, lack of credit, lack of maintenance, poor or no training, theft, poor administration, and difficulties working with governments. In urban areas of developing countries, conventional utility electricity is often priced below the cost of production, providing an effective barrier to grid-connected PV technologies. One of the biggest problems confronting

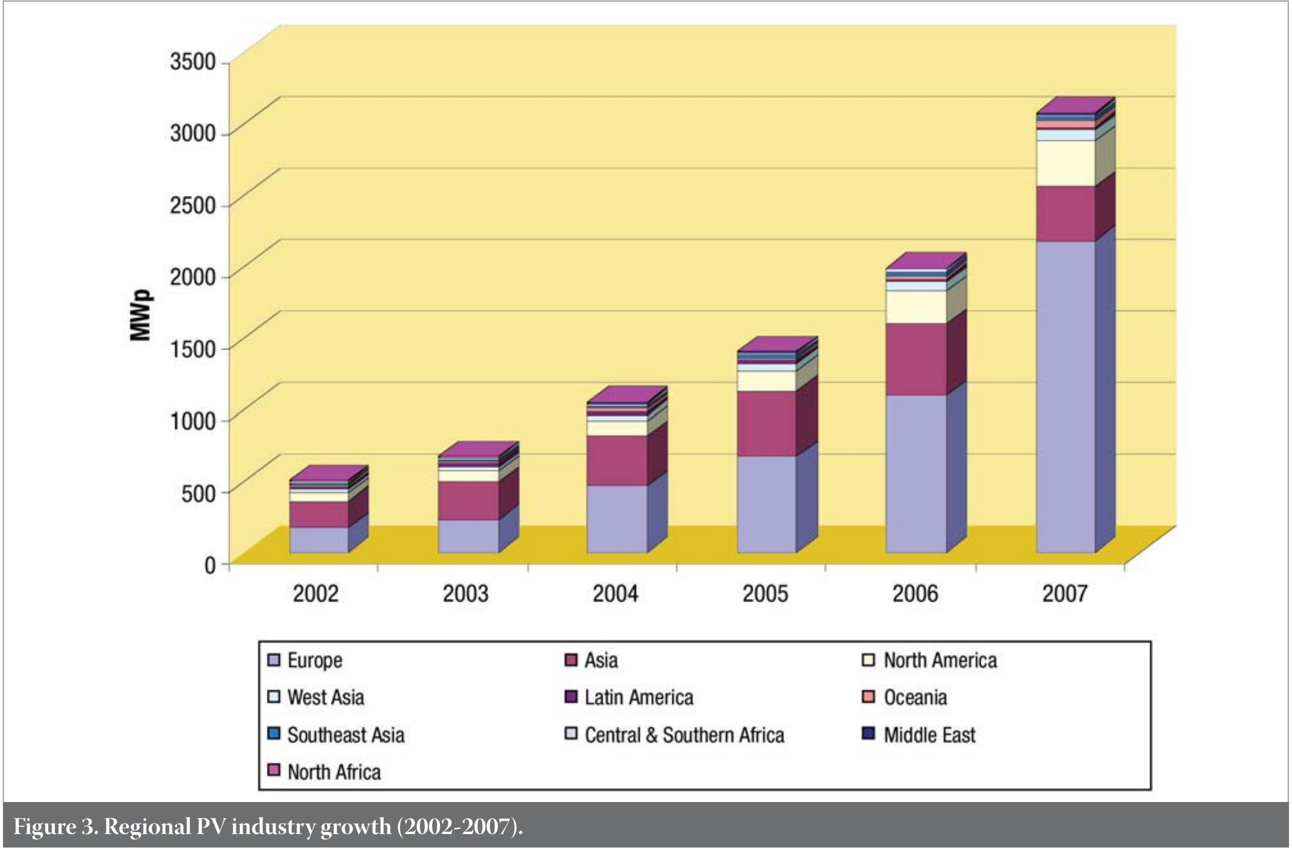


Figure 3. Regional PV industry growth (2002-2007).

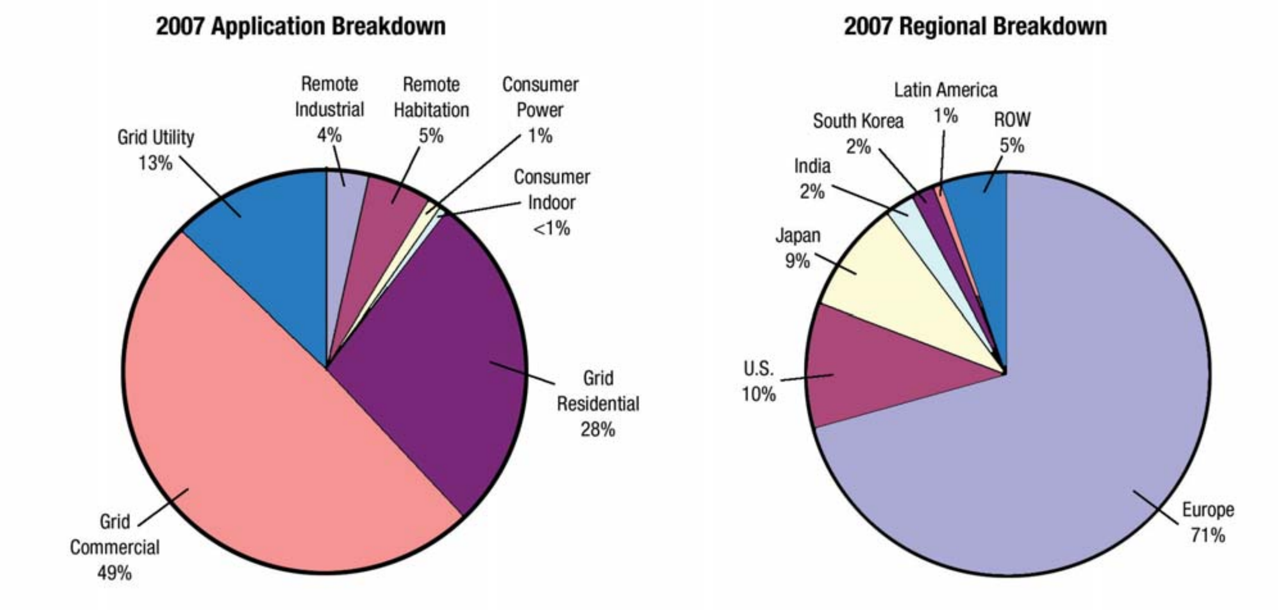


Figure 4. Global demand 2007 – breakdown by region and application (total demand in 2007 was 3073.0MWp).

suppliers of PV to the developing world remains the difficulty of coordinating and working with different government departments. Other problems include graft, lack of a local PV industry, and taxes that increase the difficulty of selling to developing countries (rendering the price of the product beyond local affordability). The current shortage of raw material has recently made sales to the developing world unattractive to manufacturers of product.

At this point, the international solar industry continues to celebrate its strong success and extraordinary growth, while at the same time anxiously looking for the next strong market. As long as this growth remains subsidy-driven, it is also artificial.

One of the biggest problems confronting suppliers of PV to the developing world remains the difficulty of coordinating and working with different government departments.

The industry must continue to lower costs, while convincing all participants along the value chain to lower margins and profits so that a sustainable (long-term) market can emerge.

The grid residential application experienced extremely strong compound annual growth from 1997 onwards. During this time, the original German program, along with Japan and California, were strong drivers for residential system installation. Growth in the grid-residential application slowed in the 2002-2007 period, to a CAGR of 24%. During the forecast period, the residential sub-application is expected to experience strong growth of 36% to 52%, with the high forecast achieved through the development of new business models.

Market Category	Status – Valuation – Reliability	Customer Description
Remote Industrial	• Earliest commercial market	• Most sophisticated customer
	• High credit for economic value	• Requires detailed specifications but lesser systems support
	• Reliability required: high – urgent	
Remote Habitation	• Second market entered in volume	• Least sophisticated customer, in developing countries
	• Medium value and reliability	
	• PV is life-cycle-competitive now	• Most systems support required
Consumer Power	• Established niche markets	• More sophisticated customer in industrialized countries
	• Novelty, portability, and independence from conventional power are key	• Little customer support required
Grid-Connected	• Market penetration continuing, driven by incentive and investment models	• Industrial country consumer
	• Gaining credit for economic value	• Education needed to raise perception of value
	• System reliability required: high	• Ongoing support structure required
	• Lifetime required: long	• Beginning of interest from building industry
		• New investment models changing paradigm from owning means of producing electricity back to renting electricity from an independent source
Consumer Indoor	• 1980s – market entry and saturation	• Broad, global customer base
	• Economic value: non-issue	• Little customer support required
	• Reliability, life required: low	• Short lifetime expected

Table 3. Photovoltaic application segment overview.

Driven by feed-in tariff laws in Europe, and the PPA model in the U.S., the grid-commercial application (specifically, installations >1MWp) will continue to experience strong growth. From 1997 to 2002, the grid commercial application grew at a compound annual rate of 36%. From 2002 through 2007, the grid-commercial application grew at a compound annual rate of 116%. For the forecast period, the sub-application is expected to grow at a CAGR of 32% to 48%, with closer to the latter figure assumed.

The model under which utilities purchase solar, particularly in the U.S., is changing. RPS standards in the U.S. and strong growth in Spain are factors driving strong growth in the grid-utility application. In the U.S. RPS, standards with solar set-asides require utilities to produce a percentage of electricity from solar sources. For utilities, it is the cost of the components, not the price of a system, that is the important buying factor. However, some utilities in U.S. states without the RPS requirement are showing interest in PPA installations. A steady decrease in the cost of solar components could encourage stronger use by utilities.

The grid-utility application grew at a compound annual rate of 22% for the 1997 to 2002 period. The sub-application experienced compound annual growth of 110% from 2002 to 2007 because of strong growth in 2007, primarily into Spain. In 2007, over 2006, the grid-utility application grew by 1642%. For the forecast period, the sub-application is expected to continue at strong compound annual growth of 42% to 59%.

For remote applications, though affordability is still an issue, the cost – or simply the possibility – of extending the grid to remote populations far outweighs the cost of the PV system.

The grid-connected application is the largest and fastest growing of all of the photovoltaic market segments, with an 80% share of global volume in 2004, an 82% share in 2005, an 86% share of total volume in 2006, and a 90% share of total volume in 2007. Clearly, this incentive-driven trend is here to stay. The fastest growing sub-segment of this application is large (>1MWp) field and roof installations.

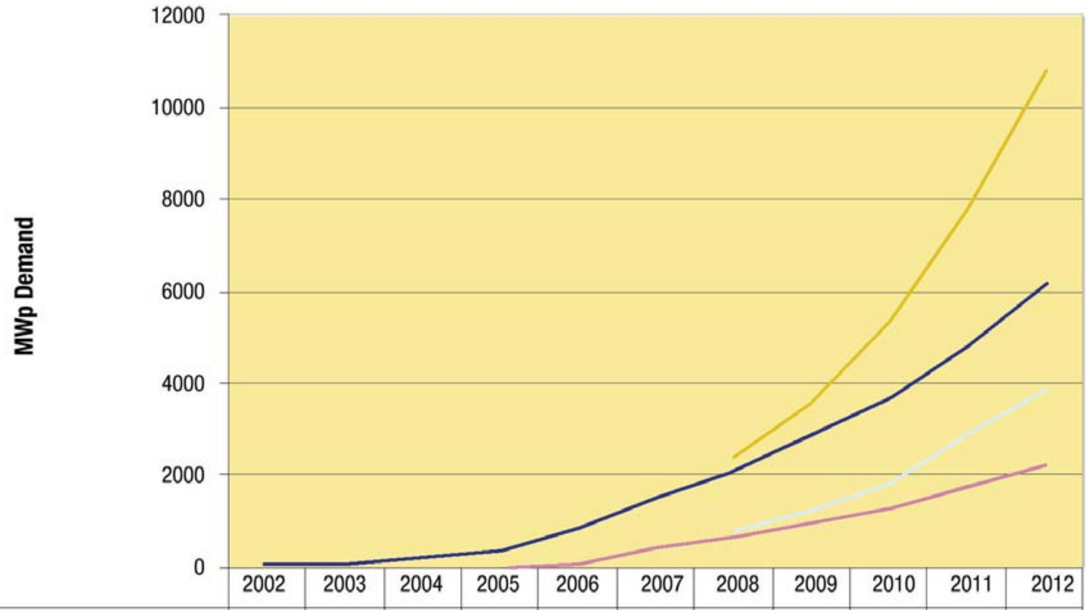
Table 4 provides a history of grid-connected application growth and clearly illustrates that success for the grid-connected application has not been easy, nor has it been seamless. In the beginning, the majority of grid-connected installations were government or utility demonstrations with no real commitment to investing in the technology. In 1983, a year of several demonstration projects, the application grew by 213% over the previous year, had a 50% share, for a total of 7.5MWp installed. In 1984, growth declined by 21% and the application had a 34% share. In 1990, the application grew by 200% over the previous year, and had an 8% share of total application sales (meaning that off-grid applications had a 92% share). In 1995, growth into the grid-connected application declined by 22% after growing by 197% the previous year.

	Grid-connected MWp	% Yearly Change	% Total Demand
1982	2.4	55%	31%
1983	7.5	213%	50%
1984	5.9	-21%	34%
1985	4.1	-30%	22%
1986	1.7	-59%	8%
1987	1.0	-41%	4%
1988	1.6	58%	5%
1989	1.1	-28%	3%
1990	3.3	200%	8%
1991	3.9	18%	8%
1992	3.8	-2%	7%
1993	3.9	3%	7%
1994	11.6	197%	19%
1995	9.0	-22%	13%
1996	11.6	28%	14%
1997	38.8	235%	34%
1998	41.8	8%	31%
1999	68.4	64%	39%
2000	128.2	87%	51%
2001	209.7	64%	59%
2002	338.3	61%	67%
2003	484.2	43%	72%
2004	838.2	72%	80%
2005	1161.2	40%	82%
2006	1707.2	47%	86%
2007	2762.9	62%	90%

Table 4. Grid-connected yearly application growth and percentage of total demand (1982-2007).

Year	Total MWp	Off-Grid	Grid-Connected	Consumer Indoor
	Worldwide	% Total	% Total	% Total
1992	54.1	88%	7%	5%
1993	55.7	88%	7%	5%
1994	61.0	76%	19%	5%
1995	71.5	82%	13%	5%
1996	82.6	81%	14%	5%
1997	114.1	62%	34%	4%
1998	134.8	65%	31%	4%
1999	175.5	58%	39%	3%
2000	252.0	47%	51%	2%
2001	352.9	40%	58%	2%
2002	505.0	30%	67%	2%
2003	675.4	27%	72%	1%
2004	1049.8	19%	80%	1%
2005	1407.7	17%	82%	1%
2006	1984.6	14%	86%	<1%
2007	3073.0	10%	90%	<1%

Table 5. Application trends (1992-2007).



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Commercial Conservative	32.5	51.3	235.3	345.6	848.1	1519.6	2069.7	2802.4	3699.3	4789.1	6150.8
Utility Conservative	9.5	6.8	8.4	8.5	22.2	386.8	663.9	970.1	1280.5	1784.2	2214.3
Commercial Accelerated							2416.8	3557.6	5336.8	7748.8	10788.3
Utility Accelerated							775.2	1231.5	1847.3	2886.8	3883.8

Figure 5. Grid-connected application forecast (2002-2012).

In 2000, the grid-connected application grew by 87% and had a 51% share of application sales, a trend that has continued leading to the >90% share that the application enjoys in 2008.

The current trend is to large-field or utility-scale applications where an investor group installs >1MWp of PV, and sells the electricity to an end user, or end users. This trend is expected to continue to dominate application sales. Figure 5 observes growth into the commercial and utility grid-connected applications from 2007 through 2012. Business models that do not require system ownership have accelerated the already strong growth rate of the grid-commercial application, and stimulated the utility-grid application.

> In recent years, the current high volume of industry demand, coupled with raw material shortages, presented a new challenge to the industry.

The remote applications (habitation, industrial, consumer power) are cost effective without subsidies – and have been for years. For remote applications, though affordability is still an issue, the cost – or simply the possibility – of extending the grid to remote populations far outweighs the cost of the PV system. This does not mean that affordability is not an issue; simply that conventional utility electricity may not be possible.

For many years, the PV industry was dominated by the remote application. Table 5 provides data on application trends from 1992 to 2007. In 1992, grid-connected applications were 7% of total demand. By 1997, grid-connected applications were 34% of total demand, and now make up 90% of global demand.

Conclusion

The PV industry remains beset by many obstacles: the continuing (expensive) need to invest in R&D, the need to reduce manufacturing costs and increase efficiency (common issues for thin-film and crystalline technologies), downward price pressure forced upon the industry by its need for incentives, constant anxiety that incentives will end before sustainable demand is obtained, too little capacity to meet demand, too much capacity and, as a result, under utilization, competition from other energy sources and most difficult of all, higher expectations that the industry needs to meet.

In recent years, the current high volume of industry demand, coupled with raw material shortages, presented a new challenge to the industry. Unfortunately, with a significant amount of new capacity coming on line in the next few years, there may be a fresh set of obstacles to be overcome.

The industry faces many challenges, coupled with a wealth of success stories to prepare it for the battle. And with the world now viewing solar as a mainstream energy choice, this battle is almost won. The energy future is a renewable one, and it is looking as if solar electricity will be a major part of that future.

About the Author

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