Seventh Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS

REC Wafer and SINTEF improve cell efficiencies in our wafering focus

Fraunhofer ISE: overcoming challenges in back-side metallization

Moser Baer scales single-junction a-Si from 6% to 7% stable efficiencies

SEPA examines utility solar business models that are changing future energy

EPIA provides in-depth analysis of feed-in-tariff schemes

First Quarter, February 2010

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Photovoltaics International

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Front cover shows monocrystalline ingots. Picture courtesy of REC Group.

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Publisher's foreword

German market steadies growth while new opportunities abound.

The past three months have been dominated by the continually looming shadow over the German FiT caused by recent political change. Protesters from among the German solar industry have managed to force the government to push back 15% of the cuts to the solar feed-in tariff to June or July. The German market has consistently driven growth in the solar industry, and so any changes are keenly monitored by the rest of the world.

Even though the clouds are currently hovering over the German market, the outlook looks brighter for others. The USA (p. 152) could double installations this year led by a resurgence in the utility segment now that funding has become more available. With 50% of Italy's market comprised of BIPV installations, the market for building-integrated solar projects is set to grow significantly with reports of grid parity in Sicily, according to **GIFI** (p. 167). Japan's new government has done wonders for the industry so far (p. 171) with over 484MW of domestic solar shipments, representing 21% growth year-on-year.

Another ray of sunshine appeared when the United Kingdom (p. 171), one of the last mature western economies not to have a feed-in tariff, announced the generosity of their incentive scheme set to start on April 1st. The tariff is set at GBP£0.41/kwh (almost €0.47/kwh) and IMS research has already forecast a market of 250MW in 2011.

Many of you already know that our headquarters are based in London, and over the past couple of years I have been involved in encouraging the domestic market in the UK. Should your organization be looking to enter the UK market, I encourage you to get in touch with us so that we can help point you in the right direction.

As the solar industry looks optimistically ahead to 2010, we have collected some of the best technical information and analyses for you to help guide your strategic decisions through the year. In this issue:

Applied Materials has acknowledged (p. 96) that amorphous silicon thin films are coming under tremendous cost pressures from the rapid decline in ASPs (Average Selling Prices) of their crystalline counterparts. In this issue we get our first technical look at what a-Si manufacturer **Moser Baer** (p. 101) is doing to increase the company's competitiveness in the market.

Our wafer feature comprises of two important papers looking at ways to increase cell efficiencies. The first by **REC Wafer** (p. 45) applies extensive characterisation to the wafering process, while the second from **SINTEF** (p. 49) covers the importance of heat transference.

2010 marks the beginning of a new decade in which we will see the manufacture of photovoltaics moving more and more towards China. In response to this emerging trend, *Photovoltaics International* is now producing content in Mandarin to better serve our Chinese audience. From February onwards, we are issuing a weekly e-newsletter in Mandarin as well as providing news through our web portal www.pv-tech.org. And for the first time ever, during this year's SNEC in Shanghai in May, we will be distributing our first ever *PVI Lite* supplement in Mandarin reviewing some of the best technology used in the PV supply chain.

We are looking forward to the rapid market developments and the challenges of keeping you up-to-date on the solar industry in 2010. As always, we welcome any and all feedback and I hope to see you in Shanghai at our booth this coming May.

Sincerely,

David Owen
Photovoltaics International

Photovoltaics International

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

Editorial Advisory Board

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

Gerhard Rauter, Chief Operating Officer, Q-Cells SE

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

Takashi Tomita, Senior Executive Fellow, Sharp Solar

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

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

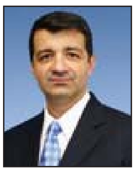
Dr. Kuo En Chang joined Motech in 1999 as Chief Technology Officer and became President of the Solar Division in 2008, with responsibility for all technology and manufacturing. Motech is the sixth largest solar cell producer in the world. Before Dr. Chang joined Motech Solar, he worked on secondary battery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

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

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

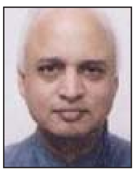
Dr. Zhengrong Shi, Chief Executive Officer, Suntech

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



Dr. John Iannelli, Chief Technology Officer, Emcore Corp

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

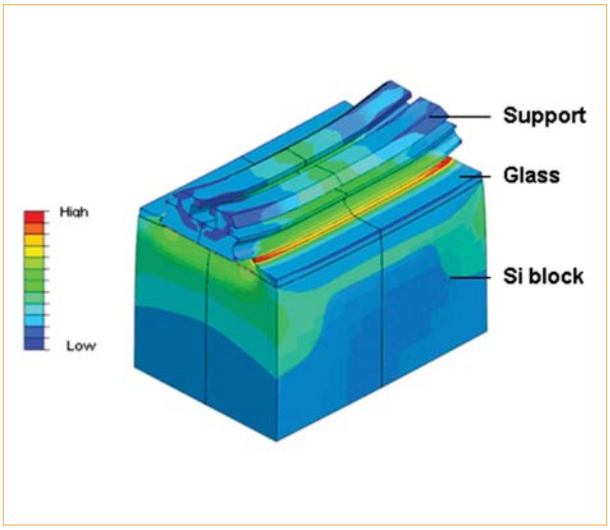


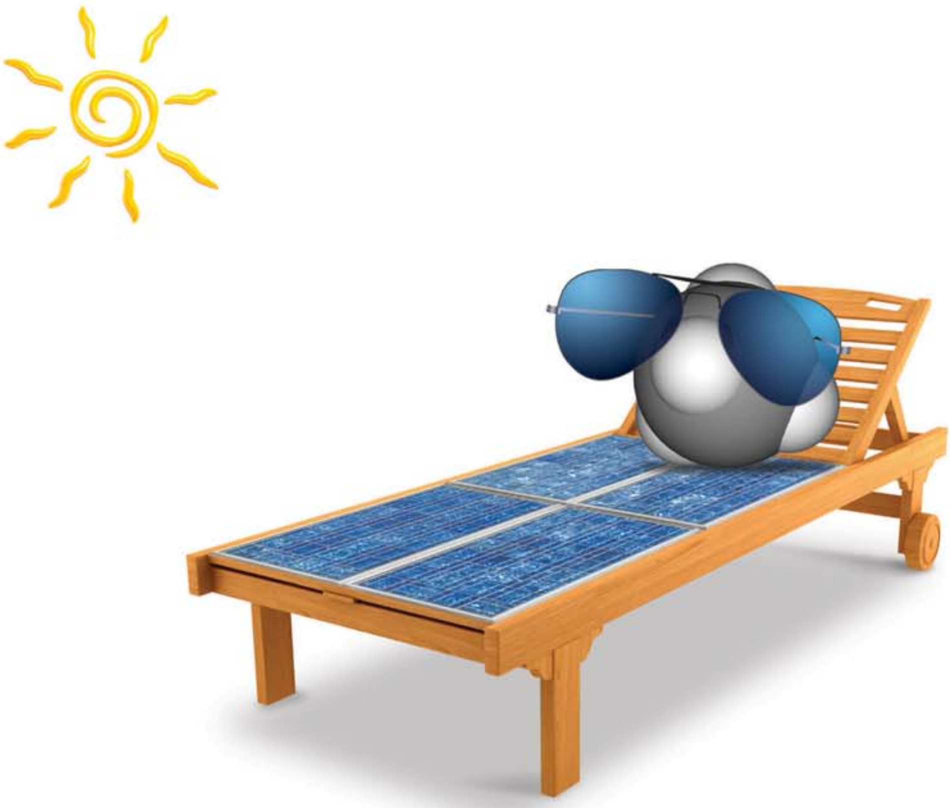
Dr. G. Rajeswaran, President and CTO of Moser Baer Photovoltaic Ltd

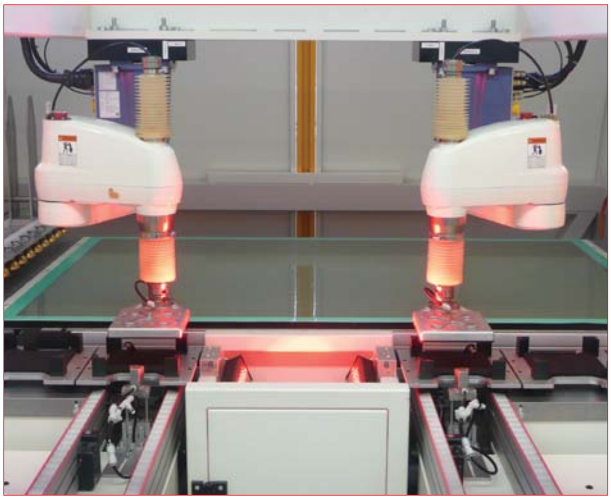
Raj served as President and CTO of Moser Baer Photovoltaic Ltd. from July 2007 until October 2008, since which time he has been Group CTO for all the Moser Baer business units and holder of the CEO function for launching new businesses. He spent 22 years with Eastman Kodak Company as the Vice President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

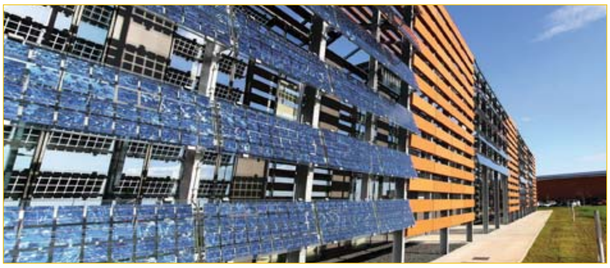
Contents

Photovoltaics International



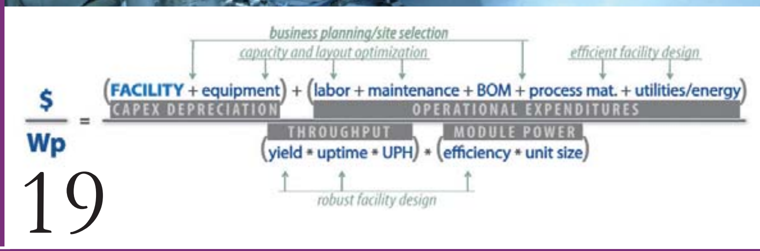






Fab and Facilities

Courtesy of DuPont Apollo



News

DuPont opens new PV applications lab in Geneva

With the intention of speeding up the introduction to market of new innovative products for the photovoltaics industry, DuPont has opened the Meyrin Photovoltaic Application laboratory at its European Technical Center in Geneva, Switzerland. The lab will operate as an open centre, enabling technological exchanges and research collaborations between DuPont and customers, industrial partners, institutes and academia.

DuPont said that the lab is designed to advance state-of-the-art solar module design and deliver cost-effective, high-performance solutions for the photovoltaic industry.

"Addressing energy needs is a global concern. The generation and storage of renewable energy will be the fastest growing sector in the energy market for the next 20 years," said DuPont Chair and CEO, Ellen Kullman (pictured). "We can apply the power of our market-driven science to offer products and technologies that can transform the sun's potential into clean energy, contributing to decreasing dependence on fossil fuels."

Courtesy of DuPont.

DuPont's President and CEO Ellen Kullman.

DuPont's Meyrin Photovoltaic Application Laboratory at its European Technical Center in Geneva, Switzerland.

Capacity News Focus

Suntech selects City of Goodyear, Arizona as first U.S-based module plant location

The town of Goodyear, west of Phoenix, Arizona, will be the location of Suntech's first U.S.-based solar module manufacturing plant. An existing building will be used, speeding up the schedule for the start of manufacturing, which is planned for September. The plant will start out with an annual capacity of 30MW but can be scaled to over 120MW, the company said. Initially 70 local jobs will be created. Suntech will become the first China-based solar producer to locate and operate a plant in the U.S.

Suntech said that the plant will use the latest equipment and technology and be an innovation hub for U.S.-centric modules. The announcement was made during the AZ4Solar Symposium on January 27th.

DuPont's Tedlar films form the main component of photovoltaic backsheets.

DuPont invests a further US$175 million to complete Tedlar production line

DuPont has announced an additional investment of US$175 million to complete the multiphase expansion of its Tedlar PV2100 series-oriented film production line. Added to the investment of US$120 million in capacity expansions announced by the company in August 2009 for raw materials used to make the film, this brings the total investment to US$295 million.

The film line expansion will be located at the DuPont Circleville, Ohio facility using existing and retrofitted assets. With film production scheduled to start in September 2011, this expansion provides the capacity to support global demand of over 10GW of PV module production.

DuPont also plans to increase monomer and polymer resin capacity by more than 50%. Construction is underway for the new monomer and resin facilities at the DuPont Louisville, Kentucky, and Fayetteville, North Carolina, sites, respectively. Both facilities are scheduled to start up in mid-2010.

Confluence Solar's monocrystalline ingots.

Confluence Solar to build US$200 million ingot plant in Tennessee

Single crystal substrate start-up Confluence Solar is to build a solar silicon ingot plant on a 25-acre site in Clinton, Tennessee at a cost of US$200 million. The company claims that its 'HiCz' single crystal ingot-growing technology offers 15% better cell conversion efficiencies but at a cost comparable or better than using multi-crystal silicon ingots. Tennessee is fast becoming a hub for polysilicon producers with new plants being built by Hemlock Semiconductor and Wacker Chemie, in the state.

"Two years ago, we set upon a strategy to make Tennessee a significant player in the solar industry," said Governor Bredesen. "Since then, we've seen more than two billion dollars in capital investment and more than a thousand jobs created. The announcement today by Confluence Solar is further proof that Tennessee is being recognized as a leader in renewable energy and that a new economic engine is emerging in our state."

The stealthy start-up initially received funding from VCs of US$12.7 million in September 2008. It also has secured raw material from DC Chemical.

ECD airs plans to build 30MW solar laminate production facility in France

Energy Conversion Devices has announced plans to build a 30MW amorphous-silicon thin-film solar laminate manufacturing facility in France. The company said it has begun its initial site selection process and is evaluating various sites, particularly in the Alsace region. The move comes amid restructuring, production cutbacks, and layoffs at ECD's U.S. production fabs.

Citing France as "one of the world's fastest-growing and most progressive solar markets", ECD president/CEO Mark Morelli said the country "has expressed its long-term support of alternative energy in the 'Grenelle de l'environnement' objectives, and the recent change to its feed-in-tariff structure establishes a sustainable foundation to meet those objectives."

The expected terms of the project – including the anticipated launch date – were not disclosed and are subject to completion, according to the company.

ECD becomes the second thin-film PV manufacturer to recently announce plans to build a factory in France. First Solar and partner EDF Energies Nouvelles said in December that they intend to start construction on a 100MW CdTe facility near Bordeaux during the second half of 2010.

ECD to upgrade equipment at Auburn Hills 1 plant with US$13 million tax credit

Energy Conversion Devices (ECD) is using the US$13.275 million received from the U.S. Department of Energy and the Department of Treasury as part of the Manufacturing Investment Tax Credit system to assist in the equipment upgrades at its Auburn Hills 1 thin-film manufacturing plant. Total investment for the deposition tool upgrades is US$42 million and is expected to create 600 jobs in Michigan.

The upgrades were said to lower the cost of manufacturing while increasing the efficiency of the solar laminates. The tax credit was received by United Solar Ovonic, a subsidiary of ECD.

ECD/United Solar Ovonic's solar laminates integrated into a Mario Botta-designed building in Piazza San Lorenzo, Italy.

SolarWorld raises €400 million for continued production capacity expansion plans

As part of previously announced plans to expand module production internationally, SolarWorld has successfully issued a €400 million bond. SolarWorld said the bond was placed with banks and intermediaries in the private sector. Capacity at its Freiberg site is being expanded to 450MW at a new facility nearby.

The new funds were to be primarily allocated to its Freiberg, Saxony, facilities, which will generate approximately 500 new jobs, bringing the total in Freiberg to over 2000 employees.

Other News Focus

Yingli gains approval for State Key Laboratory of PV Technology

Yingli Green Energy has received approval from the Ministry of Science and Technology of China to establish the first national-level key laboratory in the field of PV technology development. The State

Schmid's 6000m² solar technology centre in Dunningen, Germany.

Key Laboratory of PV Technology will be developed at Yingli Green Energy's manufacturing base in Baoding.

Yingli has dedicated technology and management resources to facilitate both the application and the initial set-up of the laboratory. The State Key Laboratory will be established to drive the Chinese development of PV technology in China. The Laboratory, as an independent research entity, has had the support of Baoding Yingli Group Company Limited, an affiliate of the company, throughout the application process to satisfy relevant application criteria.

Schmid touts R&D capabilities and new collaboration with the University of Constance

A new R&D centre now provides Schmid with the ability to work with customers on processes and new technologies from the wafer through to the module, making it the only system provider worldwide to offer complete vertical integration for R&D projects, according to the company.

A 6000m² solar technology centre is now operational at the former factory of SEAG in Dunningen, which complements its existing technology centre for solar cells in Freudenstadt, Germany. The company has also established the "Schmid Photovoltaic Innovation Center of Expertise" (SPICE) at the University of Constance, which includes basic and applied science solar projects.

According to Prof. Giso Hahn, of the University of Constance, a 40-strong photovoltaic department in the faculty of physics is functioning and cooperating with Schmid.

Solar Cell Production Focus

Suniva receives US$5.7 million in Recovery Act Advanced Manufacturing Tax Credits

Suniva has received US$5.7 million in Recovery Act Advanced Manufacturing Tax Credits to expand its solar cell manufacturing facility in Norcross, Georgia.

The company now operates two solar cell production lines with an annual capacity of 100MW from its Norcross facility and is currently preparing to construct its third. This is expected to increase production capacity by 75% and create more than 50 manufacturing jobs in 2010.

"In little more than a year, Suniva built the capacity to produce hundreds of millions of dollars worth of solar technology, and we've created over 130 green jobs in the process," said Suniva CEO John Baumstark. "These tax credits enable us to continue expanding and supplying the rapidly growing American solar market with products developed in American laboratories and made by American workers."

AIS Automation Dresden installs MES at Bosch's Arnstadt facility

AIS Automation Dresden has been tapped by Bosch Solar Energy for one of its manufacturing execution systems (VPC-MES) for installation in Bosch's Arnstadt crystalline solar cell manufacturing factory.

This order marks the fourth AIS Automation MES system to be installed in a Bosch facility, and will enable the increase in Bosch's production capacity by approximately 400MWp.

With production scheduled to start at the Arnstadt facility in early summer 2010, the transfer and installation of the tool will be sped up to accommodate the impending start date.

The new MES system will aid in the provision of extensive information on factory management, production, and quality assurance.

Special report: Is JA Solar setting ASP decline trends for 2010?

With only a handful of major solar-related manufacturers having released fourth-quarter and full-year financial results, a picture is already emerging as to the health and wealth and 2010 trends for the solar industry. Having reported financial results and conducted its quarterly conference call in mid-February, JA Solar gave a lot of data points to digest about average selling prices (ASPs) for 2010. As a major low cost producer of solar cells its purchasing power and insight strongly indicate where pricing for products is heading in 2010.

There would seem little doubt that market demand returned to robust status in the fourth quarter, with PV producers noting production was at full capacity and demand outstripped supply. The first quarter would also be very strong in comparison to the same period in 2009.

Polysilicon ASPs

One of the eye-opening price points company executives revealed, related to its current average weighted polysilicon costs and projected price declines during the year. JA Solar noted that it was paying slightly below US$50 per kilogram and that the company expected this to decline approximately 10 to 20% in 2010. That could translate to a US$40 per kilogram price existing the year, should the 20% decline happen.

The messaging from MEMC in its most recent conference call, noted a moderation in the price declines for polysilicon and solar wafers. However, we have seen significant price declines that started in late 2008 and continued through 2009, so a 'moderation' in ASP declines would seem to fit well with the 10% decline guidance given by a polysilicon purchaser, though I doubt MEMC would conclude a 20% reduction by year-end was actually moderate.

Indeed, JA Solar's expectation that it would be buying polysilicon near the US$40 per kilogram price point would suggest that many polysilicon producers will be selling close to manufacturing cost, with smaller producers struggling to make any profits or worse.

The key aspect here is that polysilicon capacity continues to be added by some of the major producers such as Hemlock Semiconductor and Wacker as well as numerous new players such as GCL Poly.

I have lost count of the number of China-based small players but the end-result is that supply will continue to be added throughout 2010 and pricing pressure is set to continue. Moderation in price declines is perhaps the right call but perhaps only because selling prices will reach manufacturing cost even for the major producers.

Solar cell ASPs

Although JA Solar cannot meet projected demand without increasing cell production to at least 1.1GW in 2010, it did expect wafer prices to continue to decline. Executives put the ASP decline at between 10 and 15%, compared to prices in 2009.

JA Solar did not explain why wafer ASPs could decline but this is likely being fuelled by feed-in tariff (FiT) reductions in Germany. Should that market's demand weaken when changes take effect, then we could see further price drops that mirror a 15% decline. Potentially, this would happen in the second half of the year, because prices would seem to have firmed since the fourth quarter as producers' production capacities were fully utilized.

However, as seen last year, China-based PV producers were very aggressive in module pricing as inventory overhang and weak demand in the German market helped kick-start a shipment and installation recovery.

Continued price declines would seem to be a recurring theme in 2010 as the threat or perception that a slowdown in the most important market could require further support with lower prices as the year unfolds.

Production cost per watt

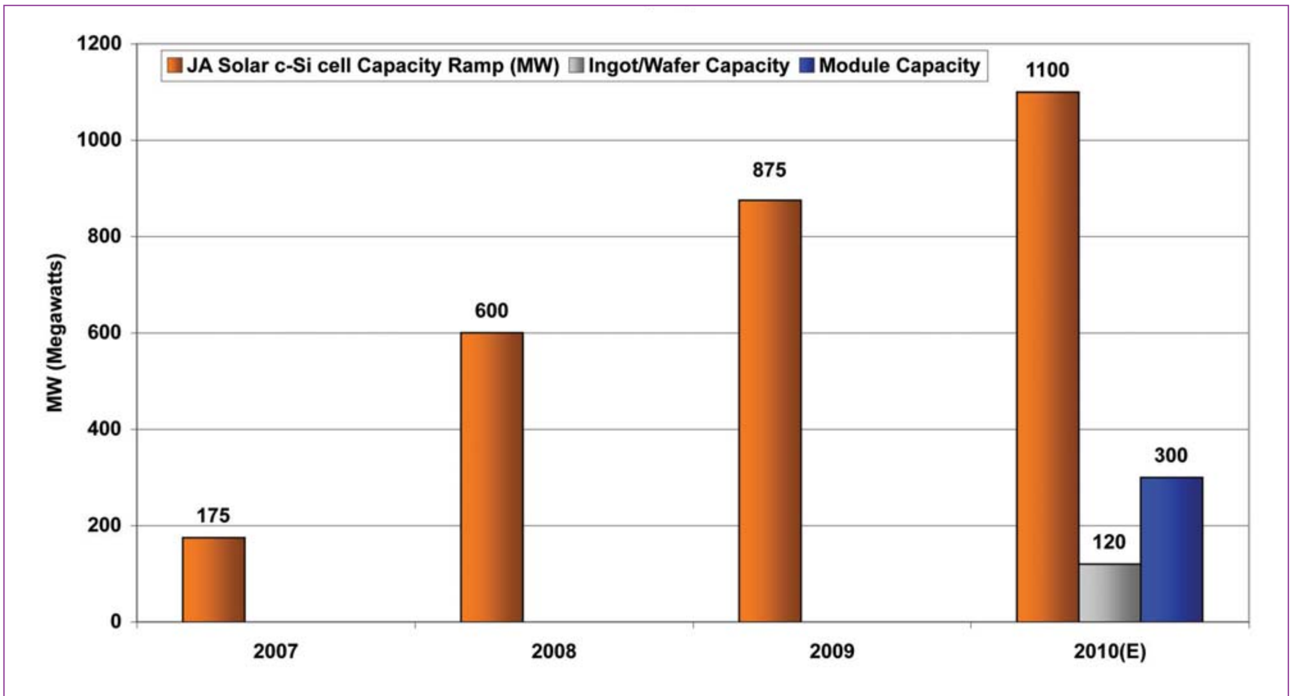
JA Solar also noted that, excluding its polysilicon cost, the production cost per watt in the fourth quarter was US$0.82. In comparison, First Solar has reported that its CdTe thin film production costs had reached US$0.80 per watt.

JA Solar expects at least a 15% reduction in its production costs in 2010 and claimed that it was the lowest cost producer in the market, with at least 20 to 50% cost per watt advantage over its crystalline competitors.

Although the company noted that these production cost reduction targets included the migration to higher efficiency cells, actual output in 2010 of higher performance cells will only make up a small fraction of its output. However, executives did say that they expect some of the cost reductions to come from lower material costs (pressure on suppliers) and improved production yields and overall throughput improvements.

During the call it was noted that although nameplate capacity would reach 1.1GW, these productivity improvements could result in capacity reaching 1.3GW by the end of the year, further improving cost structures. As a result, shipments could exceed 900MW in 2010, at least 100MW above its new shipment guidance for the year.

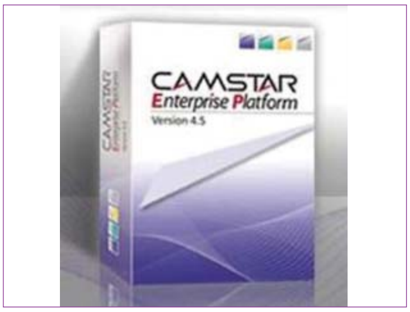
The pressure to reduce costs and boost cell efficiencies remains at the forefront of JA Solar's goals for 2010. To compete with JA Solar, cell competitors will have to beat the figures they have revealed if the claimed gap in costs is to be closed. Any company that is not focused and prepared to relay the same strategy could be in for a nasty shock.



JA Solar: Integrated capacity ramp forecast (MW) 2010.

Product Briefings

Camstar Systems



Camstar's Enterprise Platform Version 4.5 offers closed-loop quality process for global manufacturers

Product Briefing Outline: Camstar Systems has released the Camstar Enterprise Platform Version 4.5 for general availability. Enhancements in Version 4.5 – driven in collaboration with leading manufacturers using the platform – include expanded enterprise-calibre capabilities for global enterprises with multiple manufacturing locations and outsourced operations.

Problem: Competition to deliver the lowest cost-per-watt requires continuous improvement and reliable quality and delivery from every plant and every line. Solar manufacturers must grow globally while containing costs in order to compete. Removing manufacturing variability to consistently produce highly efficient products is required as well as continuously improving design and manufacturing to increase yields and resource utilization.

Solution: The Camstar Enterprise Platform advances product quality throughout the product lifecycle, from design to planning and from supply to manufacturing to customer product experience – all in a closed-loop learning process that allows future products to be better designed and manufacturing processes to be leaner and more efficient. Camstar reports that full traceability from finished product back to raw material enables easier root cause analysis across multiple batches and devices. Expanded enterprise-calibre capabilities have been included for global manufacturers with multiple locations or outsourced operations. Augmented platform configurability and usability are included to allow users to quickly adopt the solution with minimal training – and realize benefits earlier.

Applications: Global manufacturers with multiple locations or outsourced operations.

Platform: Camstar Enterprise Platform Version 4.5.

Availability: Currently available.

W. L. Gore & Associates (Gore)

Gore's PTFE filters can be used in bulk high-purity chemical applications

Product Briefing Outline: W. L. Gore & Associates (Gore) has added hydrophilic PTFE filters to its expanding line of cartridge filters for bulk high-purity chemicals used in microelectronics manufacturing, including LCD, semiconductor, hard-disk drive and photovoltaics.

Problem: Gore filters for high-purity chemical processors can be used as drop-in replacements for existing filters to achieve significant flow improvements while maintaining or increasing particle retention. This increased performance can provide a retention upgrade while maintaining system flow, reducing processing time, or decreasing the number of filters required for a lower total cost of ownership.

Solution: The new filters incorporate Gore's proprietary high-flow hydrophilic PTFE (polytetrafluoroethylene) filtration media, which do not require IPA (isopropyl alcohol) pre-wetting and completely eliminate de-wetting issues in most applications. They are well suited to filtration of aqueous and high-surface-tension liquids, especially where out-gassing or bubbles are a concern. Applications include high-throughput filling, packaging and recirculation systems.

Applications: Bulk high-purity chemical filtration.

Platform: Gore's PTFE filtration media is incorporated into standard-size filters that can be used as drop-in replacements for existing filtration systems and industry standard housings.

Availability: Currently available.

Schneider Electric

Schneider Electric offers active energy management architecture from plant to plug

Product Briefing Outline: Schneider Electric is offering an approach to create intelligent energy management systems under the EcoStruxure banner. These systems are simplified, save money, and most importantly, reduce waste by enabling a guaranteed compatibility between the management of power, white space, process and machines, building control, and security.

Problem: Capacity constraints, efficiency losses due to poor system design, lack of standardization, low adoption of renewable energy and implementation conflicts between broad and local energy policies are some of the factors that contribute to the ongoing energy obstacles that companies face.

Solution: EcoStruxure is based on a comprehensive portfolio of purpose-specific applications in five domains of expertise that are essential to solve the energy equation: *Power:* Complete power management solutions for facilities, plant and large site operations. *Datacentres:* APC by Schneider Electric's InfraStruxure architecture uses a modular, scalable approach to optimize power and cooling utilization and mitigate inefficiencies from overbuilding. *Process and machines:* Automation solutions dedicated to industrial and infrastructure companies or machine builders with a focus on flexibility, scalability, performance and ease of use. *Building control:* Management solutions that focus on reducing installation and operational costs while enhancing end-users' comfort through real-time temperature, lighting and shutter control. *Physical security:* Architectures include Pelco by Schneider Electric, with industry-leading technology in access control, intrusion detection and video surveillance.

Applications: Energy management for manufacturing facilities.

Platform: EcoStruxure is able to connect the five domains of expertise within an open and flexible ecosystem of technology that relies on the use of IP and web services, allowing purpose-specific applications to connect whenever needed, at the right level.

Availability: Currently available.

Product Briefings

Air Products

Air Products' ChemGuard 1000 safely handles delivery of $POCl_3$ solar cell dopant

Product Briefing Outline: The Air Products ChemGuard 1000 Automated Chemical Delivery system was developed exclusively for the photovoltaics market to help customers reduce phosphorus oxychloride ($POCl_3$) dopant bubbler refill costs by more than 45%.

Problem: $POCl_3$ is commonly used as an n-dopant in solar cell manufacturing. The molecule is very reactive and hygroscopic – exposure to moisture will generate phosphoric acid, so experience in safely handling this molecule is vital. Conventional dopant bubbler refill procedures affect tool uptime, generate chemical waste and increase overall shipping and handling costs.

Solution: The ChemGuard system is designed to improve delivery system safety and reliability, while the risk exposure to a highly toxic chemical is virtually eliminated. Productivity is enhanced with the elimination of tool downtime. Each system saves up to 460 hours/year of production-critical downtime, due to host container replacements and cost reductions resulting from the elimination of chemical waste (typically 15% or up to 77.6kg/year). Another benefit of the system is its ability to improve and maintain material quality and minimize contamination, with a potential 20-fold reduction in the opening of wetted-surface connections. The system ensures clean connections by implementing proven purge sequences and h/w designs. A full menu of alarms, events and diagnostic functions is available to prevent exposure and equipment damage.

Applications: Crystalline PV manufacturers using $POCl_3$ doping furnaces.

Platform: Air Products offers a comprehensive $POCl_3$ Solution, including molecules, bulk containers, and related delivery equipment and is part of Air Products' 'SunSource' range of products and services for the photovoltaic industry.

Availability: Currently available.

Vistrian

New version of Vistrian's FactoryLOOK alerts on process anomalies in single dashboard view

Product Briefing Outline: Vistrian have released version 5.0 of their 'FactoryLOOK' software platform. FactoryLOOK is a manufacturing intelligence system used by a number of companies including manufacturers of solar, semiconductor, LED, data storage, networking and electronic assembly products.

Problem: There is a real need for manufacturing intelligence solutions that allow users to collect and analyze real-time process data and interpret, aggregate, calculate and deliver a single dashboard view of relevant events, alerts and Key Performance Indicators (KPIs) required for making timely manufacturing decisions.

Solution: FactoryLOOK is used as a tool to integrate all processes and equipment data and to provide access to all users using a web browser. This includes the Facility, Environmental, Tooling, Test Equipment, Flat Files, Legacy systems (MES, ERP) and Operator interfaces. The tool set features provide analysis, alerts, dashboards and reports using the integral rules engine in real-time, thus providing the user with timely information to optimize operations and processes. The software integrates enhanced dashboards, a user-configurable rules engine and the ability to be utilized in virtually any type of industry or process with modest configuration changes. FactoryLOOK 5.0 stores and archives all collected data for use in query analysis.

Applications: For use in both high-volume and pilot production environments to increase yields, reduce process and development time and increase process uptime.

Platform: When implemented in a manufacturing plant, each piece of monitored equipment is equipped with a Vistrian Spider, which is equipped with a variety of data input interfaces including analog inputs, digital inputs, serial, USB, as well as Ethernet ports. Data is then pre-processed by the Spider's on-board CPU and then sent over the LAN to the FactoryLOOK server that is typically located in a server rack remotely.

Availability: Currently available.

HORIBA

HORIBA's SEC-N100 Series digital MFC handles PV manufacturers' gas flow requirements

Product Briefing Outline: Fluid control specialist HORIBA has introduced a new range of Mass Flow Controllers (MFC) competitively priced to fit the economic and production needs of the photovoltaic manufacturing sector. Manufactured in Japan under strict quality conditions by HORIBASTEC, the SEC-N100 Series Digital Mass Flow Controller reliably controls the flow of process gases and cleaning gases. Multi-gas and multi-range functions allow the user to configure the desired gas and flow range to increase flexibility and reduce overall costs.

Problem: When an MFC falls out of specification, the process becomes unknown which directly affects the final product quality and yield. The faulty MFC will need to be replaced, which causes logistical and downtime issues, increased risk of contamination and the associated costs. Another issue with a standard MFC is if a process is changed, the MFC may need to be removed from the gas line and exchanged.

Solution: If the process is changed, the N100 series is fully programmable so there is no need to break the line or replace the MFC. The series provides analog/digital, DeviceNet and PROFIBUS communication functions compatible with solar cell manufacturing equipment. The range offers 1% set point precision and less than 1 second response with an extensive line-up of models with metal or elastomer seals covering flow ranges from 1/10ths of a cubic centimetre per minute up to 200 litres per minute.

Applications: The SEC-N100 Series controls the flow of inert and corrosive gases to all PV-making processes for crystalline silicon, thin-film silicon, CIGS and sensitized dyes.

Platform: Key features of the SEC-N100 Series include: high performance, a fast response and set point accuracy; multiple interfaces: Analog 0~5V, Analog 0~10V, Analog 4~20mA, Digital RS-485, DeviceNet, Profibus. The Series is fully programmable, allowing the user to reduce inventory and flexibility and change gas and flow.

Availability: Currently available.

Scaling up: aiding solar manufacturers using lessons learned from past high-tech industry scale-ups

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ABSTRACT

As demand for solar products prompts producers to scale up their manufacturing operations, CH2M HILL's advanced technology manufacturing experts consider some of the most significant issues related to factory expansion. This article consists of the direct experiences these experts have gained from the scale-up activity in other industries with technological similarity to solar – most notably from the semiconductor and flat panel realms.

Introduction

Solar PV manufacturers have pressing needs to build new or expand existing operating facilities to gain market share and meet business objectives. The drivers for the owner are familiar ones of schedule, cost and quality. However, most of these companies have limited resources and their expertise is often focused on technology, finance, and operations – not on building factories. Dealing with all the details (e.g. permitting, contracting, site selection, equipment selection and utility needs) presents a daunting logistical challenge. Missteps during this process can cost money, cause schedule slippage and adversely affect the resulting quality of facility and product, ultimately impacting a company's bottom line.

Like owners in industries that preceded them, solar manufacturers need all the insight they can find to correctly calculate their individual risk/reward profiles. Many of those insights can be gained by looking to the lessons learned in manufacturing industries whose processing technologies have much in common with solar: semiconductors and flat panel displays. The authors' extensive experience in both of these more mature industries has given us many insights to solar PV manufacturing. In this article we focus on a few of the most important considerations owners need to ponder before deciding where, how, and when they should consider scaling up their operations.

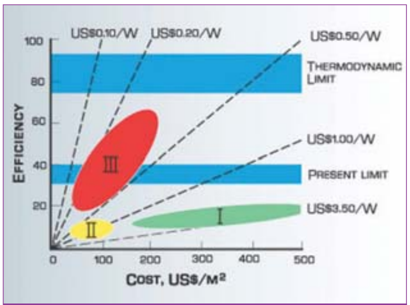
Because solar processing technologies are diverse, there is no one-size-fits-all roadmap to solar scale-up decision-making. Each solar processing technology (c-Si, a-Si, CdTe, CIGS, etc.) has its own unique wrinkles. Neither the smaller producers nor the industry leaders are immune to the challenges and risk of learning painful lessons through growth. The history of growth in related industries has repeatedly reminded us that there are many opportunities to go down the wrong path, particularly for producers coming out of a pure research background or buying turnkey solutions.

Semiconductor manufacturing experienced many challenges related to growing pains during the late 1980s and early 1990s. The benefits of scaling up were supported by solid metrics; the conversion to 300mm wafers and the 'geometry shrink' driven by Moore's Law around the turn of the century provided a combined output advantage equal to 4x per wafer and a 30% cost reduction. But despite the benefits, the whole process of scaling up sites, structures, and the quantities of chemicals, gasses, materials and throughput was a rough learning experience for many in the business.

> "The history of growth in related industries has repeatedly reminded us that there are many opportunities to go down the wrong path."

Flat panel display manufacturing also endured a steep learning curve, especially because the industry's facilities are inherently large to begin with. In a period of just four years, the flat panel industry sprinted from Generation 3 glass panels (measuring roughly 550mm x 650mm) to Generation 10 panels (2,880 x 3,130mm). Generation 11 dimensions of more than 3,000mm per side are not far behind.

The solar industry today is at a crossroads of its own, as owners contemplate production capacities of a gigawatt and beyond. As shown in Fig. 1, solar product efficiencies are expected to steadily increase, with a corresponding steep drop in cost ($/watt).



Source: University of New South Wales.

Figure 1. Efficiency and cost projections for first-, second- and third-generation photovoltaic technology.

Putting building and facility costs into perspective

Rather than focusing only on the straightforward aspects of scaling up manufacturing capacity, such as increasing the size of a facility and the number of tools a facility houses, it is informative to look at increasing a facility's productivity and output in terms of 'cost per megawatt,' just as the semiconductor industry used the metrics of 'cost per computation' or 'cost per memory.'

Using 'cost per megawatt,' we arrive at four strategies for scaling up solar facilities:

1. Provide the flexibility to integrate novel manufacturing technology improvements into a facility. This strategy does not have to involve higher facility costs, but rather attention to the details that allow an owner to anticipate and incorporate future improvements.
2. Increase the throughput of a plant's processing equipment using manufacturing integration and Lean manufacturing principles, automation, optimization of line balancing and cycle times, etc.
3. Increase the size of substrates produced where technically feasible.
4. Take the conventional approach of increasing factory output by increasing

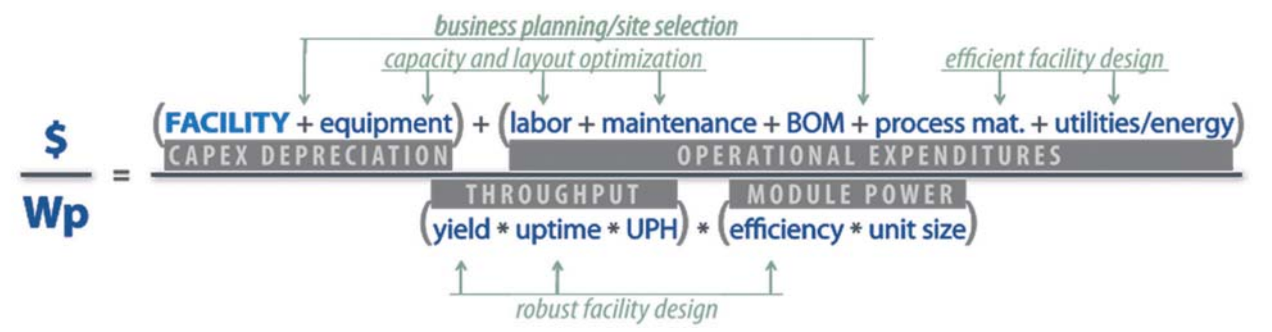


Figure 2. Cost per Wp: simplified calculation.

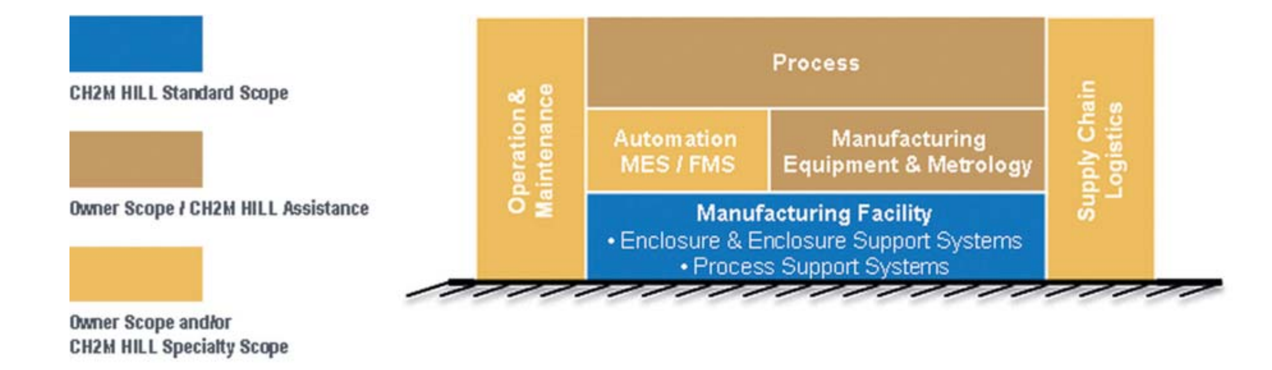


Figure 3. The manufacturing facility as the base building block of a robust, efficient and safe operation.

the size of the facility and the scale and/or quantities of processing equipment in the facility.

Simply increasing the size of the facility and amount of processing equipment is a straightforward means of achieving scale-up, but this approach can consume more capital than necessary. Missteps during the factory scale-up process can cost money and cause schedule slippage, adversely affecting the resulting quality of facility and product, thus impacting an owner's bottom line. Managing information from the owner's side is imperative for facilitating a smooth and reliable path to bring a very large factory to an operating state.

"When prioritizing the elements that comprise a scale-up strategy, it is important to put into perspective the relative importance of each element."

When prioritizing the elements that comprise a scale-up strategy, it is important to put into perspective the relative importance of each element.

In the case of thin-film solar processing, for example, building and facility-related costs constitute 1-5% of overall cost of ownership, calculated in \$/Wp (depending on technology and depreciation method – see the simplified formula in Fig. 2). As a first conclusion, one could rightfully state that facility costs are thus not very significant in the overall cost of manufacturing. This is a dangerous conclusion, however: the facility is the backbone of the manufacturing activity, and non-optimized facility designs can dramatically impact productivity and output.

The planning of the site and the design and construction of the facility have a great impact on various elements of the cost and performance factors – an impact which can overwhelm the initial capital cost of the facility.

1. **High uptime and yield, and best module/cell efficiency through robust facility design**. When scaling up manufacturing capacity, it is critical to have stable conditions for the equipment, material handling and – most importantly – the process, in order to achieve the best overall factory performance. The goal is to achieve a narrow distribution of average module/cell efficiency close to the champion efficiencies achieved in mass production, while ensuring high uptime and world-class line yields (>>90%). Assuming facility depreciation is 3% of overall production costs, a 1% increase in either yield or uptime would more than compensate for a 30% higher building cost. In other words, if your yield, uptime and average efficiency were to suffer more than 1% each (more than 3% total), then one should not accept the building even if it is free.
2. **Efficient facility design**. Here again, the cost for process materials (e.g. industrial gases for vacuum deposition, chemicals for etching), general utilities and electricity are usually higher than the facility depreciation cost; i.e., in order to plan for the lowest lifecycle costs when scaling up, a greater focus needs to be given to operational expenses vs. facility capex expenses.
3. **Reduction of equipment, labour and maintenance costs by capacity and layout optimization**. With intelligent facility design through capacity and layout simulations, one can save on equipment capex on the initial set-up, and also when the manufacturing lines are being upgraded and/or scaled up in the future. Many factors play into optimizing a factory floor layout – whether adopting in-line or batch processing approaches, applying Lean manufacturing techniques, or implementing a Manufacturing Execution System (MES) and new QA strategies (inline/offline). Advanced industrial engineering using modern dynamic simulation tools optimize tool count, material handling flow and labour requirements to operate and maintain the equipment.
4. **Reduction of capital and operational costs through business planning and site selection**. A key element when scaling up manufacturing capacity is the choice of the site. Not only must the site fulfil all technical and space requirements, it also significantly drives capital and operational costs. Some

regions are ready to offer attractive incentive packages that help an owner offset the 'first costs' of capital investment into facility and equipment. However, the majority of the costs over the lifecycle of the factory are operational costs, and it is critical to consider the influence of the site selection on parameters such as local labour costs and education levels, access to inexpensive utilities and electricity, ability to generate some process gases onsite, distance to major BOM suppliers, etc.

Advanced planning issues

There are many advanced planning issues to consider when contemplating scale-up. Many of these – such as strategic analysis of competitors, or the potential for economic development incentives to offset scale-up costs – are not site-related. For this article, however, we are focusing only on a few key site-related priorities related to advanced planning.

One priority for scaling up manufacturing in existing facilities is to improve the long-term energy efficiency of the facility using technologies that may not have been applied when the original manufacturing facility was built. For example, advanced approaches can be used to reduce the long-term costs of controlling heating and cooling loads. This can be done by integrating more passive heating and cooling approaches that exploit local climate conditions, and introducing intelligent environmental control systems. This is an advanced planning issue, because an important contributor to achieving such advantages is the orientation of buildings on a site to optimize the harnessing of solar energy, or to reduce the potential for a building's airborne emissions to contaminate the building's makeup air. Airflow modelling applied inside as well as outside a planned building environment is a valuable tool to precisely define the kinds of energy-saving advantages that can be realized on a specific scaled-up site. These techniques can also be applied during 'greenfield' facility design to optimize energy efficiency of the new construction.

Another important topic for any scale-up effort (greenfield or expansion) is permitting and other regulatory issues. These can be insidious impediments, especially when the planning process assumes that past regulatory standards will apply to the new facility. It is wise to challenge this assumption in the earliest stages of any scale-up program, and to validate whether a facility's existing permits provide adequate flexibility to accommodate the degree of desired expansion. Critical aspects of this analysis include water consumption, air and wastewater discharge, hazardous materials storage, and transportation requirements. In the U.S., for example, owners must be aware of the latest 'threshold quantities' requirements for the storage and handling of certain chemicals that were an outgrowth of Homeland Security provisions in the last few years. Another forward-looking consideration to plan for is the ability to comply with anticipated future requirements to reduce a facility's carbon footprint, such as 'carbon tariffs.' Bringing older buildings into compliance with these and other potentially more restrictive codes can be cost prohibitive.

> "A common pitfall of upscale project teams is the tendency to be overly optimistic about the amount of time required to resolve regulatory issues."

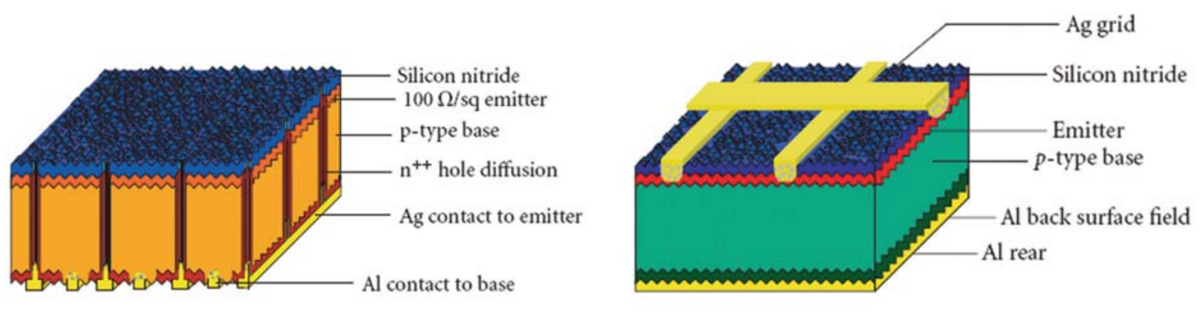
A common pitfall of upscale project teams is the tendency to be overly optimistic about the amount of time required to resolve regulatory issues. Overlooking this important step during the advanced planning phase increases the potential for misunderstandings and a change of the rules mid-project, resulting in rework and delay. A 'Plan B' should be available which would engage a strategy to expedite permitting approvals. Such a strategy best relies on personal intervention of code experts representing the owner. Particularly in international regions, where regulatory officials may not be familiar with a facility's planned processes and the hazards associated with the chemicals supporting those processes, it can be very effective to engage regulatory officials in direct dialogue to explain the particulars of the planned manufacturing processes.

Form factor scaling

Form factor scaling is a productivity approach that CH2M HILL has observed in both the semiconductor and flat panel display industries. This approach typically generates equipment productivity improvements, since the rate of increase in product output exceeds the rate of required increase in manufacturing floor space. In the semiconductor and flat panel industries, for instance, 2x output increases associated with diameter or generation changes respectively have historically been associated with roughly a 30% increase in capital investment. The net result is significant cost reduction (output/capex).

A related scaling phenomenon is also occurring in the PV manufacturing industry. In silicon wafer-based manufacturing processes, scaling is currently occurring through the thinning of the silicon substrates. Since silicon costs are one of the highest direct manufacturing costs for a wafer-based PV line, thinning the substrate provides a direct reduction in cost-per-watt metrics. Thinner wafers, however, can cause other issues with the manufacturing process, such as increased yield loss due to the handling and processing of thinner wafers. Facilities and automation systems must anticipate these trends in wafer thinning and deliver equipment and systems that can grow with these trends.

The thin film industry is already benefitting from form factor scaling. Applied Materials has successfully deployed manufacturing processes at Generation 8.5 form factor that scaled up from 30cm by 30cm 'minimodules.' Other manufacturers, such as Oerlikon, have successfully deployed processes using Generation 5 substrates, and we expect this trend to continue among other thin-film equipment manufacturers. One issue currently hindering scale-up in the thin-film industry is the lack of form factor standardization. This lack of



Source: Hindawi Publishing Corporation.

Figure 4. Example of emitter wrap-through process.

standardization makes it more difficult for factory owners to pick and choose specific equipment from various suppliers, instead forcing owners to take delivery of an entire turnkey equipment line from one supplier. This is typical of an industry in the early stages of growth, and this issue is especially noticeable in the amorphous silicon market.

However, again based on trends observed in the semiconductor and FPD industries, we expect that eventually the various segments of the thin-film market will standardize on specific form factors, allowing increased competition in the equipment market. What this means for the facility owner is more uncertainty in the long-term manufacturing equipment set, line configuration, and facility infrastructure requirements over time. However, experience on related projects verifies that a solid facility design approach can address this uncertainty without adding significant cost. For instance, a facility owner may reconsider decisions about column spacing, crane capacities, utility sizing, and clear heights when anticipating form factor scaling changes over the lifecycle of the factory.

Process issues

Critical to optimizing performance of a PV manufacturing facility is the ability to continuously adopt processes and technology breakthroughs that improve cost-per-watt metrics. These improvements are anticipated to come in the form of improved power conversion efficiency, improved yields and better reliability of both manufacturing equipment and products. To this end, both thin-film and silicon wafer high-volume manufacturing facilities must be constructed with the ability to adapt to emerging technologies, manufacturing equipment and process chemicals.

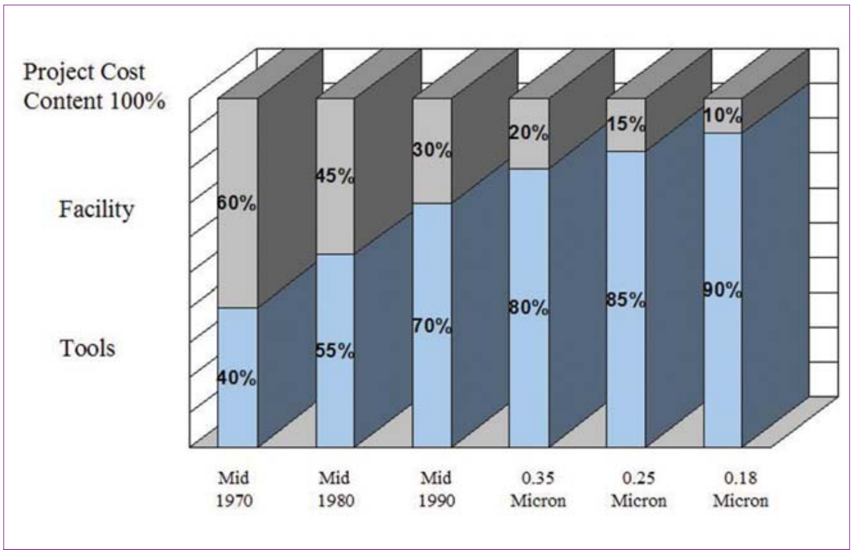


Figure 5. In the semiconductor industry, the ratio of tool to facility costs steadily skewed in favour of tools as the industry matured and manufacturing processes became more complex.

In the crystalline silicon PV market, for example, many process improvements are currently under consideration or are being adopted to improve power generation efficiency. While some incremental improvements can be expected through the optimization of existing processes and manufacturing equipment, major improvements will be required to reach grid parity. Metal and emitter wrap-through processes, for example, are just two of many methods in the early phases of deployment in high-volume manufacturing that are expected to increase power conversion efficiency. However, these processes require new tooling (lasers) and improved lithography alignment techniques.

Longer-term efficiency improvements, such as photon up- or down-conversion, may include the deployment of advanced quantum dot materials and solution processing equipment such as inkjet-based equipment, neither of which is in widespread use in manufacturing today. As was the case in previous semiconductor and flat panel industry scale-ups, solar processing improvements require additional factory floor space, place increased burdens on process chemical supply and waste treatment systems, and may introduce new regulatory restrictions on the facility. These issues can be mitigated through careful upfront planning of the facility with the owner.

The situation is similar in the thin-film PV market, where technologies must also significantly improve cost-per-watt metrics. In the amorphous silicon market, many companies are focusing technology development on improving the performance of interfaces and the incorporation of new materials to increase efficiency through improved absorption by light scattering and improved reflection. These approaches are likely to result in either new equipment or the modification of existing equipment. Either approach can have an impact on the manufacturing line, either by requiring additional equipment or by altering the line balance by changing equipment throughput. In CIGS and CdTe, where the focus is on optimizing existing processes and improving the productivity of manufacturing equipment, improvements over time may also result in line imbalances and potential lost output. In order to maximize the capital investment, large thin-film factories must be designed with the flexibility to adapt to these dynamic scenarios in order to maximize output.

CH2M HILL has demonstrated that, through careful scenario planning and modelling, inexpensive or cost-neutral decisions regarding infrastructure and utilities can be incorporated during facility design to address evolving technology. These changes are expensive, impractical, or impossible to implement later on in an operating manufacturing facility. We have used this approach with great success in both the semiconductor and flat panel display markets to design affordable flexibility into manufacturing facilities. For instance, by understanding the evolution of the photolithography roadmap in the semiconductor industry, CH2M HILL was able to help a client minimize lifecycle facility costs while ensuring adequate floorspace for vibration-sensitive equipment over the expected lifetime of the facility (several process generations).

Chemical issues

On the small scale, manufacturers only need small containers of chemicals to function effectively. In high-volume manufacturing, everything changes. It is critical to plan for:

- Significant space needs and cost of bringing chemicals in by the tank truckload. This requires space for a tank farm, truck unloading, and effective traffic patterns.
- Sources of supply: is the supply chain in a given location adequate to supply the chemical types and quantities you need?

For example, manufacturers whose process uses large amounts of argon would be constrained in locations where this gas is difficult to access. Argon is incrementally more expensive to produce than many other gases, and cannot be produced on site. When manufacturers transition to larger argon quantity demands, it can become necessary to take delivery of argon in liquefied, cryogenically transported form. Argon is just one example of how owners' chemical and gas supply chains can become very tenuous when they locate far from where their needed materials are produced; these issues can have a profound impact on a facility's overall cost structure.

In general, thin-film processes use a lot of nitrogen. For some of these processes, scaling up will require the on-site production of nitrogen. In order to do this, the owner must plan for the necessary real estate, coordinate with the gas company, and provide for the additional power required at the site. Coordination with the gas company is especially critical; the lead time for a 2000 CFM nitrogen plant is currently 18 months, and plant components alone have a nine-month lead time. There are other scale-up issues related to chemicals,

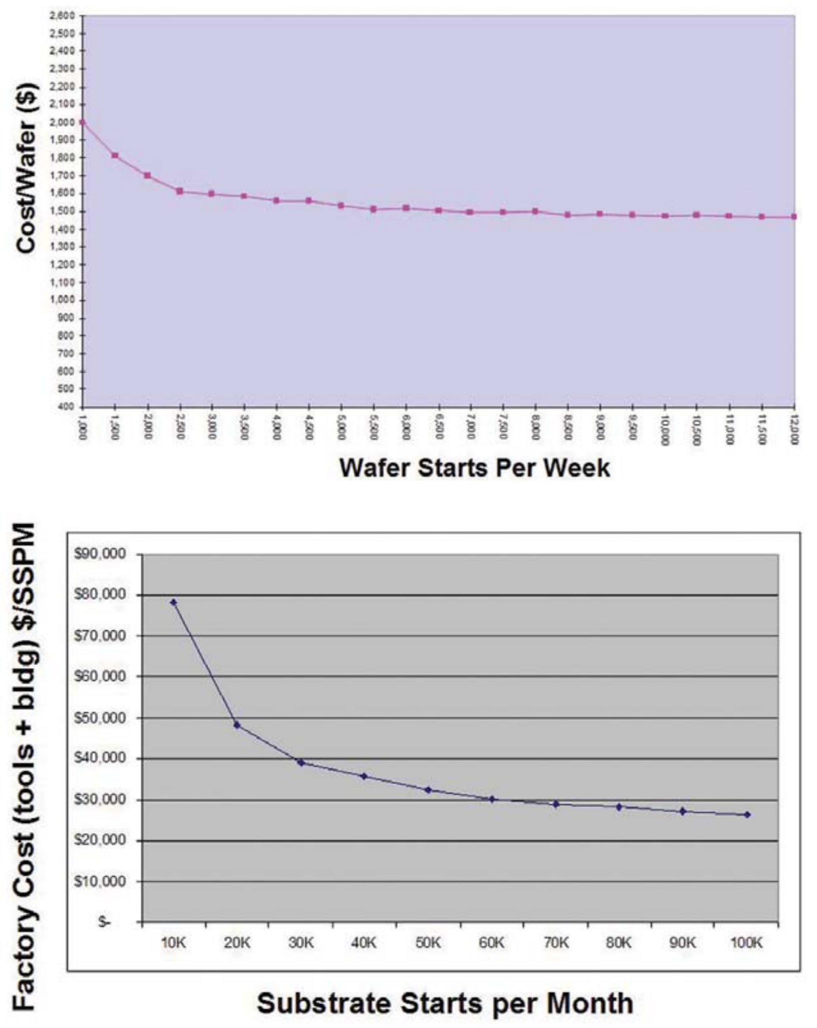


Figure 6. These graphs for the semiconductor (top) and flat panel industries (bottom) reflect how capital costs per unit of capacity fall rapidly, then level asymptotically as capacity increases. We see a family of such curves for PV solar, one curve for each technology. Critical to economic competitiveness is proper selection of factory capacity.

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such as how to decide when it may be most feasible to produce hydrogen on-site instead of trucking it in for certain thin-film processes.

Managing the challenges of dealing with larger silane quantities is also a critical consideration for some thin-film manufacturers. Silane is currently manufactured only in Japan, Korea, the U.S. and Germany, and it is challenging to ship. A 1GW amorphous silicon thin-film facility will consume roughly two trailers of silane every three to four days, or 100 trailers per year. It is easy to see that a hiccup in the supply chain can have a significant negative impact on production.

Facility needs

One of the fundamental considerations in scale-up planning is the physical distance between buildings and discrete processing tools, utilities, and support systems on a site. In a scaled up facility it is more efficient to combine and centralize the chilled water plant and the heated water plant. The downside of this approach is the resulting long utility runs from the central system to a tool or user. The pressure loss eventually gets sizeable enough to move centralization into a grey area of advisability. For that reason, owners need to carefully calculate the relative advantages and detriments and then consider their options. It is more expensive to implement two systems, of course, but in the long run such an approach might be advantageous.

Some due diligence design work is required to pinpoint where the break point is in this balance, which is bound to be different in every situation site depending on the distances involved on a specific site. The systems need to be laid out ahead of time to see which approach is most practical. In the case of an exhaust system, for example, what is the cost of running a 5-foot duct 500 feet? Would it be cheaper to have two systems?

One of our solar clients originally planned to construct a new greenfield 450MW facility as one phase, but eventually decided to split the building in half to be constructed in two phases. In hindsight this was a good move, because if the entire operation had been centralized, there would have been problems further down the road because the distances on their site were so large.

Other scale-up issues that need to be considered related to facility needs include optimizing space adjacencies (consolidating hazardous materials to minimize a scale-up's impact on code issues), consolidating equipment and centralizing support rooms to reduce a facility's distributed HVAC loads and reduce utility runs, and shifting to bulk chemical storage vs. distributed chemical management. Scaling up capacity also calls for a careful review of an upgraded facility's sustainability goals. This is a topic deserving of a separate article, but generally speaking, every owner must carefully weigh the benefits against the liabilities of seeking sustainability only for sustainability's sake. With the right technologies, sustainability should always be expected to deliver long-term enhanced economic value to a manufacturer as well as ethical gratification.

Manufacturing integration

Strong industrial engineering expertise is at the heart of successful scale-up strategies. Refining factory floor configurations during scale-up is a task best begun with process line simulation modelling to virtually test process line variations in the search for the best blend of tool selection and positioning. It has been the authors' experience that factory line simulation modelling can lead to significant savings to owners in the form of reduced floor space requirements, reduced number of required processing tools, and improved overall equipment effectiveness (OEE, equal to the availability x performance x quality). Relating this back to our previous discussion of capex, optimization of OEE can improve a facility's overall bottom line significantly, depending on the degree of complexity associated with a particular process.

Consolidation of functions is an approach that is integral to leveraging the value of the scale-up investment. Consolidating processing equipment, for instance, reduces HVAC loads that would otherwise be widely dispersed in a factory, and enables improved building occupancy and simplification of fire separation. It also enables greater processing flexibility, improved equipment OEE, and cost efficiencies related to work in process. Consolidation is more conducive to integration of automated WIP buffering to hold WIP in place to help downstream operations moving at an optimal pace. Enhancing the adjacency of processing tools allows one or more tools to be taken off line without impeding overall output. Centralized support rooms reduce the length of utility runs, and allow greater utility cost efficiencies, such as shifting from distributed chemical systems to a bulk chemical storage approach.

Wastewater

While water consumption is not as critical in solar PV manufacturing as it is in the semiconductor industry, wastewater is more insidious. Because the solar industry is not a big water user, there is a tendency to reduce wastewater to 'out of sight, out of mind' status when in fact there are nuanced specialty wastewater issues that become vitally important.

The approaches used to resolve wastewater issues at low production levels may not be adequate for scaled-up production. Owners must understand the 'wastewater profile' of the scaled-up facility, in terms of both quantity and quality. There are no industry standards that enable owners to anticipate the next level of issues, and scaled-up facilities face external factors that are not explicitly driven by regulations. Rather, they are infrastructure- or location-driven, and can have serious repercussions if not considered well in advance. When ramping up the volume of wastewater a facility discharges, sustainability headroom issues arise in the form of the ability of the local receiving plant to deal with the wastewater. It is critical to start early communication with the receiving entity to understand the design and cost implications of wastewater infrastructure, capacities, permits, etc.

All too often, the site selection process drives owners toward 'light industrial' candidate sites, often located in smaller communities offering all sorts of incentives, without recognizing the potential impacts of the wastewater side. For instance, with a 60MW line, a facility may comfortably fall within certain wastewater thresholds, but when scaling up they enter a different category. One example: many solar facilities use large amounts of ammonia, which is variably regulated. In some places ammonia does not matter, and in some places it matters a lot. If the facility in question is in a location where it matters a lot, it can cost a lot: the wastewater cost estimate can double in a location that does not 'want' any ammonia.

Conclusion

On the road to very high-volume manufacturing capacity facilities, every industry struggles with the many variables and uncertainties that complicate calculation of the risk/reward ratio. The solar industry will be no different. The antidote to trepidation is preparation; the best way to minimize the inevitable concerns associated with any new capital investment is to review every aspect of a scale-up's requirements by adhering to a structured and rigorous 'checklist' approach.

> "The scale-up strategy should have the flexibility to smoothly integrate new processing technologies as they develop."

The scale-up checklist should begin with an unvarnished analysis of building characteristics, facility infrastructure capacities, the process technology roadmap, process methodology, and automation strategy. Examine how these costs stack up against anticipated


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return on the owner's capex investment. The checklist should assess a range of advanced planning concerns, with particular focus on those issues that can provide the desired short- and long-term value to the owner such as improving energy efficiency and avoiding regulatory delays. The scale-up strategy should have the flexibility to smoothly integrate new processing technologies as they develop into the facility and its utilities and tool sets. There should be no skimping in the area of manufacturing integration, considering the repeatedly demonstrated ability of this field of expertise to return bottom-line value – improved equipment productivity – that far outweighs its cost.

When considering all of these factors, the authors' experience has repeatedly demonstrated that the most successful scale-ups in related industries such as semiconductor and flat panel have tended to be those that made owners active participants in all aspects of the scale-up process. Building an efficient factory and reducing product life-cycle costs requires information and decisions from owners on key issues related to facility needs and site. If the development of critical information such as this can be well managed from the owner's side, a smooth and reliable path can be followed to bring a factory into operation.

About the Authors

David Krick, Principal Technologist, primarily assists clients with the commercialization of emerging advanced technologies in the field of renewable energy, focusing on solar photovoltaic production and other semiconductor-related industries. He also leverages his extensive expertise in semiconductor research, development, and manufacturing to evaluate high-technology manufacturing and technology roadmaps. He has authored multiple papers and has been an invited speaker at conferences, both domestically and abroad.

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Electric power glitches and PV manufacturing: using SEMI standards to increase yield and reduce costs

Alex McEachern, Power Standards Lab, Alameda, California, USA

ABSTRACT

PV manufacturers can quickly reduce their costs, and increase their yields, by using SEMI standards that were originally designed to help semiconductor fabs deal with power glitches and power costs. SEMI, the global industry association serving the manufacturing supply chains for the microelectronic, display and photovoltaic industries, has two well-established electric power standards that could prove especially useful for PV manufacturing: SEMI F47, which helps equipment deal with power disturbances, and SEMI E6, which helps users understand how much electric power is used in their recipes. This article provides a method of lowering costs and increasing yield by applying these standards in the PV manufacturing industry.

Power glitches at PV factories

PV manufacturing equipment is sensitive to power disturbances. At a typical PV manufacturing location, equipment can be exposed to about one disruptive disturbance each month. Although these power disturbances can and do occur at every location, there tend to be more disturbances in grids located in developing countries, and more disturbances in locations that have a high isokeraunic level (frequent lightning).

These disturbances come in many forms: voltage sags or dips (a reduction in voltage for one second or less); voltage swells (a brief increase in voltage); high frequency impulses (microsecond-level bursts up to several kilovolts, caused by lightning and inductive loads); frequency variations (caused by generator disruptions), among others. By far the most common power disturbance at PV manufacturing facilities is the voltage sag.

Most voltage sags arrive at the factory from the public grid, but some are created in the factory itself when large motors such as air compressors turn on abruptly, or when an electrical worker accidentally causes a short circuit.

Power companies cannot fix this problem

So why do electric power companies not eliminate these voltage sags? The secondary reason is that the electric power grid is designed for lights, heaters, and motors; sags just do not encroach upon these loads. However, the primary reason is that the power companies are *unable to* fix these problems. Sags are caused by short circuits, or 'faults,' on the public distribution grid (see schematic in Fig. 2). These short circuits can be caused by anything from animals, to weather, to workers digging up underground cables. When a short circuit occurs, large currents flow, and the voltage for all users on the nearby grid

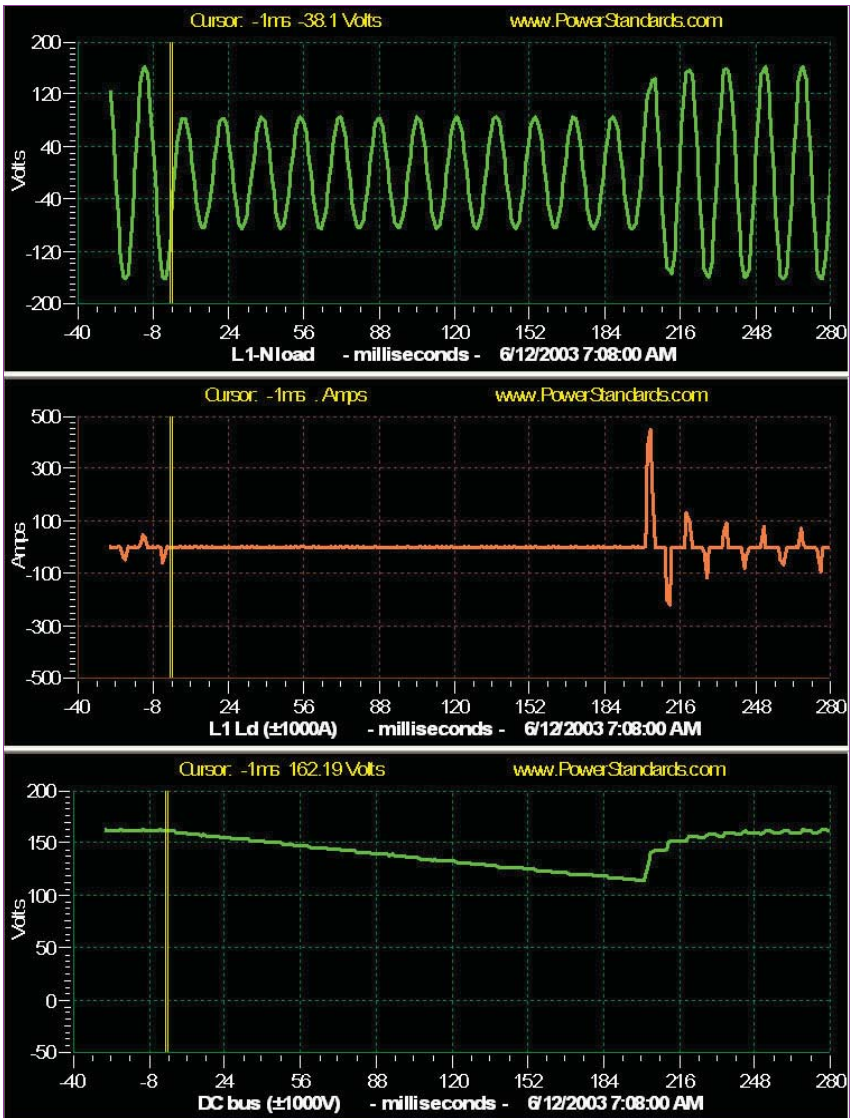

Figure 1. A typical voltage sag (top graph) during SEMI F47 testing. The middle graph shows the equipment current, and the bottom graph shows a DC power supply reacting to the sag. This equipment shows a large increase in current immediately after the sag – one of the most common sag-induced failure mechanisms.

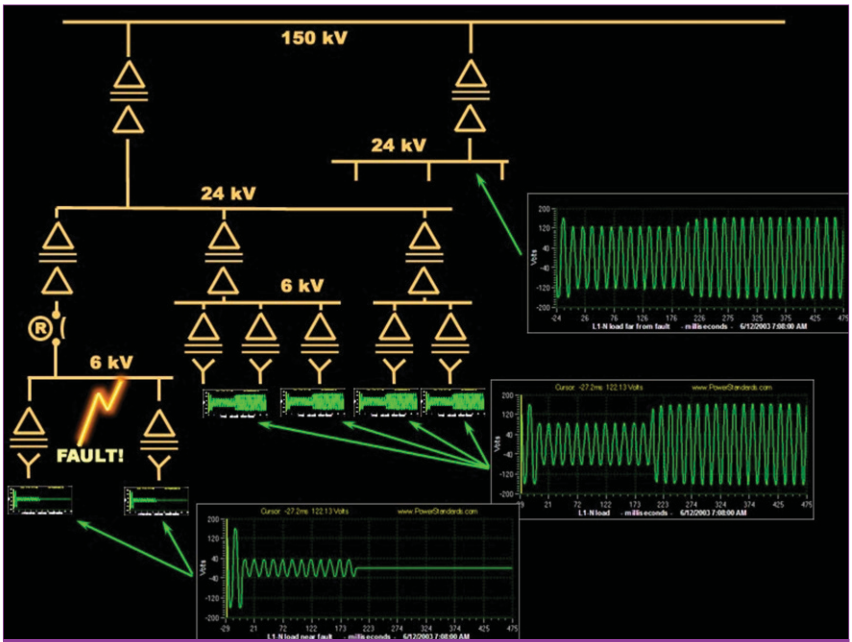

Figure 2. Typical electric power distribution grid showing voltage sag disturbance. A fault, or short circuit (bottom left) causes a power interruption for a few customers in the region, simultaneously causing a voltage sag for many other customers.

Figure 3. Small, low-cost power quality monitors should be installed in every PV factory, such as this PQube monitor that records power disturbances on a digital camera SD memory card.

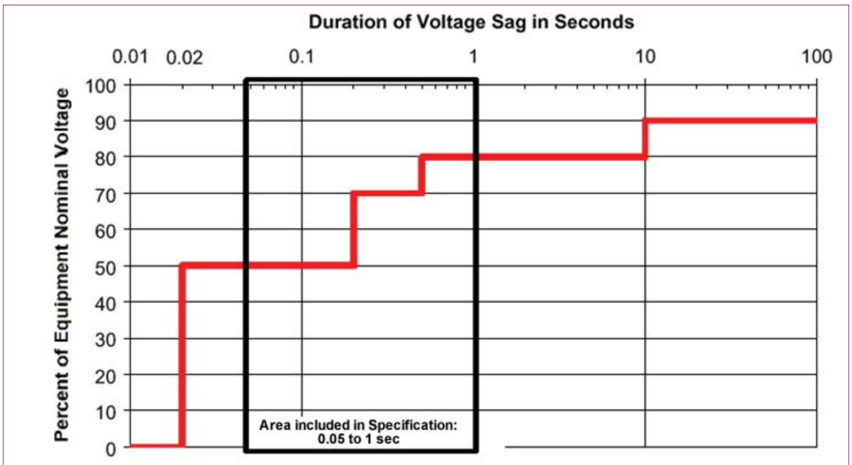

Figure 4. The SEMI F47 curve. PV equipment must tolerate electric power voltage sags that fall above the red line. As a practical matter, about 90 per cent of the sags at PV manufacturing facilities will be above the red line, so SEMI F47 certified equipment will 'ride through' about 90 per cent of the sags.

abruptly decreases, causing a voltage sag. After several cycles of large current, a fuse on the grid opens, or a circuit breaker trips, and the users downstream from the fuse see an interruption or power cut. At this point the other nearby users see the end of their voltage sag as the voltage returns to normal. Given the exposed, public nature of power distribution, it is impossible for power companies to avoid occasional short circuits.

Without instrumentation, it can be very difficult to find the root cause of intermittent equipment failures. Indeed, there is often a temptation to blame intermittent failures on electric power problems when no other explanation is available. But other causes are equally likely: operator errors, software bugs, loose cables, feedstock flaws, bubbles in process cooling water, pressure drops in CDA, ambient temperature or humidity variations, and so forth.

The best way to fix voltage sag problems

So what should a PV factory do? The most expensive and wasteful approach would be to install power conditioning devices to eliminate the sags. While this is a technically feasible approach, it does not make economic sense (except in the most extreme cases, such as ultra-reliable data centres) as the cost per kilowatt is just too high. A far better approach is to purchase PV manufacturing equipment that is certified to tolerate 'normal' voltage sags, as defined by the SEMI F47 standard: equipment should tolerate 50 per cent of nominal voltage for 200 milliseconds, tolerate 70 per cent of nominal voltage for 500 milliseconds, and tolerate 80 per cent of nominal voltage for one second.

Any equipment that can tolerate these three sags will typically tolerate nine out of 10 sags that actually occur at a PV factory. Furthermore, it is quite straightforward and inexpensive to tweak equipment design so that it tolerates sags of these depths and durations because most of the power going into the equipment goes to insensitive loads. Taking a process oven as an example, only the controller is typically sensitive to sags, while the electric heater elements are insensitive. However, the heater elements use roughly 98 per cent of the power. This means that only about 2 per cent of the total power going into the oven needs to be conditioned, which is why it is so much less expensive to adjust the equipment design than it is to clean up the power. Tiny power conditioners can be built in specifically for the most sensitive portions.

Note that equipment that meets the SEMI F47 requirements can tolerate about 90 per cent of real-world sags, not 100 per cent. This is an economic tradeoff. While it is cheap to adjust equipment to handle most of the sags, making the necessary adjustments to handle all of the sags, no matter how deep or how long, is much more expensive. After years of experience and revision, the SEMI F47 Working Group selected this reasonable tradeoff.

Figure 5. Engineers use an Industrial Power Corruptor (centre) to create calibrated voltage sags. Using these sags and the SEMI F47 standard, specialists from the Power Standards Lab can increase the immunity of almost any equipment to voltage sags, increasing yields and reliability.

Interestingly, two related IEC standards, IEC 61000-4-11 and IEC 61000-4-34, reached almost the same conclusion as SEMI F47 regarding this tradeoff. In general, manufacturing equipment that is specified to meet any of these standards will be far more reliable during voltage sags.

Voltage sag-sensitive equipment

The best time to specify SEMI F47 voltage sag immunity is before the equipment is purchased – an approach taken by all major semiconductor companies. Thankfully, it is perfectly possible to test and retrofit equipment that is already installed at a PV factory (see Fig. 5). In cooperation with field engineers from PV equipment manufacturers, specialist engineers from Power Standards Lab regularly carry out this kind of work in North America, Europe, and Asia. Using a large device called an 'Industrial Power Corruptor', they intentionally create programmed voltage sags and observe exactly how the equipment fails. When a failure is identified, a small low-cost solution – typically a capacitor on a DC supply, or even a tiny UPS – is installed at the appropriate location inside the equipment, and the PV equipment is retested. Another failure mode may occur; that failure is addressed, and the process is repeated until the PV equipment fully meets the sag immunity requirements. This process makes sense if there are several identical pieces of equipment because the same solution(s) can be applied to all. However, if a single piece of equipment is in question, it is generally cheaper to avoid the engineering cost and just install a voltage sag correcting device in front of that equipment.

Equipment energy consumption: a huge zero-cost opportunity

In the semiconductor industry, reducing process energy is just one of many potential cost reductions. But in the PV industry, reducing process energy is vital: ultimately, before any PV device can benefit the environment, it must first pay back the energy that went into its manufacture. Finding zero-cost opportunities to speed up this payback requirement is critical.

In the semiconductor industry, it has become apparent that opportunities for reducing energy consumption are driven almost entirely by recipe design, not – in the short term – by manufacturing equipment design. The same is most likely true in the PV industry. Although recipe design is critical, recipe designers are rarely given information about how their process choices affect energy consumption.

SEMI developed a standard that helps fix this problem, SEMI E6 (see Fig. 6). The electrical energy section of SEMI E6 sets out a standard way of presenting the energy consumption during a recipe or process. Several years of experience with this standard have shown that recipe designers, if they are simply given information about the energy costs of each step of their process, can easily reduce the energy costs by 10 per cent or more – sometimes by shortening a recipe step, or by performing two processes in parallel, or simply doing a process at a lower temperature or pressure.

The good news is that whenever an Industrial Power Corruptor is connected to equipment for performing voltage sag immunity tests, it records all of the energy consumed by the equipment, and generates the graphs for recipe designers. SEMI E6 energy reduction strategies are an almost free side-effect of SEMI F47 voltage sag immunity testing.

If the PV industry makes use of the knowledge base incorporated in SEMI E6, there is every reason to believe that 10 per cent or more can be removed from the process energy simply by making the process designers aware of the energy costs of each step.

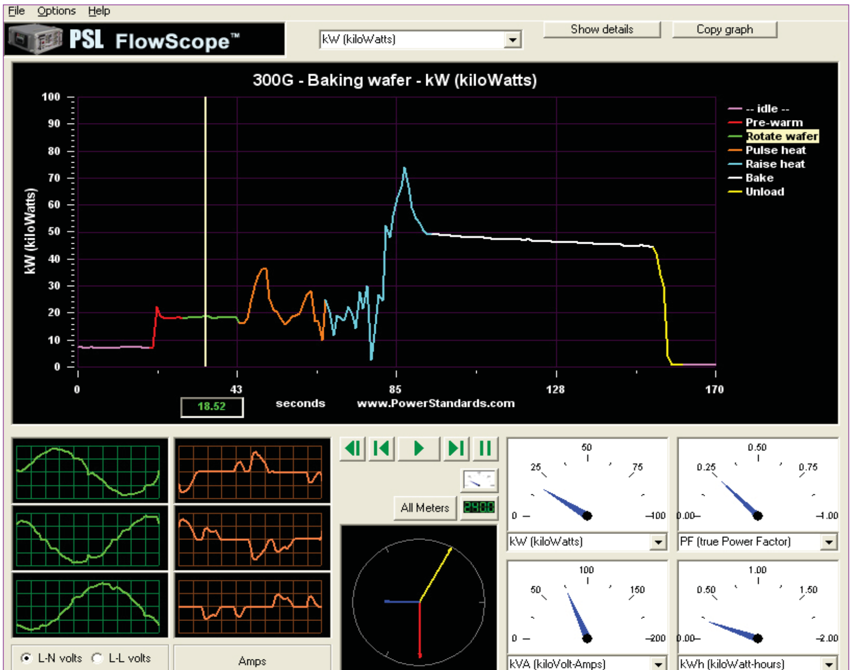

Figure 6. Zero-cost reduction of process energy consumption using the SEMI E6 standard. If process designers are given all information about the energy used during every step of a recipe, they can make adjustments. This graph can be automatically produced by Industrial Power Corruptor during SEMI F47 testing.

Recommendations:

- Specify SEMI F47 (or IEC 61000-4-34) voltage sag immunity whenever you purchase equipment for your PV factory.
- Install power quality monitors near the sensitive equipment, so you know exactly what power disturbances occur at your PV factory.
- If you are having problems with voltage sags with specific equipment, and you have several identical pieces of equipment, consider having a specialist engineer test, modify, and certify the equipment for SEMI F47 voltage sag immunity.
- Use SEMI E6 energy recording to find opportunities to reduce recipe energy consumption.

About the Author

Alex McEachern is President of Power Standards Lab and is an expert on electric power problems at sensitive locations, including semiconductor fabs, hospitals, automobile factories, and data centres. He is based in Alameda, California, but visits an average of 19 countries per year to solve difficult and interesting power problems. He is the principal author of SEMI F47-0706, and the Task Force Lead on IEC 61000-4-11 and IEC 61000-4-34, and has been awarded 29 U.S. patents on power-related topics.

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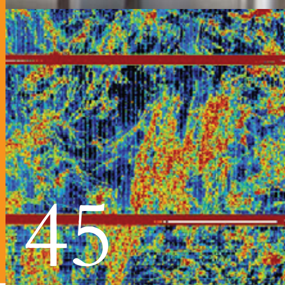
Materials


34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MultiLifter
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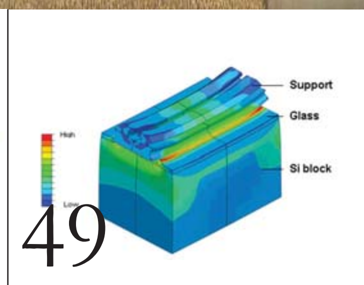
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Si block
49

SiXtron airs antireflective passivation coating that reduces light-induced degradation on PV cells

SiXtron Advanced Materials has introduced a patent-pending antireflective passivation coating technology that it says will greatly reduce the light-induced degradation problem for crystalline-silicon solar cells. The company claims to have demonstrated an 88% reduction in LID on cells treated with its silane-free Silexium coating.

The optimized process flow and reference architecture was developed by SiXtron at its lab in Montreal, with resulting cells benchmarked by the University Center for Excellence in Photovoltaics (UCEP) at the Georgia Institute of Technology.

The company says that with appropriate process optimization, solar cells coated with Silexium films can deliver net efficiency gains to existing production lines. The precursor for the AR films is delivered to standard plasma-enhanced chemical vapour deposition equipment by the firm's SunBox silane-free gas generation system.

To minimize the effects of LID – a phenomenon that can decrease the efficiency of modules in the field by up to 5% in the first hours of solar exposure – manufacturers of high-efficiency monocrystalline cells have had to opt for expensive high-grade boron-doped p-type Czochralski wafers or use alternatives to the traditional wafer manufacturing process to try to maintain end-of-line efficiency once cells are deployed to the field.

SiXtron's Silexium silane-free antireflective passivation film on a solar cell.

Solar cells made with Silexium coatings also deliver increased shunt or leakage resistance and reduced reverse current by an order of magnitude, representing additional significant protections against cell degradation, according to SiXtron.

The company says that its AR passivation coating process technology offers manufacturers a drop-in solution to the LID problem that enables maximum flexibility within their silicon wafer supply chain and can result in further economic advantages to higher-priced LID reducing technologies.

Polysilicon News Focus

UMG solar cell manufacturer Calisolar buys 6N Silicon, raises $22.5M in additional funding

Calisolar has bought 6N Silicon, in a stock-for-stock transaction between the two privately held companies. In addition to the acquisition, US$22.5 million in funding was raised from existing Calisolar and 6N investors, according to the companies.

The new funds will be used to increase capacity at Calisolar's Sunnyvale, CA, UMG-grade silicon photovoltaic cell manufacturing facility and expand silicon purification operations in Vaughan, ON, where 6N will operate as a wholly-owned subsidiary of the parent company.

Calisolar says it will tightly integrate 6N's innovative, low-cost, silicon purification techniques into its manufacturing process to deliver high-quality, high-performance solar cells. By optimizing silicon for wafering and cell manufacturing, the company hopes to significantly lower manufacturing and energy costs, improve silicon yield, and enable scrap silicon recycling.

The company began commercial shipments of solar cells in January on the heels of finding out at the end of 2009 that it was the recipient of a U.S. clean energy manufacturing investment tax credit of US$51.6 million. The company says that the credit will help it speed up the completion of its 60MW manufacturing plant and increase its production capacity to more than 200MW in the coming year.

PV Crystalox shipped 239MW of solar wafers in 2009

Solar wafer producer PV Crystalox said that it shipped slightly more solar wafers than had previously guided for 2009, on the back of strong demand at the end of the year. The wafer producer shipped 239MW, up from guidance of 230-235MW provided in November. The company had experienced deferred shipments in the first half of 2009 due to poor demand.

However, continued market overcapacity in polysilicon and wafer production means that pricing continues to come under pressure in 2010. The company said that continued cost reduction strategies at its new polysilicon and established wafering plants would continue to remain competitive.

MEMC notes solar wafer price falls stabilizing

After significant polysilicon and wafer price declines in 2009, MEMC executives have become more upbeat about demand and price stability entering the first quarter of 2010 and beyond. In a conference call to discuss fourth quarter results, the company noted that capacity utilization of silicon wafer production was at approximately 80%, with a demand recovery underway in the semiconductor industry, enabling a firming in prices to that sector. In solar, price declines were said to have moderated and the company is now shipping wafers to 10 of the top 25 PV manufacturers, compared to having made shipments to only two solar customers at the beginning of 2009.

"I think pricing stopped declining at a rapid rate we've had in the fourth quarter,

PV Crystalox's ingot cutting wire saw.

declined at a rate that we could digest," commented Tim Oliver, Senior VP and CFO at MEMC in the conference call. "And I think in Q1 we are hoping it would stay stable at that level."

MEMC reported net sales of US$356.7 million for the fourth quarter, representing an increase of 15.1% from third quarter 2009 net sales of US$310.0 million, and a decrease of 16.2% from fourth quarter 2008, when net sales were US$425.7 million.


Single crystal silicon ingot and wafer from M.Setek.

AU Optronics to invest US$540 million to expand polysilicon production at M.Setek

In an effort to keep pace with other polysilicon producers' capacity expansion plans, AU Optronics is to invest approximately US$540 million in further polysilicon capacity expansions at M.Setek. The monocrystalline silicon wafer producer will construct a second wafer fab, which will boost capacity from 3,000 tons to 7,000 tons per annum.

AU Optronics also said that it was building a solar module production line in Taichung, Taiwan, which will be ramped up in Q1 2010. A 'Reliability Lab' for PV module quality assurance was also being built. In June, 2009, AU Optronics began shipping modules to Europe. A 3MW solar park in Hungen, Germany was the first to use its modules.

Targray sees solar silicon sales volume rise 128% in 2009

Privately held materials supply specialist Targray Technology International said it has seen a 128% increase in sales volume from its solar-grade silicon, ingot, and off-spec or scrap materials business during 2009. Although a difficult year for the industry, the company cited its global infrastructure and specialist staff for the business increase in 2009.

"We expect 2010 to be an even stronger year," noted Howard Alter, director of Targray's silicon division. "As solar markets rebound worldwide, Targray's silicon transaction volume stands to expand significantly."

Targray has been involved in the distribution of solar-grade silicon to wafer, cell and module manufacturers in the PV industry, only since 2006. The company also supplies major consumables, including metallization pastes, $POCl_3$, silicone sealing, potting and adhesives, and interconnect wire, amongst others.

JA Solar outlines material ASP decline trends for 2010, starts in-house ingot production

Following its reporting of fourth quarter and year-end financial results, JA Solar gave some data points to digest about capacity ramps with a significant commentary on average selling prices (ASPs) for 2010. There would seem to be little doubt that market demand returned to robust status in the fourth quarter, with PV producers noting production was at full capacity and demand outstripped supply. The first quarter should also be very strong, unlike the previous year.

However, JA Solar executives responded to questions on the conference call that could set the tone for ASPs in 2010. One of the eye-opening responses related to its current average-weighted polysilicon costs and projected price declines for throughout the year. JA Solar noted that it is currently paying slightly below US$50 per kilogram and that the company expects this to decline by between approximately 10% and 20% in 2010, which could translate to a US$40 per kilogram price.

The company has responded by outlining plans to start in-house ingot production in response to robust customer demand for solar cells and OEM modules and to reduce production costs. Executives at JA Solar noted that it expected in-house ingot/wafer capacity to reach 120MW by the end of 2010. The company has placed an order with GT Solar for DSS furnaces to start ingot production, which is expected to come online between 2Q10 and 3Q10.

The key aspect is that polysilicon capacity continues to be added by some of the major producers such as Hemlock Semiconductor and Wacker as well as numerous new players such as GCL Poly.

Although JA Solar cannot meet projected demand without increasing cell production to at least 1.1GW in 2010, the company did expect wafer prices to continue to decline in the year. Executives put the ASP decline to be between 10 and 15% drop, compared to prices in 2009.


Targray solar-grade silicon ingot.

Chemical and Gases News Focus

Ultrapure steam system maker Rasirc signs exclusive U.S. distribution deal with Matheson Tri-Gas

Matheson Tri-Gas and Rasirc have signed an exclusive distributor agreement, in which the gas company will distribute the equipment manufacturer's purification and delivery systems for controlled humidification and ultrapure steam generation for solar and microelectronics applications throughout the United States.

Rasirc's liquid and gas delivery products.

The companies say they finalized the deal at a recent meeting between Volker Heilmann, Matheson's senior VP of strategic products and equipment, and Rasirc founder and president, Jeffrey Spiegelman. Rasirc, which has done development work with Fraunhofer ISE and a number of solar sector manufacturers, says that its technology can improve PV materials and production processes.

Ultrapure steam can be used to form the transparent conductive oxide that improves solar energy capture and can also be employed to grow wet thermal thick oxides on the backside for current isolation in backside contacts, the company says. In addition, steam can help create isolation layers between films and annealing of films to reduce defects and enhance cell efficiencies.

Matheson Tri-Gas gains rights to Gelest's high purity germane product

Matheson Tri-Gas has secured exclusive rights to the global sales and marketing of high purity germane (GeH_4) from Gelest to be offered to the electronics and photovoltaic industries. Billed as a joint venture, the partners also plan to expand manufacturing of germane to meet future demand.

Matheson believes that its capabilities in high-purity specialty gases applications, R&D purification, and analysis for the electronics sector are best suited to offer Gelest production capabilities to both markets on a global basis.

Other News Focus

Kuraray adds new production line in Europe for PVA module encapsulant

Materials provider, Kuraray Europe GmbH, a subsidiary of Japan-based Kuraray Co has expanded production of polyvinyl butyral (PVB) resin to meet demand for its branded encapsulant for solar cell modules, 'TROSIFOL,' amongst other products. The new production line adds 10,000 tons of capacity at its site in Frankfurt am Main, Germany, taking total capacity to 39,000 tons per annum.

Kuraray Europe said that it had finished trial operation, and just started commercial production.

Slurry recycling company Metallkraft receives €10m investment

Climate Change Capital Private Equity, the €200 million fund dedicated to investments in clean technology companies, has led a convertible bond issue in Metallkraft, the Norwegian company that has developed a patented process to recycle spent slurry used in cutting solar silicon wafers.

CPE subscribed for NOK85 million (€10.3 million) of the NOK140 million (€17.0 million) total convertible bond issue alongside existing shareholders and other investors. The convertible bonds have a 12% coupon per annum and a three-year term. Metallkraft will use the proceeds from the convertible bond issue to support its new plant in Singapore, which will service the 740MW wafer plant being commissioned by REC.

SMG Indium completes US$5.8M private placement

SMG Indium Resources has closed a private placement for total gross proceeds of US$5,818,000. Rodman & Renshaw acted as placement agent for the offering.

SMG plans to use the net proceeds to purchase and stockpile processed and mined indium ingots and for general corporate and working capital purposes.

SMG Indium ingots.

Order Focus

GCL Silicon places CHF35 million wire saw order with Meyer Burger

As part of its plans to boost multicrystalline solar wafer production capacity to as much as 2GW in 2010, Jiangsu GCL Silicon Material Technology Development Co., a wholly-owned subsidiary of GCL-Poly Energy, has placed an order with Meyer Burger for wafer slicing equipment worth CHF35 million. Wafer inspection systems from Hennecke Systems, a subsidiary of Meyer Berger, have also been purchased. Delivery is scheduled for completion in the third quarter of 2010.

GCL-Poly is ramping polysilicon capacity to 21,000MT by the end of 2010 and is currently constructing wafer production facilities.

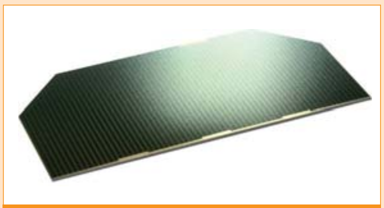
AXT to supply Azur with germanium substrates for solar CPV cells

AXT has signed a five-year contract with Azur Space Solar Power to supply germanium substrates to be used for the fabrication of triple-junction concentrator photovoltaic cells for space and terrestrial applications. The companies say that their collaboration efforts have resulted in average TJC conversion efficiencies of 40%. The financial terms of the deal and the amount of Ge substrate materials to be provided have not been disclosed by the companies.

Patrick Kilper, Azur's manager of supply management, said that "AXT has been a great partner to work with throughout the qualification process. Its germanium substrates consistently met our stringent requirements, and we are pleased that the company has its own source of germanium raw materials to ensure adequate supply as customer demand for our solar cells continues to rise."

GT Solar inks deals worth more than $60 million with GCL-Poly and Chinese start-up

GT Solar has signed contracts of more than $40 million with two wholly-owned subsidiaries of China-based GCL-Poly Energy Holdings. The first agreement, with Jiangsu Zhongneng Polysilicon Technology Development, is for GT Solar's trichlorosilane (TCS) production technology solution, while the second deal, with Jiangsu GCL Silicon Material Technology Development, is for the equipment company's directional solidification system (DSS) furnaces and ancillary equipment.



GaInP/GaAs/Ge on Ge substrate triple-junction solar cell from Azur Space.

These contracts represent the first purchases of GT Solar equipment and services by GCL-Poly and its subsidiaries.

The company also announced a follow-on order from China-based solar wafer start-up Jiangxi Sornid Hi-Tech for its GT-DSS450 ingot growth furnaces and ancillary equipment and services. Its first furnaces were delivered in the first quarter of 2009. The new contract is worth more than US$20 million.

This order was booked in GT Solar's current fourth fiscal quarter and revenue is expected to be recognized in subsequent periods. The company noted in its latest quarterly conference call that lead times for furnaces had shortened due to lower order intake and improved operations.

Linde secures gas supply deal to Bosch Solar's new cell line in Erfurt/Arnstadt

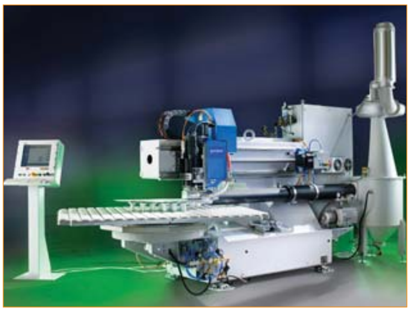
Linde gas delivery.

Bosch Solar Energy and Linde Nippon Sanso (LNS), a company of The Linde Group, have signed a new gas supply deal that now includes the new c-Si solar cell plant. LNS will supply the 630MW facility cluster with bulk silane and ammonia gas. Linde is the main gas technology supplier to all of the production lines. To date, Linde has partnered with customers on projects with a target capacity of more than 6GW.

"Linde's technology leadership in high-efficiency gases for PV manufacturing and our ability to provision these safely, has helped us bolster our collaboration with Bosch Solar Energy," said Andreas Guenther, president of LNS. "We value the opportunity to support Bosch's capacity expansion and partner in the establishment of Erfurt/Arnstadt as an important PV manufacturing site in Europe."

Product Briefings

Bystronic glass



Edge grinding of glass substrates using Bystronic glass's champ speed machine offers 99.5% yield

Product Briefing Outline: Bystronic glass has introduced the champ speed-series of glass substrate edge grinders, using experience gained from the automotive industry to provide clean, ground edges, free from cracks and shell defects, boosting yield and productivity in PV module production.

Problem: Cleanly ground edges of substrates are absolutely essential to ensure a smooth production process for solar modules. High edge quality free from cracks and shell defects is the only way to prevent glass breakage during the process. This is an important pre-condition for efficient and economical production since glass breakage is a relevant cost factor and always means a stoppage of the system, which must then be run empty and cleaned, increasing downtime and reducing throughput.

Solution: Thanks to a mineral cast machine bed, champ speed-series machines are completely vibration-free and can therefore provide the greatest precision. Substrates can be ground with extremely fine tolerances of +/- 0.1mm on absolutely perpendicular sides, even if the starting substrate has large deviations in the angles. As the machines are designed as polar grinding machines with a play-free table, both edges and corners are polished in one pass, with radius or facet. All axes are equipped with maintenance-free and highly dynamic CNC direct drives.

Applications: Most glass substrate sizes. Tolerances of +/- 0.1mm on perpendicular sides.

Platform: The modular layout of the series, champ speed machines can be expanded to create large manufacturing cells with an integrated handling device and additional drilling machine. Champ speed grind makes it possible to grind edges from a minimum finished dimension of 200 x 200mm to a maximum finished dimension of 2200 x 2600mm with C grind or K grind. The yield is claimed to be 99.5%.

Availability: Currently available.

Festo

ATBT air bearing from Festo uses minimum air consumption due to microporous structure

Product Briefing Outline: The Festo air-bearing ATBT offers contactless handling of substrates and was conceived for handling large and heavy substrates with minimum air consumption and maximum precision due to the incorporation of a microporous structure. The system allows secure high-speed transport of the work piece, while controlling the flight height with an optional integrated diagnosis function. The key to the system is that the bearing uses an air cushion without the need for high pressure. The even airflow ensures maximum precision and short cycle times.

Problem: The transport of thin-film modules between different production steps means lifting heavy and delicate goods. For process steps such as laser etching, contact with the substrate needs to be limited to avoid residue on the surface. Furthermore, the transport itself has to be very precise and smooth.

Solution: It is ideally suited to almost any task in the field of transporting and conveying flat products. The ATBT can be used for loading and unloading; as an intermediate buffer; for lifting and centring; for use in inspection and test equipment; for precise XY-movement systems or photolithography equipment. The system can also be used for holding and clamping items while applying vacuum, via the micro-porous structure.

Applications: Adjustable to individual requirements from conveying and automation to XY-motion system applications. It is offered in different sizes and with the option of rail mounting.

Platform: The air bearing consists of an aluminium extrusion frame with an air-permeable microporous structure. It is available in four sizes from 200mm to 500mm in length. Furthermore, it offers the possibility to mount high-precision air bearing rails with a special attachment system. The ATBT contains no poisonous materials and complies to a high cleanroom class.

Availability: Currently available on request.

SiXtron Advanced Materials

'Silexium' coating from SiXtron reduces light-induced degradation of c-Si solar cells

Product Briefing Outline: SiXtron Advanced Materials has introduced a patent-pending antireflective passivation coating technology that it says will greatly reduce the light-induced degradation (LID) problem for crystalline-silicon solar cells. The company claims to have demonstrated an 88% reduction in LID on cells treated with its silane-free 'Silexium' coating. The Silexium films can be used with high-performance monocrystalline boron-doped p-type Cz (Czochralski) silicon solar cells without the use of silane gas.

Problem: Solar cells fabricated with boron-doped p-type Cz wafers suffer from performance degradation when exposed to light illumination. They become 3 to 5% (rel.) less efficient when first exposed to the sun. Within hours, small amounts of oxygen in boron-doped monocrystalline solar cells (resulting in B-O (boron-oxygen) complex) react with sunlight to decrease the solar cell's output efficiency.

Solution: Silexium films have been demonstrated to effectively passivate these B-O complexes, which are responsible for LID under illumination. In this way, LID can be significantly reduced to less than 2% rel., typically 1% rel., thereby increasing stabilized (post-LID) solar cell efficiency. Silexium films can provide key benefits such as comparable end-of-line cell efficiency of SiH_4-free SiC_xN_y to pyrophoric SiN_x for front-side n^+ emitter passivation and ARC, producing significantly less LID with excellent stability. Further benefits include higher shunt resistance and lower reverse leakage current. With rear-side p-type silicon surface passivation, the PECVD SiO_2/SiC_xN_y stack has better cell efficiency than PECVD SiO_2/SiN_x stack for a PERC-type cell.

Applications: Flexibility of various passivation coatings from a single source: SiC, SiCN, SiCO, SiCON etc., for both front- and rear-side passivation.

Platform: The precursor for Silexium films is delivered to industry-standard PECVD equipment by SiXtron's SunBox silane-free gas generation system.

Availability: Currently available.

Product Briefings

ACI-ecotec

ACI-ecotec's wafer singularization system has 4,300wph throughput

Product Briefing Outline: ACI-ecotec has introduced a new wafer singularization system that is fully automatic and enables wafer separation of 4,300 wafers per hour. The ecoSplit IXL system includes a low breakage rate that has been reduced by up to 0.1% and comes in a compact plug-and-play configuration.

Problem: There is a growing need for high-throughput wafer separation equipment to meet the demands of high-volume wafering to reduce production costs. However, there is also the need to focus on wafer breakage with low breakage rates to boost yield and reduce material costs.

Solution: Running normally, the system splits over 3,000 wafers per hour and at peak times is capable of separating over 3,600 wafers/h. To achieve this, the system has two loading stations, which can each be fed with stacks of up to 250 sawn wafers once they have been pre-cleaned and manually checked. The feeding solution makes this system unique because it can be loaded during operation and thus avoid stopping times. The ecoSplit IXL functions without the need for costly gripper or handling systems. With the so-called 'dealing' technique (in the sense of dealing playing cards), in each case the bottommost wafer is removed from the stack by a special roller system. No marks are made on the surface of the sensitive solar wafers. The technology also permits wafers to be removed from the stacks one at a time, thus ensuring reliable singularization. Once wafers have been separated, they are transported by individually-adapted units to a cleaning station. The ecoSplit can be combined with any common cleaning system. During singularization, wafers are kept constantly moist to prevent them from drying out. The complete process – from loading the wafers right up until they are cleaned – is monitored and controlled by sensors as well as visualized on screen.

Applications: Bare wafer separation.

Platform: The ecoSplit IXL is made completely from stainless steel and also the plug-and-play construction with integrated switching cabinet.

Availability: Currently available.

RENA

RENA's wafer line offers 200MW production capacity

Product Briefing Outline: Due to technology partnerships and longtime experience, RENA has been able to optimize the handling and process sequence for the complete process chain after wafer sawing with its 'Wafer Line' system. With this complete system, 200MW production per annum is possible.

Problem: Complete optimization of the wafer separation process chain is required to boost capacity and throughput. The move to larger brick sizes to reduce costs requires careful system integration or separation to enable the right processing strategies.

Solution: The MultiLifter system takes out the sawn wafer beams from the saw and positions the wafer beam into a wafer basket, which is positioned in a PreWaClean transport tank. The transport tank is either dry, filled with water or with glycole, depending on the type of slurry used in the saw. The transport tank is brought into the PreWaClean, where the system loads the basket with the already pre-cleaned and 'unglued' wafers into a transport tank filled with water. The wafers are held in the basket by brushes. With a lifting transport cart the PreWaClean transport tank is brought to one of the WaSep wafer separation units where, using the integrated lifting unit, the whole basket is positioned in the Wafer Separation tank, which is filled with water. The system then distributes the wafers onto the inline lanes necessary for the inline cleaning. A cross conveyor technology is used in the case of dry wafers to position the wafers from several lanes onto one lane.

Applications: Optimization of the handling and process sequence for the complete process chain after wafer sawing.

Platform: The PreWaClean has more than double the capacity of the two follow-up lines. Therefore only one PreWaClean is necessary as supply for two WaSep-InWaClean-VarioUnload-QCheck lines. Each of the two lines has a 3000 wafer per hour capacity. Each WaSep has two separation units which work totally independent; if a failure occurs on one side, half the capacity, 1500 wafers per hour, is still available.

Availability: Currently available.

RASIRC

The RASIRC Steamer '02 promises improved oxide growth rate, film quality, and reduced operating costs

Product Briefing Outline: RASIRC has made several new improvements to its RASIRC Steamer '02, which handles controlled and purified water vapour that can then be delivered into most carrier gases for film growth in furnaces. Users of the RASIRC Steamer are claimed to have obtained improved oxide growth rate, film quality, and reduced operating costs.

Problem: Until now, the delivery of water to a process has been difficult. Choices are limited to direct liquid injection (DLI), bubblers, or membrane contactors. DLI is costly and problematic with different flow rates. At low flow rates control has limited accuracy and at high flow rates it is susceptible to bubbles in the liquid, which generate erratic values.

Solution: The Steamer technology allows the use of DI water for critical processes by removing volatiles, ionic contaminants, and other impurities from steam. Yield is increased because metals, hydrocarbons, and particles are rejected by the non-porous membrane to deliver the purest steam possible. Throughput is increased with continuous unattended 24/7 operation and up to 20% improvement in growth rate. Compared to pyrolytic torches, there is no thermal build-up with increased flow rate; it is safer as hydrogen and oxygen are eliminated from the oxidation process; it operates at significantly lower temperature, and handles a wide range of pressures and flow rates. Additions to the Steamer '02 include a control loop for the heated steam process line between the Steamer and the tool.

Applications: Wide variety of diffusion processes.

Platform: The basic system has a mass flow control device, a vaporizer that contains a source container, a heater and a membrane assembly to allow the carrier gas to enter the source, become saturated with the source vapour, and exit the vaporizer without direct contact with the liquid.

Availability: Currently available.

Outlook for consumables used in crystalline silicon cell and module manufacturing for 2010

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ABSTRACT

With growth in 2009 suffering from recession and an ongoing credit crunch, this paper presents a review of the key trends in cell and module manufacture for the crystalline silicon (c-Si) PV module market. The c-Si segment remains the largest segment, and is competing effectively with less mature thin-film technologies. PV is still a largely uneconomic way to generate power, and requires subsidy to maintain sales volume and growth. While subsidies exist, the industry treads the narrow path of growing at a healthy clip, developing robust technology and business models, and mapping paths to profitable business without subsidies once PV installations become economically viable.

Introduction

In 2010 the dynamics of the solar industry will remain at the whim of the political landscape that supports industry subsidies. Drivers to reduce carbon emissions, decrease reliance on foreign fuel supplies, or to create jobs will put support for alternative energy on the menu of policy alternatives around the world. As national governments see local advantage in promoting PV-related industry, whether through tax credit incentives or various feed-in-tariffs, carefully designed incentive schemes will be introduced. However, governments need to be sensitive to the fine line of over-subsidizing PV projects: poorly designed programs run the risk of putting money in the pockets of the project financiers as happened in Spain in 2008, or overestimating the falls in module pricing, reducing incentives, and under-stimulating the PV food chain and the subsequent installation of new projects.

Importantly, this balancing act needs to be dynamic. As silicon went into oversupply in 2008, followed closely by the global financial crisis, spot and contract pricing for polycrystalline silicon crashed from historic highs; wafer manufacturers not tied to supply contracts were able to cut prices, which flowed through the supply chain reducing module prices dramatically. As these prices fell, governments in large module-consuming countries (especially Germany) scrambled to review and adjust incentive levels in line with cheaper supplies. This balancing act will continue over the next year as western economies struggle to get out of recession.

The solar industry has built its very existence on the promise of recovering free energy from sunlight at an economic cost. What exactly the economic cost is depends on many factors, most beyond the scope of this article, but the absolute requirement to reduce the cost of the final module has been a driving force behind PV cell development for 30 years or more, and will likely continue for five years or more. This relentless push to reduce cost for a given functionality may look like Moore's law, but is subtly different. Without incentive and subsidy programs, the PV industry would be starved of the volume demand that fuels innovation and cost improvement necessary to achieve an economically sustainable cost of power generation, and would lose momentum.

> "The first dictum for the introduction of new materials: do not add cost, and provide a viable roadmap for future cost reduction."

Materials trends in the near future

With a few notable exceptions, c-Si cells (both mono- and multicrystalline) are manufactured with H-bar grids on the front and back of p-type wafers with an n-type junction on the front side, and an aluminium back surface field. This process is a compromise between low cost of manufacture, and cell efficiency. The challenge for the future is to redesign this cell architecture not only to improve efficiency, but to achieve an overall reduction in cost. In fact, this points the way to the first dictum for the introduction of new materials: do not add cost, and provide a viable roadmap for future cost reduction.

So what might a c-Si cell look like in one to three years as the industry works to achieve the point where solar power generation competes directly with other technologies? These cells might look reminiscent of cells that are produced in 2010, but there will be differences in the detailed architecture, and process flows in manufacturing.

Linx-AEI c-Si roadmap

The intrinsic cost of high-purity silicon will drive its reduced use for any cell design. Wafer thicknesses will decrease the point where either the efficiency of the cell is sub-optimal, or the physical yield of processing is low enough to impact the economic value. The Linx-AEI roadmap which captures c-Si process trends in the near and medium term is shown in Fig. 1.

	Current Leading Edge	Medium Term 2012	Future
Wafer	Multi c-Si 180 mm Mono c-Si 145 mm Predominantly p-type Wire sawn	Multi c-Si 140-160 mm Mono c-Si 120 mm Mainly p-type Diamond Wire sawn	Multi c-Si <120 mm Mono c-Si <100 mm n- and p-type Thin film on carrier substrate Cleaved
Texturization	Multi c-Si Acid based Mono c-Si Alkali based	Multi c-Si acids / alkali Mono c-Si acids / alkali Formulated texturizers	Acids / alkali Laser Dry etch
Junction Engineering	Single diffusion	Selective Emitter Deposited passivation	Backside selective emitter Boron BSF Emitter wrap and metal wrap
Anti Reflection	PECVD	PECVD PVD Coat	PECVD PVD Coat
Contact	Printed Paste	Plated Front grid Back contact Non-contact paste deposition	Silicide Point contact + Al Interdigitated back grid Interconnect on Backsheet

Figure 1. The Linx-AEI c-Si Technology Roadmap.

Materials

Areas in yellow are the most important areas of technical interest.

In the following sections we review some of the material developments that may be introduced in the next few years.

Key material trends to watch in 2010

Texturization and cleaning

Wet processes are important determinants of cell efficiency. By forming a surface that entraps light for conversion, and determining the quality of the silicon surfaces, wet processes can be a large influence in the final cell efficiency. Ultraclean processes, aggressive chemicals, and automated handling are all common in semiconductor processing, but carry costs for the pure chemistry, safety precautions, and eventual disposal of the used etchants.

In texturization, wet chemistry has shown that it is a viable and cost-effective approach to producing high quality texturization in both mono- and multicrystalline wafers. However, some of the etch conditions used are problematic. Many etchants are temperature dependent, and temperature uniformity in a cooled bath is difficult to maintain. Surfactants also present a challenge for in-line filtration, since concentrations can vary with filtration time, and high surfactant concentrations can even block filters. Several commercial suppliers have introduced formulated caustic and acidic etchants for texturization which are gaining market traction.

In subsequent processing carrier lifetimes, recombination at defect sites and passivation quality are all impacted by cleaning efficiency. The line between cleaning and etching is blurring, and in cell processing removal of a thin layer at the silicon surface both removes defectivity, and undercuts particles and contamination, helping removal. A side benefit is also the reduction of very high surface dopant concentrations that results in a more consistent resulting doping profile, and higher cell yield. Again, multiple wet chemistry suppliers are introducing formulated cleans which are seeing adoption in leading edge cell makers.

Metallization

Printed paste, despite the cost of the base metal powders used, represents a remarkably cheap and efficient way of putting metal where it is needed. As cells develop limits of the screen-printing technology (edge acuity, aspect ratio, etc.), these become the gating factors on the process. Various techniques have been introduced aimed at increasing aspect ratio and line acuity, and improved pastes formulations are continuously being evaluated to improve conductivity, and formation of ohmic contacts to various doping levels and types of silicon.

For example, work is progressing on double print techniques that increase the aspect ratio. Increases in printer alignment accuracy are important to enable double printing and collaboration between equipment makers and materials suppliers is necessary to develop viable processes.

> "Increases in printer alignment accuracy are important to enable double printing and collaboration between equipment makers and materials suppliers is necessary to develop viable processes."

Some cell designs are replacing much of the Ag front paste with plated Ni/Cu/Sn stacks, which offer high conductivity and solderability with significant reductions in Ag use. These techniques still require a seed layer of fritted Ag paste to make contact to the emitter, so the plating is performed in an incremental process step. We expect lines using this technology to move into production this year, but problems of plated defects on SiN pinholes and defects still are a concern.

In the longer term, and especially on high efficiency cells, we expect emitters to migrate to the back of the wafer, and interdigitated metal lines to collect current. This technique requires laser-ablated point contact through a rear-side passivation, and alternate metal deposition processes. Subtractive techniques may offer better quality, but it remains to be seen if this approach can be more cost-effective in standard cell designs. Our work suggests that some novel subtractive lithographic contact grids offer cost advantages over standard lithography, while improving line quality, and offering efficiency improvements of printed lines.

Selective emitters

In the drive to squeeze more efficiency out of the cell, the search to reduce the resistance at the metal/silicon contact while maintaining the optimum doping profile in the photocell has received considerable attention. For many semiconductor professionals this is best achieved with multiple masking steps and diffusion processes. However, in the relentless push to avoid additional cost, multiple routes to reduce processing steps and achieve the same result have been developed, mainly by turnkey production line manufacturers.

Techniques to achieve these selective emitters include the following approaches, among others:

- Etching back highly-doped silicon from open areas while leaving the grid line areas untouched.
- Laser doping the emitter areas, and using the paste firing to drive in a light diffusion from spray-deposited phosphoric acid.
- Differential doping through laser patterned oxide masks prior to standard processing.
- Printing dopant pastes over emitter areas that dope n^{++} emitter regions.
- Using etchant screen print pastes to open windows in an oxide before standard deposition.

All of these techniques increase efficiency with modest increases to capital and process costs; however, the reported benefits in absolute efficiency (from 1% to 1.5%) increase the power output of a panel by as much as 10%, or significantly reducing the cost per kWh and LCOE of an installation, offsetting the higher manufacturing cost. Broad introduction of SE processes started in 2009, and will continue apace in 2010 onwards.

A further development of selective emitter technology is leading the emitter contact through the wafer and making metal contact at the rear side. This can either be done by doping the walls of a laser drilled hole at the same time as emitter diffusion (emitter wrap through – EWT), or lining the through hole with metal leading to a rear-side grid (metal wrap through – MWT). While some companies have developed viable MWT and EWT processes, few are currently in volume production. We expect these technologies to become more common in two to five years.

While these processes are elegant, the laser drilled holes can weaken thin wafers, reducing mechanical yields. Some wrapped processes do not add novel materials, but some processes use conductive pastes to make contact at the back contact point. Additionally, techniques for depositing metal through the laser via will need to be implemented, possibly with plating technology.

Encapsulant

For many years, standard c-Si modules have followed a very consistent moduling approach using glass frontsheets, thermally crosslinked encapsulant, and a laminated backsheet. Well-designed cells with high-quality materials continue to perform well, and recent studies have proposed extending standard module lifetimes to 30 years or more. However, in the spirit of continued cost reduction, elimination of high-cost materials and processes are constantly being evaluated.

Thermoplastic encapsulants offer reduced laminator process times since the materials do not need a hold time at temperature to crosslink of the common encapsulants, predominantly ethylvinylacetate (EVA). This reduced processing time improves throughput, and potentially offers capital cost savings due to the reduced number of laminators

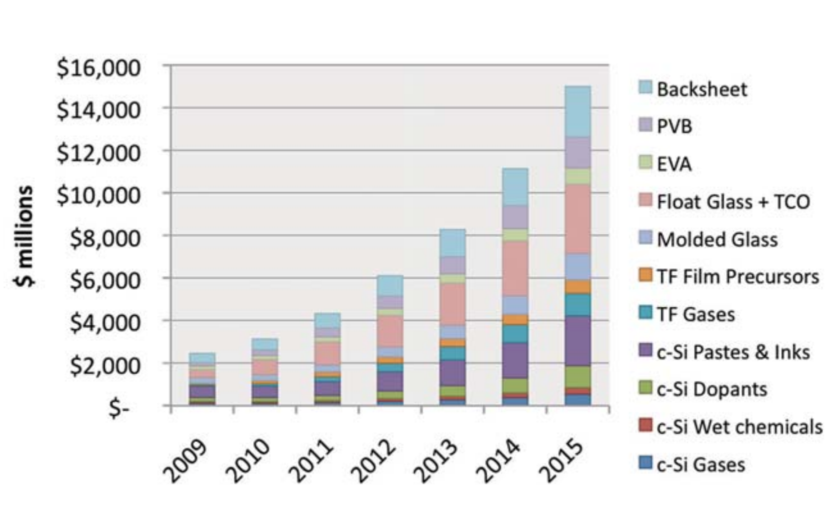

Figure 2. Materials demand forecast for PV cells and modules.

required. Critical to the introduction of thermoplastic encapsulants are the properties of the materials, and their ability to meet performance characteristics used by EVA. Novel encapsulants using PVB, olefins, urethanes and silicones have all been announced and multiple manufacturers have products in development. Certifications are underway with international test organizations, and these materials will compete in both thin-film and c-Si modules.

Backsheets

Japan was one of the first countries to promote PV installations with subsidies, and a strong domestic industry developed in the 1980s. C-Si modules used a laminated PET backsheet that offered good insulation, but that was degraded with exposure to UV light and harsh environments. As a consequence, module lifetimes were guaranteed at only 10 years. In contrast, most modules for commercial and residential use in Europe and North America are expected to last significantly longer, and the use of fluoropolymer cladding materials – mainly PVF – became common. Time supply constraints and the consequent search for alternative materials have brought in PVDF and other fluoropolymer alternatives. Simultaneously, backsheet laminators and module makers have experimented with other materials that may still satisfy the longer lifetime guarantees without failing. Additionally, the incorporation of materials with high IR reflection or good UV and visible reflectance can increase module efficiency, and reduce the environmental stresses on the PET insulation layers.

The highly customizable nature of backsheets is leading to a large number of module maker-specific products that incorporate different materials. Key for material acceptance is not only certification by UL, TÜV or IEC, but the ability to supply the very large film volumes that are needed if materials are adopted by leading module makers.

Frontsheets

For both thin-film and c-Si modules a key material is the frontsheet. While glass is a cheap, plentiful material, glass frontsheets are technically complex, with moulded surfaces to aid light capture, aesthetics, and module durability, and narrow composition specifications to meet transparency needs.

Improvements to glass for c-Si modules have focused on tuning surface morphology, while adding anti-reflective coatings to ensure more light is captured. These ARC layers can couple up to 4% more light into the cells, but their cost must be lower than the benefits of increased efficiency. Several suppliers are now offering coating materials based on xerogels, or solgels that can be applied to frontsheet glass to in-couple more light, some together with application equipment, and others in collaboration with glass suppliers. It is critical that these materials demonstrate high durability for acceptance since they will be on the outside of modules. A small percentage of c-Si modules use ARC today, but as costs are better understood, we expect the proportion to increase.

While some thin-film modules use polymeric ETFE front coatings, the high durability of these materials, combined with better transmittance, has lead some c-Si makers to offer polymer frontsheets instead of glass. Acceptance of these materials is still limited, but weight savings may open access to roof mount markets that cannot carry large additional weight.

> "Any shortfalls in market growth for thin-film modules will be easily met with c-Si modules."

Summary

Despite a significant slowdown in 2009, the outlook for the PV materials supply industry will see a slow year in 2010 with high growth in some segments. Revenues in the areas of c-Si wafer processing material in 2009 were US$916 million, with only US$134 million worth of gases and materials used in all thin-film manufacturing. The largest material segment was the moduling materials, which for the purposes of our segmentation included all glass, and finished 2009 at an estimated US$1,405 million.

Growth in 2010 will rely on the progress made in efficiency and manufacturing for Si-based thin film and CI(G)S modules. If these module types meet their efficiency and cost targets it is likely they will gain market share. In our baseline scenario thin-film manufacturing materials demand will double in 2010, while the c-Si materials demand will not grow in 2010. Moduling materials demand is forecast to grow 39% in 2010. Our belief is that any shortfalls in market growth for thin-film modules will be easily met with c-Si modules.

Fig. 1 shows our forecast for materials market growth to 2015. The overall market will grow from $2,455 million in 2009 to $8,275 million in 2013. The market growth forecast is reliant on a 'business as usual' subsidy environment. Alternative scenarios are presented in the Linx AEI Consulting report "Advanced Chemicals and Materials for PV cells and modules" published in January 2010.

The growth opportunities identified here are all important contributors to the effort to make the PV industry commercially viable without subsidy, and once successful, self-sustaining. If materials suppliers can collaborate with equipment makers and process developers to bring these innovative processes to market, the point where PV competes with utility supplied power will only come sooner.

About the Author

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

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Influence of wafer quality on cell performance

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ABSTRACT

An improved understanding of multicrystalline wafer quality can explain variations in cell performance across multicrystalline silicon blocks. Infrared scanning can detect precipitates in a silicon block, while photoluminescence combined with defect etching can reveal needle-like precipitates along the grain boundaries. Such precipitates typically lead to reduced shunt resistance. Crystallographic defects that lower the current collection and the final cell efficiency can also be identified. Understanding the influence of these defects is important for the development of a crystallization technology that results in a substantially better cell efficiency. The use of the improved material quality in an innovative cell and module technology have led to the world record module efficiency of 17%. This paper will illustrate one example of how an improved understanding of multicrystalline wafer quality can explain the variations in cell performance.

Introduction

In order to make solar energy a viable energy source, it is important to decrease the cost per Watt peak. The use of multicrystalline instead of monocrystalline silicon for solar cell production substantially lowers the cost, but also results in a lower cell efficiency potential. REC's presence along the entire value chain allows the company to better optimize the quality of silicon ingots for solar cell purposes and in this way decrease the cost of solar energy.

Experiment & results

Experimental procedure

A lower quality silicon block was taken from normal production and wafers from bottom to top were processed into solar cells. The blocks and wafers were characterized using lifetime measurements (Semilab WT-2000-PV); photoluminescence (PL; LIS-R1 BT Imaging); IR scanning (Intego) and defect etching. Lifetime values were measured on wafers that were passivated with an a-Si:H layer. The finished cells were characterized using IV, LBIC and PL.

Fig. 1 shows the relative cell efficiency from bottom to top of the selected block, the same block as is referred to throughout this paper. As can be seen, the efficiency changes by as much as 5% relative throughout the block. In the same graph the lifetimes are shown from the as-cut wafers and from neighbouring phosphorous-gettered wafers (using standard diffusion process). As outlined in the literature [1], P gettering leads to large increases in the minority carrier lifetime across the entire block with the largest increase occurring in the bottom and top regions, a characteristic that has been illustrated by the gettering efficiency of a highly phosphorous-doped layer on mobile metal impurities such as iron. These metals are present mostly in the bottom and top part of the ingot which explains the largest lifetime increase in that area [2]; however, the lifetime in the bottom of the ingot stays relatively low due to the high oxygen level [3]. The lifetime profile along the block after gettering coincides well with the overall efficiency profile.

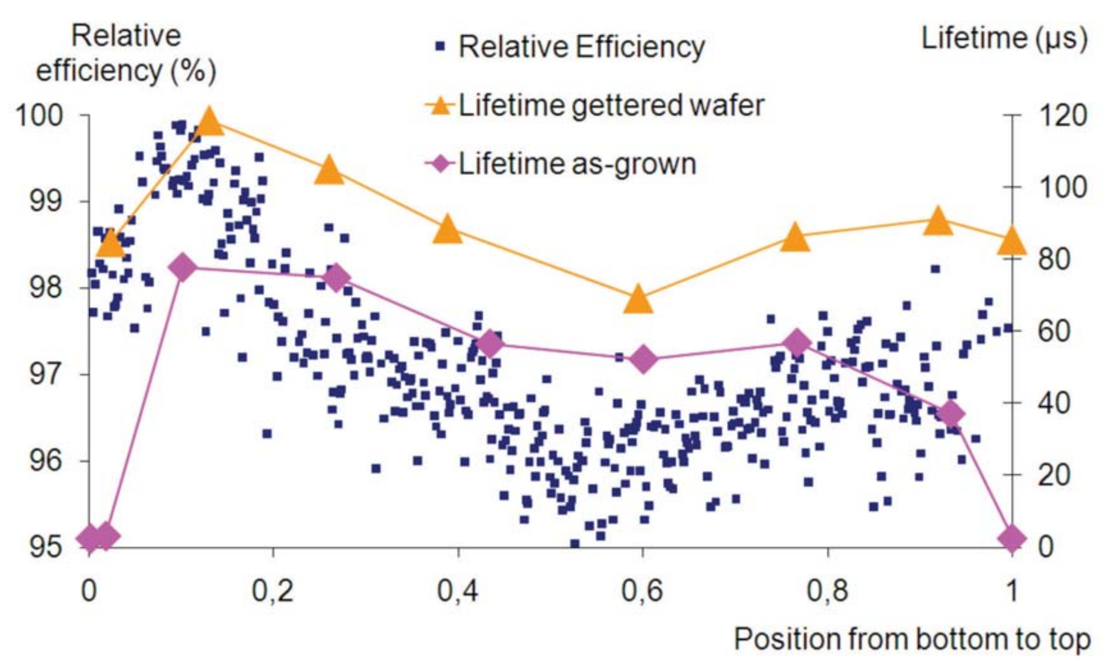

Figure 1. Relative efficiency from bottom to top of ingot showing lifetime before and after gettering of the same block.

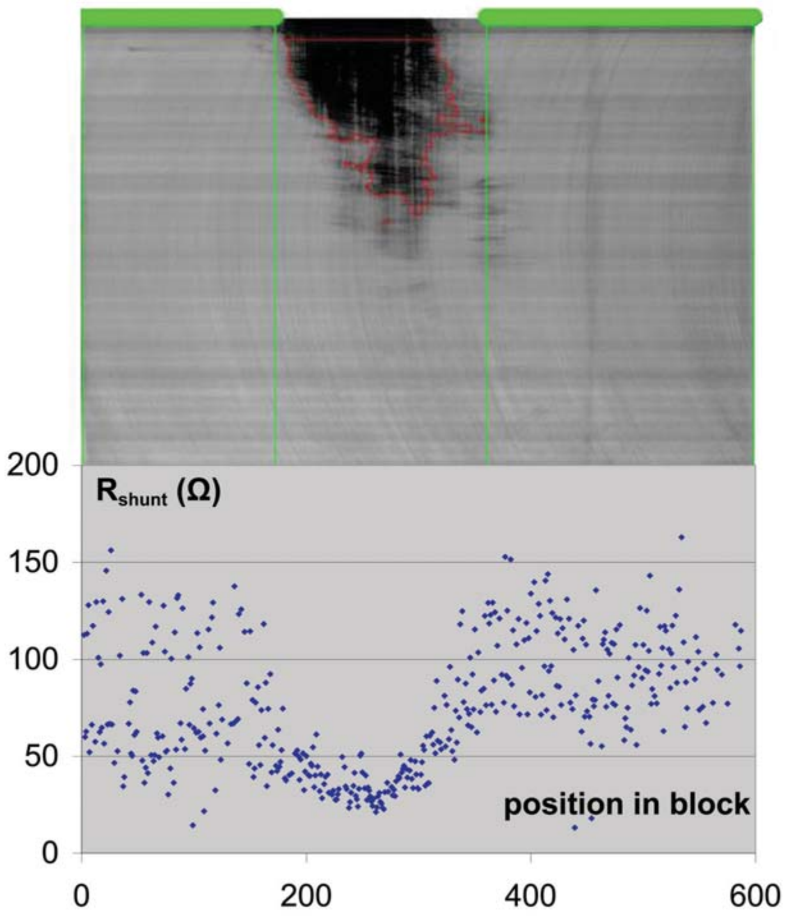

Figure 2. Influence of non-transparent area in the block on R_{shunt} of finished cells.

The lifetime of as-grown material has a less clear correlation to cell efficiency and thus has limited value for sorting purposes of initial material, as good cell performance can be obtained in low-lifetime regions of the block (e.g. the bottom and top).

Influence of inclusions

Using IR transmission, a significant non-transparent ('black') region showed in the middle of this block, as illustrated in Fig. 2. The image also shows the shunt resistance values of cells from the same position of the above block. These black areas lead to cells with a reduced shunt resistance, which led to the black areas being investigated in more detail on wafers that were cut out from this position. Fig. 3 shows the photoluminescence image of such a wafer, where the red circle corresponds with the black area of Fig. 2. The grain boundaries in that region have a low luminescence signal indicating their high activity [4].

Further analysis was carried out on these wafers using a silicon etch followed by SEM. The right-hand image of Fig. 3 zooms in on a grain boundary in that black region. One can clearly recognize the precipitate formation along the grain boundaries that reduced the shunt resistance of the cells. The nature of such precipitates has been investigated in detail by several groups [5]. It is worth noting that the reduction in R_{shunt} and the large presence of inclusions appear to begin (as crystallization starts from the bottom) roughly at the same place or slightly earlier than the drop in cell efficiency. Furthermore, the lowest cell efficiencies appear to continue for some time after the presence of inclusions has dropped, indicating that additional crystal defects may form around the inclusions and continue for some time after their disappearance.

"The lifetime of as-grown material has a less clear correlation to cell efficiency and thus has limited value for sorting purposes of initial material."

Influence of dislocations

The orange circles in Fig. 3 show regions with high dislocation density and increased recombination activity. Many investigations into this phenomenon in the past have concluded that this kind of defect originates from the metal

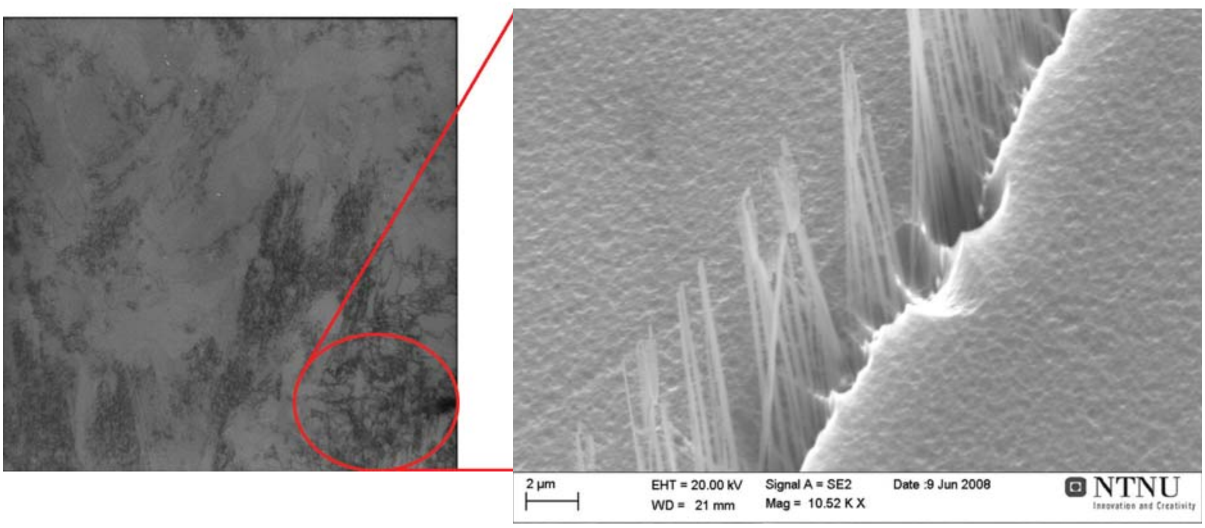

Figure 3. PL image of as-grown wafer (left) out of non-transparent area and (right) an SEM picture showing the precipitates.

decoration [6]. Fig. 4 shows the LBIC scan of a cell neighbouring the wafer shown in Fig. 3. Clearly, the dislocated areas strongly reduce the current collection [7]. It was found that the drop in efficiency in the middle of the block (Fig. 1) was mainly caused by the increasing amount of dislocated areas rather than the areas containing the precipitates [8], as explained before on the correlation between the two types of defects.

Cell results

A new crystallization technology has been developed by REC in order to minimize the influence of inclusions, metallic and crystallographic defects [9]. Fig. 5 shows the average efficiency from bottom to top for both the old and the new technology. The new technology leads to a large increase in efficiency, mainly in the bottom of the block. Towards the top of the block the efficiency decreases due to increased amounts of crystallographic defects that multiply from the bottom towards the top. Further development is carried out to reach similar efficiencies throughout the entire ingot and to align the efficiencies of all REC furnaces.

Table 1 shows the best or average cell efficiency for different multicrystalline silicon quality ranges. In industrial lines, the highest efficiencies on the best multicrystalline material are currently yielding similar efficiencies as standard monocrystalline silicon material in the same lines. This best material is taken from the bottom part of the new ingots. Using an advanced cell design, a maximum cell efficiency of 17.9% was obtained [10] and a world record module was made with 17% module efficiency [11].

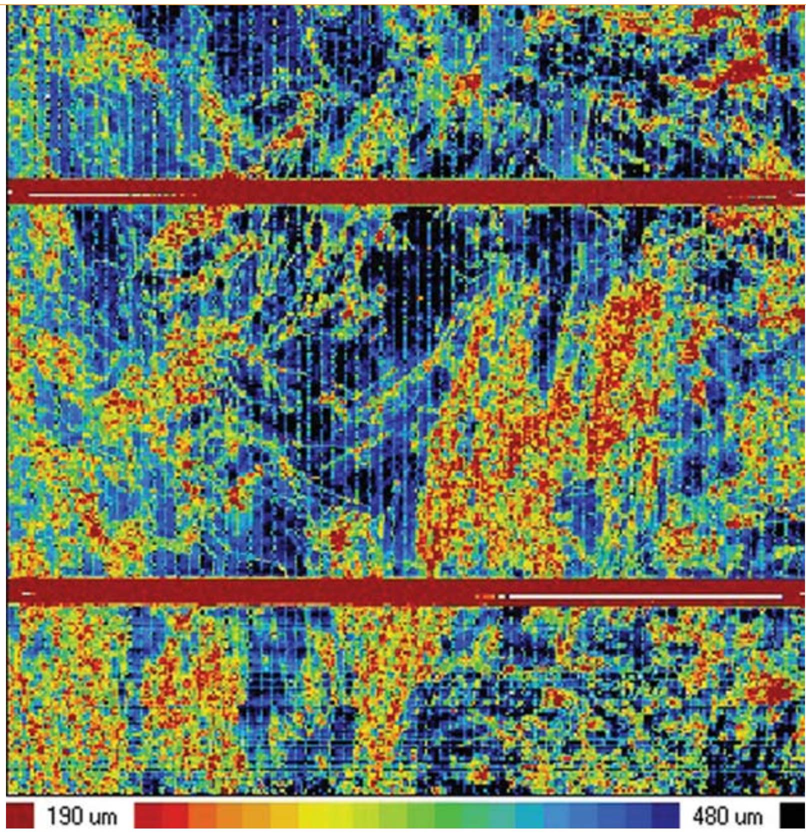

Figure 4. LBIC scan of a neighbouring cell to that shown in Figure 3.

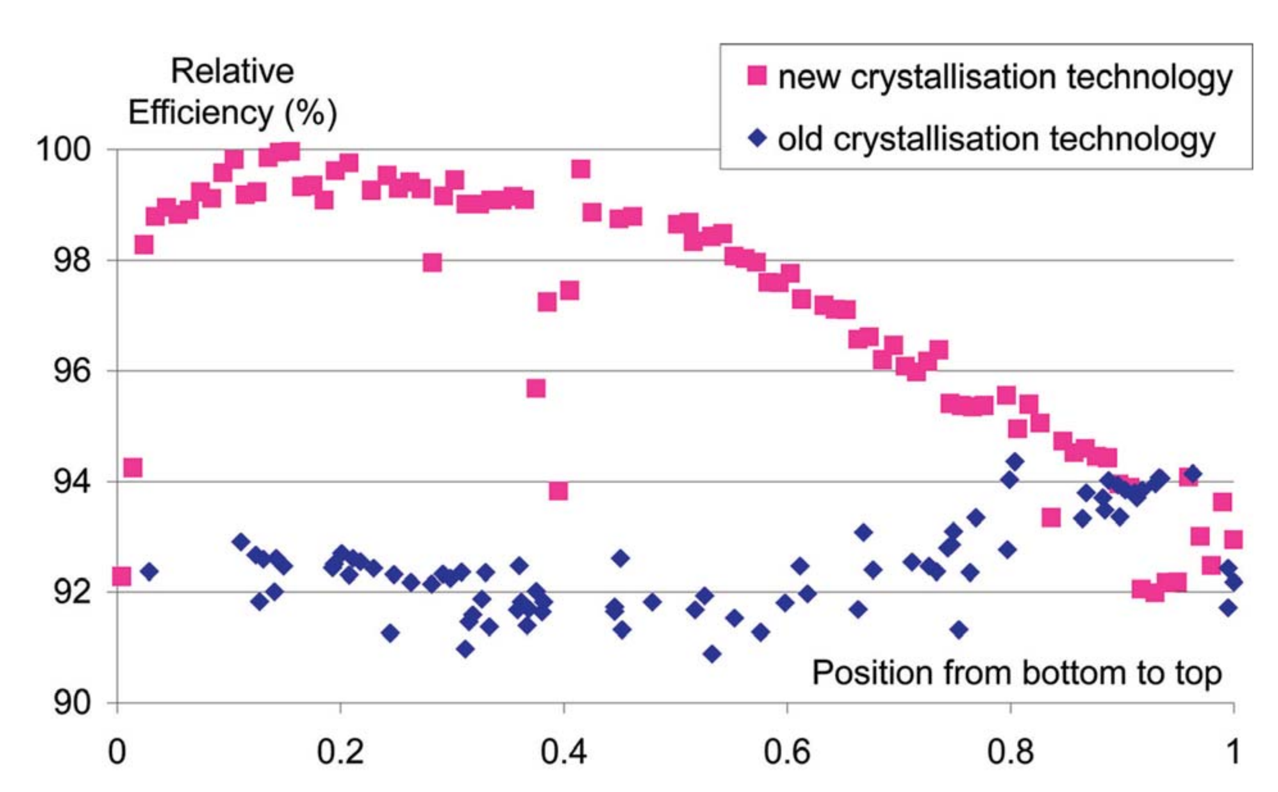

Figure 5. Relative efficiency profile from bottom to top for the old and new crystallization technologies.

Conclusions

Extensive characterization during wafer production and subsequent cell processing demonstrates the significant effect of precipitates, impurities and crystallographic defects. These are elements that limit the performance of mc-Si and are challenges in the long-term development of technology. Using an internally developed crystallization technology, a large increase in cell efficiency could be obtained, initially mainly in the bottom part of the ingots.

Quality	Cell Process	Efficiency (%)
Average multi	Industrial	15-16.5
Best multi*	Industrial	16.9
Average p-mono	Industrial	16.5-17.5
Best multi*	Advanced front side	17.9

*internally developed crystallization technology.

Table 1. Cell efficiency as function of crystalline quality and cell process type.

Acknowledgements

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The importance of temperature control during crystallization and wafering in silicon solar cell production

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ABSTRACT

Heat transfer and control of the temperature field are important in the production of silicon solar cell wafers. Present work focuses on the first steps of the production chain, i.e. crystallization and wafering. For the crystallization process, control of heat transfer is crucial for the ingot quality in terms of grain structure, impurity distribution, particle formation, and ingot stresses. Heat transfer is also important during subsequent processes, in particular the wire sawing of the silicon blocks into wafers. The paper emphasises the role of heat transfer and explains the consequences for these processes. Examples from experimental trials and measurements are combined with models and simulation methods.

Introduction

Wafer-based silicon solar cell production has today the largest market share in the photovoltaic solar energy industry. Crystallization of silicon in the form of ingots is to a large extent carried out either by directional crystallization or the Czochralski (Cz) growth process. Cutting of bulk silicon into wafers is almost exclusively done by sawing of Si-blocks in multi-wire saws.

Control of the heat transfer conditions and the thermal field is important throughout the whole production chain of solar cells. However, the importance of temperature along the production chain varies. Fig. 1 shows the most important process steps for the production of wafers. The colour of the frame depicts the importance of temperature for the process, ranked according to the influence on the wafer quality.

Ingot crystallization and wafer sawing are the process steps with the highest sensitivity to temperature variations and will be discussed in more detail later. Some importance is given to the feedstock melting phase where the high temperatures must be reached. Note that a too long melting and holding period combined with high temperatures prior to crystallization can lead to higher impurity transfer between the ingot and crucible. During block sawing the produced heat can lead to thermally-induced stresses which in addition to the sawing forces can contribute to the initiation and propagation of cracks in particular from the saw damages into the block. Therefore, the sawing speed needs to be adapted. Given that the side surfaces of the block are often grinded and polished to remove saw damages, subsequent processes such as washing/cleaning, singulation, quality control, and sorting/packing are less sensitive to normal temperature variations.

> "Control of the heat transfer conditions and the thermal field is important throughout the whole production chain of solar cells."

Temperature measurements are often challenging because of the harsh environment during crystallization and wafer wire sawing processes in particular. Thermal measurements can only be carried out in selected positions, which makes it necessary to combine measurements and modelling to investigate the transient temperature fields. On the other hand, temperature measurements can be used to verify the models.

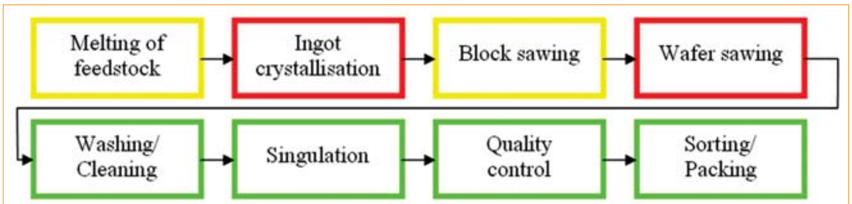

Figure 1. Main processes of the production chain in crystallization and wafering of Si solar cells (red – temperature critical; yellow – temperature moderate critical; green –temperature uncritical).

The most applied point measurement sensors are thermocouples, thermistors, resistance temperature detectors and pyrometers. Optical fibre sensors (Bragg gratings) can supply multipoint measurements along the fibre location. The most widely used method to measure the thermal field of a scene is IR imaging, which records the radiation emitted from the object of interest in the wavelength ranges 3-5µm (MWIR) or 7-14µm (LWIR). The advantages of this optical method are non-contact measurements and the ability to measure spatial distributed temperature fields within 'one shot.'

Simulation tools, in particular heat transfer models, are now available and widely used in the industry to simulate temperature fields e.g. in crystallization furnaces and during wafer wire sawing. The use of these tools is crucial during the design and optimization phases as they provide the opportunity for in-depth understanding of the process and reduce the need for costly trial-and-error approaches. For these models, the boundary conditions are crucial and it is often necessary to measure these parameters with the measuring techniques mentioned earlier.

The following two sections present in more detail the influence of temperature on the two most critical processes: crystallization of the ingot and wire sawing of the block. Models and in-situ measurements are introduced to investigate the influence of temperature fields and optimize the processes.

Crystallization

The control of the thermal field and the crystallization conditions during the silicon casting process is essential for ingot quality as many of the material properties are obtained at this stage of the process chain. Crystallization in furnaces applying directional solidification

(Bridgman) or the Czochralski process, for example, includes all heat transfer phenomena: conduction in solid parts, convection in the melt and the gas phases in addition to radiation (see Fig. 2). Due to the high temperature involved in the process, radiative transfers are the main mechanism for energy transfers in the furnace, e.g. between the heaters and other components, between the crucible support and the cooling plates, or the ingot and the furnace chamber walls.

Heat transfer and phase change

In order to better understand the crystallization process, analysis of the heat balance at the melt-solid interface can be useful:

$$\lambda_s \frac{\partial T_{sol}}{\partial n} - \lambda_l \frac{\partial T_{liq}}{\partial n} = \rho_s L V \quad (1)$$

where T denotes the temperature, λ the thermal conductivity, n the interface normal direction and ρ_s the density in the solid. Equation 1 reveals that the latent heat of crystallization (L) has to be removed through the solid phase and that the crystallization rate (V) is proportional to the difference between the thermal gradients at the solid-liquid interface. The interface growth rate or the pull speed in the case of the Cz process can be increased by increasing the thermal gradient in the solid and decreasing thermal gradients in the melt. The latter can, for example, be achieved through increased convection in the melt. Control of the temperature field and melt flow in the furnaces of industrial processes is a challenge. Due to the complexity of the transfer phenomena, the use of modelling tools is useful for process analysis and optimization [1,2].

Control of the thermal gradients during the initial stages of multicrystalline silicon crystallization is also quite important for the nucleation and growth conditions at the crucible surface. Experimental studies [3,4] have shown that encouraging dendritic growth at the initial stages of crystallization though the application of high cooling rates can result in fewer grains in the ingot. This reduces extended defects, such as grain boundaries, which is known to be beneficial for the solar cell's efficiency.

Melt and gas flow

During directional solidification processes, the flow field is not very intense and laminar flow conditions can be encountered. Nonetheless, convective transfers are important for the heat transfers and in particular for the planarity of the solid-melt interface (Fig. 2(a)) and should not be neglected in modelling studies [5]. Fig. 3 shows an example of the computed flow field in a small crystallization furnace. For the Cz process, flow phenomena are quite complex due to turbulence. The flow field and thermal gradients in the melt can be influenced through crucible and ingot counter rotations (Fig. 2(b)). In many applications, an electromagnetic field is employed to dump turbulence in the melt and control the thermal field [6]. One should also note that in contrast to directional crystallization, the contribution from Marangoni convection can be quite important in the Cz process. Gas flow does not contribute considerably to the heat transfers in the furnaces but it can affect the flow pattern due to shear stresses at the melt-gas interface and is important for the evaporation and transport of impurities.

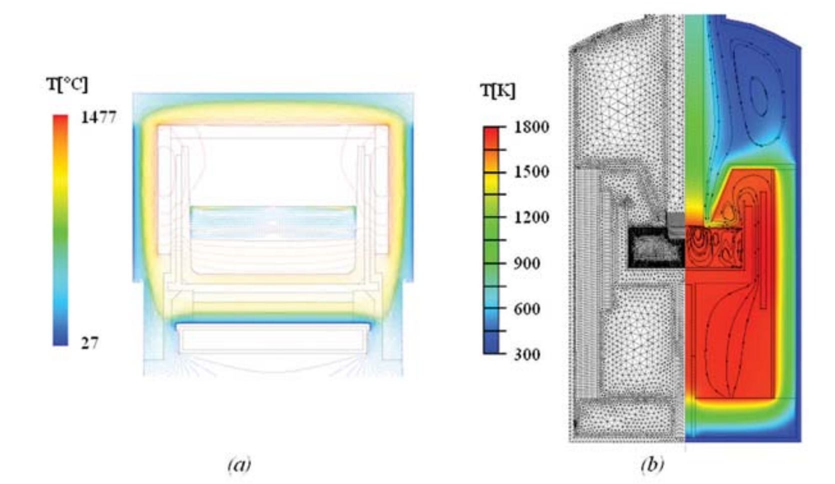

Figure 2. Simulated thermal and flow field for (a) directional crystallization and (b) the Cz process for single crystal growth [1,2].

Impurity transfers

Silicon melt flow and convection in the gas phase are very important for the transfer of impurities and therefore for the ingot quality. The impurity level depends on the quality of the feedstock. Segregation at the solid-liquid interface and convective transfer lead to variations in the impurity concentration throughout the ingot. For many impurities, the use of the Scheil equation provides a good estimate for the segregation profile. For impurities with a low partition coefficient, e.g. metallic impurities, crystallization is a quite efficient refinement process. High temperature (back) diffusion processes during the cooling phase can, however, reduce its efficiency. The furnace usually contains graphite elements to control the heating and the cooling process, while the crucible material may contain impurities such as oxygen and is usually coated with silicon nitride. Contamination from the crucible and interaction with the furnace atmosphere (e.g. oxygen evaporation) leads to the transfer of impurities from and into the silicon melt. When solubility limits are reached, precipitation of silicon carbides and silicon nitrides may occur. The control of the heat transfer and thermal field can lead to quite different flow patterns which in turn can transport impurities towards the ingot centre or to its periphery (Fig. 3) – the latter is more preferable as these regions will be removed as side cuts [7]. Particles formed during the crystallization process are known to have a negative impact on subsequent processes such wafer wire sawing.

Stresses and deformations

Although increasing thermal gradients in the solid phase results in higher growth rates, the consequence is non-uniform cooling conditions that lead to the generation of stresses and deformations in the crystallizing ingot. Even though silicon is brittle for temperatures below 600°C, it is ductile at high temperatures. In this range, thermally-induced deformations are relaxed by

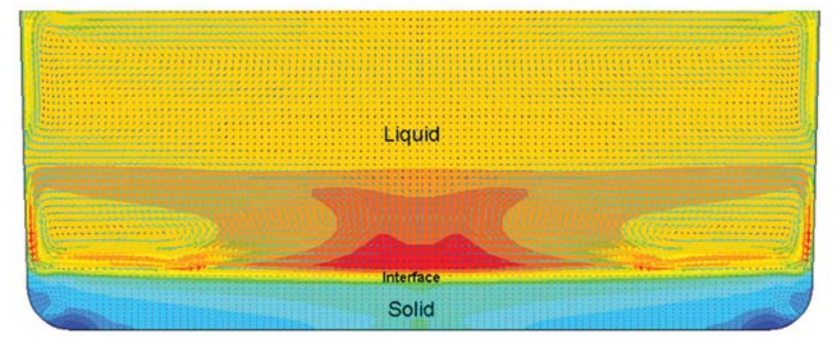

Figure 3. Velocity vectors overlaid with boron concentration (colour scale form 0.8 C0 – blue to 1.09 C0 – red). Typical boron concentration in lower circulation is 1.07 C0 while in upper circulation it is 1.02 C0 [7].

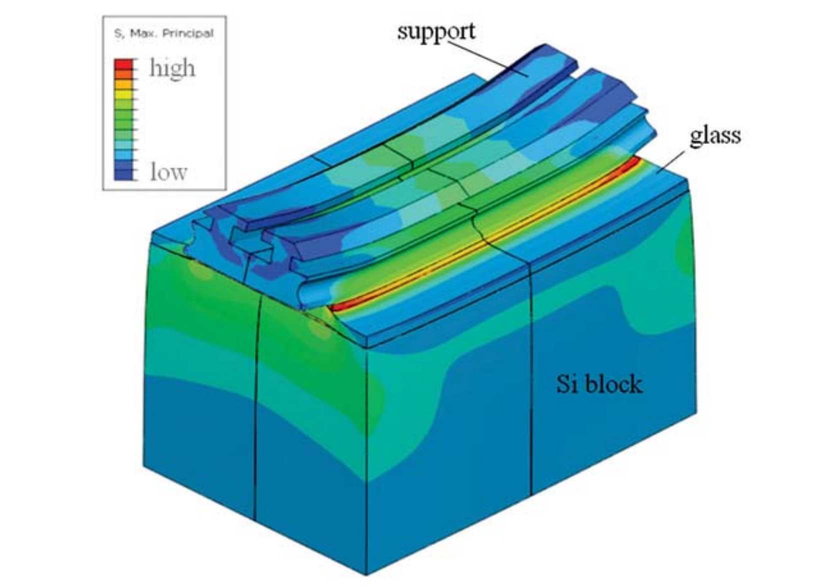

Figure 4. Computed maximal principal stresses in the silicon block after the gluing process. The deformation of the different materials is magnified.

viscoplastic deformation which contributes to dislocation generation and multiplication [8]. Note that plastic relaxation occurs during both the crystallization and the cooling phases. Knowledge of the mechanical properties of silicon at high temperatures is, therefore, important for optimizing the cooling conditions.

Control of the thermal gradient in single crystal ingots and reducing interface deflection are crucial for achieving dislocation and defect-free ingots. For multicrystalline silicon, it is important to recognise that in addition to macroscopic thermal gradients, different relative orientations of the grains lead to stress concentrations at grain boundaries, which may contribute to the generation of dislocation clusters. Note also that particles and precipitates can also lead to high short-range stresses due the mismatch in thermal expansion coefficient compared to the silicon matrix. Because of all these factors, residual stresses will build up in the ingot upon cooling to room temperature. The intensity of the latter is dependent on cooling conditions and the interactions with the crucible. Due to surface defects, it is generally preferable to achieve compressive stresses in the periphery of the ingot rather than tensile stresses to avoid fracture. In some conditions, ingot cracking may occur when ingots are removed from the furnace or during block cutting.

Wafer sawing

The sawing of Si wafers from a block is mainly carried out in multi-wire saws. Even though the first approaches to diamond-coated wire sawing are emerging to the market, the dominant technology is slurry-based sawing with silicon carbide (SiC) particles in a solution with polyethylene glycol (PEG).

Temperature is a critical factor in this process. The wire-sawing process is complex and not yet fully understood. The saw parameters used in industrial production are often based on the experience of the operators. Only sophisticated models can be used to predict the process parameters theoretically, e.g. elastohydrodynamic models [9,10].

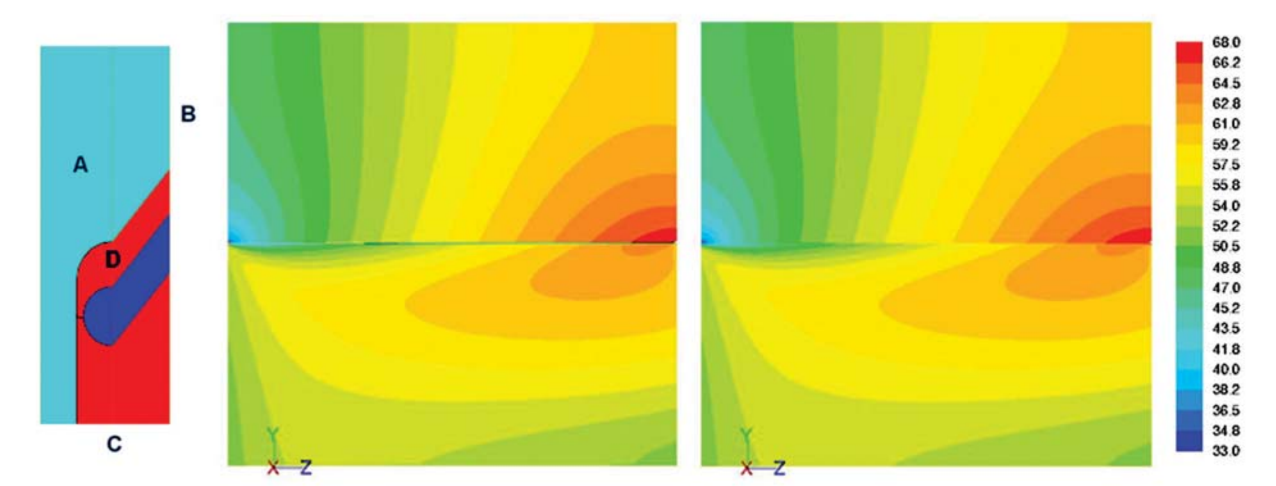

Figure 5. Simulation geometry and results. Left image: section of the computational geometry used for temperature modelling with Fluent temperature distribution (in °C) through vertical sections of the whole wafer (dark blue: wire; red: slurry; turquoise: Si-block/wafer). Middle image: midplane in the sawing channel. Right image: midplane through the wafer.

The aim of current research is to saw thinner wafers, be mindful of reducing kerf loss, while at the same time maintaining or even improving the wafer quality. The surface quality in particular has significant influence on the mechanical strength of the wafers, which becomes more important as the wafers get thinner.

Mounting of block before sawing

Prior to wafer sawing, silicon blocks are glued to a glass plate in contact with a metallic support (commonly made of aluminium or steel). During this process, the silicon brick is heated up to a predefined temperature (depending on glue properties) and then glued to the glass plate, which at the same time is glued to the metallic support. Afterwards the system cools down to room temperature. Through this series of events, thermal stresses develop in the regions in contact with the glue due to the differences in the coefficients of thermal expansion.

Finite element (FE) computations have been carried out to estimate thermal stresses introduced during the Si block gluing process (Fig. 4). Simulations have been performed to examine the effects of material properties of the glue: the initial temperature, the Young's modulus, the thickness of the glue layer and the effect of heat transfer conditions when the Si block was cooled down from 100 to 20°C. The simulations showed that tensile stresses were found in the vicinity of the block surface in contact with the glue. The main reason for the stresses developing is the difference in thermal contraction of the silicon block compared to the glue, glass plate and the support material.

The sawing process

Wafer quality is influenced by several parameters (e.g. wire speed and diameter, sawing velocity, and slurry properties). One important parameter is the temperature in the sawing zone. It is claimed that wafer warp and bow can be caused by undesirable temperature variation during the slicing [11,12]. The temperature variation will also influence the viscosity of the slurry and thus the flow conditions in the sawing gap. Slurry used in the wire sawing process consists normally of the organic liquid polyethylene glycol (PEG) mixed with silicon carbide abrasive particles. The viscosity of glycol can be seen to follow an Arrhenius dependence on temperature [13]. Also of note is that the slurry viscosity, η_s, is approximated well with corresponding temperature dependence as given in Equation 2 (temperature T expressed in Kelvin):

$$\eta_s = A\exp(T_E/T) \qquad (2)$$

The coefficients A and T_E will depend on the mean molecular weight of the PEG, the volume fraction of solid (SiC particles), and the particle size distribution. By using a value for the temperature constant in Equation 2 of T_E = 3500K, we can calculate the ratio of the viscosity at different temperatures related to the viscosity at an initial temperature T_i (i.e., the inlet temperature of the slurry). In quantifying the temperature variation, it was decided to perform temperature measurements and heat modelling of the silicon block/wafer, including the slurry and the wire. As will be seen in the following section, the temperature variation led to a significant slurry viscosity variation within the sawing gap. Whether this also significantly affects the distance between the wire and the silicon block and thereby the material removal rate is not yet clear and is currently undergoing research.

Saw parameter	Value
Wire speed	14 m/s
Wire diameter	120µm
Wafer thickness	150µm
Width of sawing cut	150µm

Table 1. Sawing parameters.

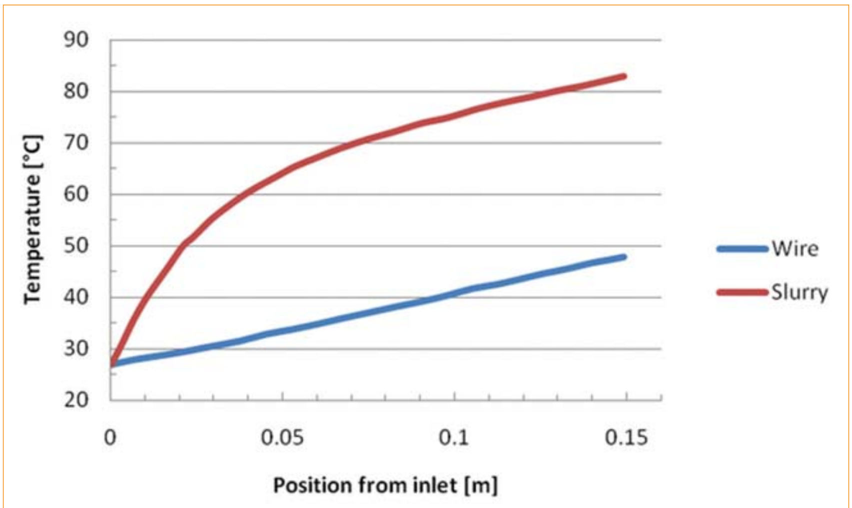

Figure 6. Profile of temperature in wire (centre) and slurry. The slurry temperature is taken in the midplane of the wire halfway between the wire and silicon surface.

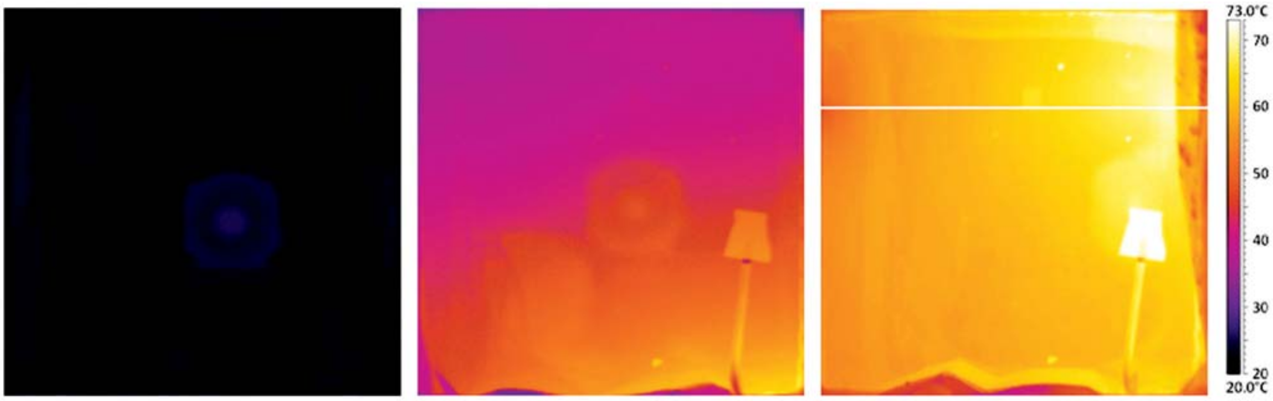

Figure 7. Full-field thermal image of the front surface of the block. An approximately 5mm area at the wire entrance and wire exit are shielded by the splash protection. Left image: a block at room temperature before sawing. The reflection from the camera is visible in the centre of the image. Middle image: temperature field at about 2mm table progress after wire/block contact. A temperature point sensor can be seen at the right of the image. Right image: temperature field at the end of the sawing process. The sawing front is indicated by the white horizontal line [14].

The following two sections present temperature measurements and heat modelling of a multicrystalline silicon block during wafer sawing. Table 1 specifies the sawing parameters used for the measurements and modelling.

Temperature modelling

The differential equation for heat conduction and convection is solved simultaneously in the silicon block, slurry and wire with the use of the computational fluid dynamics (CFD) code Fluent. End effects at the block top and bottom are neglected and symmetry is assumed between wafers. In this way, the three-dimensional geometry is confined to a volume consisting of half of the thickness of the wafer below the wire and halfway into the sawing channel. The whole wafer/block is included in the wire and sawing direction (Fig. 5).

To avoid a complicated free-surface flow problem we anticipate that the sawing channel is filled with slurry. The power supplied to the wire saw machine is partly used to remove silicon kerf from the block, while most of the power ends up as friction heat in the gap volume between the wire and the silicon surface. In the simulations depicted in Fig. 5, a power source of 10W is specified for the slurry in the region D (left-hand image). The temperature at inlet for slurry and wire is set to 300K. On the boundaries Inlet A, Outlet B and Bottom C, the heat flux is specified to be proportional to the temperature difference between the surface and the surrounding medium.

Taking a large view of the whole wafer, there seem to be only minor differences between temperatures in a midplane in the wafer compared to a midplane in the sawing channel (Fig. 5). A more close-up view is needed to reveal the local temperature variations. The graph in Fig. 6 shows how the temperature increases in the wire and slurry in the wire direction.

Temperature measurements

Temperature measurements can be carried out with an IR-camera. This is a non-contact technique and thus does not influence the process. In-situ measurements can be performed by installing a splash protection and investigating the polished front surface of the block. Furthermore, IR-camera measurements give full field information about the absolute temperature distribution of the block surface. To obtain absolute measurements it is necessary to develop a good model of the emissivity of the different regions of the block [14].

Fig. 7 shows the compensated temperature field measurements at different stages of the sawing process. The left image shows the temperature distribution before starting the saw run when the whole block is at room temperature. The temperature field in the centre image was recorded in the beginning of the saw run after about 6 minutes. This corresponds to a table progress of about 3mm after contact is made between the wire and the block. The wire has barely entered the block and is hidden behind the splash protection. It can be seen that the temperature increases rapidly when the wire starts to saw. After just 6 minutes, a maximum temperature of 60°C is obtained, but the temperature increases only slightly when the sawing process progresses.

In the right-hand image in Fig. 7, a maximum temperature of about 70°C can be seen. However, the block temperature depends on the saw parameters. Friction force increases slightly with wire speed [15] and so friction heat generation is about proportional to wire speed. A higher wire speed will therefore contribute strongly to increase the temperature. Slurry viscosity and the table speed also influence the absolute temperature.

Discussion

The presented temperature measurements verify the modelling of the temperature field. The temperature gradients during wafer sawing can contribute to deviations in several wafer quality parameters [11]. The temperature variation from the start of the saw run until the maximum temperature is reached can be estimated at about 50°C, while the temperature difference from wire entrance to wire exit after reaching stable sawing conditions is about 20°C. This leads to thermal expansion-induced shape deviations in the wafer. From the experiments, we know that the thermal conditions are almost stable after 20 minutes corresponding to a change of typically 4-8mm in table position.

Based on the coefficient of thermal expansion for Si ($\alpha_L = 2.6 \cdot 10^{-6}$ K^{-1}) and assuming unrestricted expansion of the block, an estimation for the warp and bow can be calculated. The resulting warp will be a maximum of 6.5μm. This will be superimposed on a bow of maximum 16.5μm relative to the centre wafer of the block. These shape deviations are in the range of a typical saw mark criterion for an A-wafer.

A more complex model is needed to calculate the total influence of thermal expansion taking into account the glass plate, the metal support and the thermal conditions in the saw, in particular the thermal expansion of the wire guides.

However, the most critical parameter is the change in the slurry properties. The heat is generated in the sawing channel. If the temperature increases the viscosity of the slurry will be decreased; thus, the slurry properties are significantly changed along the saw channel, which will influence the quality of the sawing process.

Conclusions

The production control of Si wafers is currently moving from a mainly empirical towards a more scientifically-based approach, which naturally requires more detailed knowledge about the processes. In this context, advanced temperature measurement techniques and the development and use of simulation tools become increasingly important.

There is a huge body of work dedicated to the study of crystallization processes and in particular to the Cz process. It is now well established that control of the thermal field, crystallization conditions and melt flow is essential for ingot quality. Dedicated simulation tools for the silicon crystallization process are now available and increasingly used by the industry to analyse and optimize the process. These requirements are in turn pushing the modelling community towards a more refined description of the process including e.g. impurity transfer with the furnace atmosphere, advanced melt flow models and grain structure predictions. The use of heat transfer models for inline control of the processes is still limited. There is, however, a growing trend towards physically-based PID controllers.

The study of the influence of temperature variations on subsequent processes is the topic of more recent research. Sawing parameters dictate the temperature field during wafer sawing. The results presented here show a typical temperature difference of more than 20°C from the wire entrance to the wire exit, with a measured maximum temperature of the Si block of about 70°C. The temperature gradients influence the warp and bow parameters of the produced wafers. Furthermore, the change in slurry viscosity is introduced as a critical parameter. The presented temperature measurements verify the models to a large degree.

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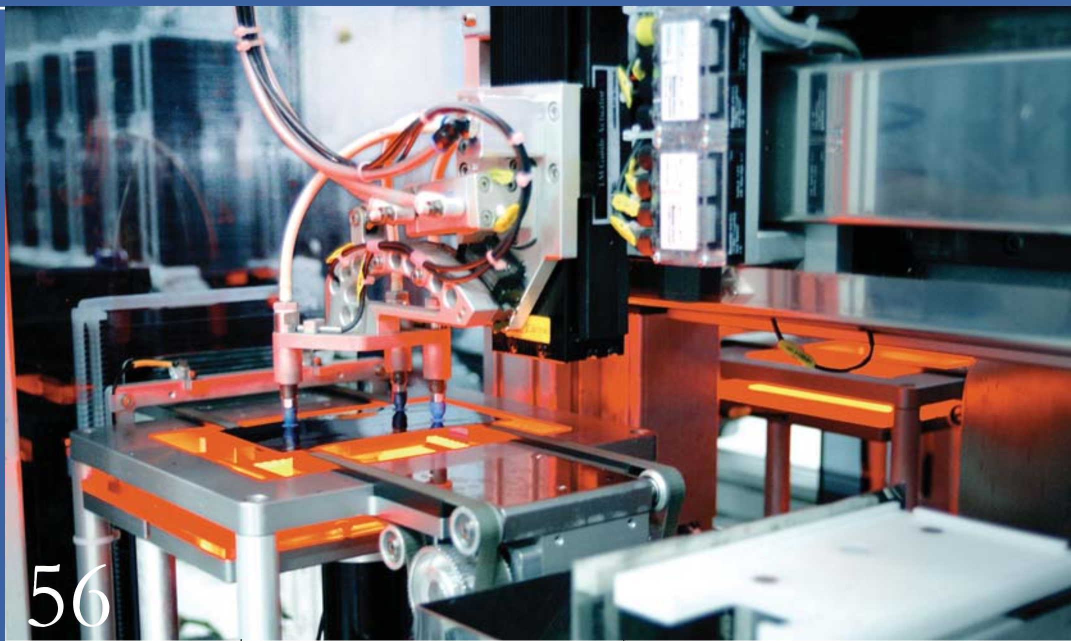
Cell Processing



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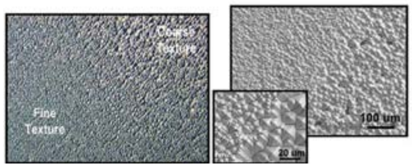


81

Roth & Rau expands c-Si market share with OTB Solar acquisition

In an effort to expand its footprint in the crystalline silicon solar cell arena, Roth & Rau has acquired Dutch firm OTB Solar, a subsidiary of OTB Group for €35.5 million. According to Roth & Rau, the acquisition will lead to an expansion of OTB's product offerings as the company has some new, highly competitive technologies that it expects to be able to develop further and expand into new markets. Roth & Rau also noted that in the future only a small number of equipment suppliers will have the expertise and product portfolio to meet the needs of large, global PV manufacturers.

Inside Roth & Rau's production facility.

"OTB's products optimally supplement our technology portfolio and will significantly contribute towards boosting our turnkey business," commented Dr. Dietmar Roth, CEO of Roth & Rau AG. "We also expect to generate synergies by integrating OTB's product development capacities and its project management team, with its successful track record on the market."

"Like cell and module manufacturers, equipment suppliers are also undergoing a far-reaching process of consolidation," added company CFO Carsten Bovenschen. "At the end of the day, there will only be a small number of providers with high process expertise, a global presence and the critical mass to negotiate with customers on equal terms. We see the takeover of OTB as a further consistent step within our growth strategy".

OTB has recently developed antireflective coating systems and turnkey production lines for use in the manufacture of crystalline silicon solar cells. It also has a core competency in PECVD coating processes and industrial ink-jet printing applications, which could become widely used for high-efficiency solar cells.

Roth & Rau said that it would issue new shares of €30.0 million and remaining amount in cash to fund the acquisition. The company expects to generate cost savings from certain synergy effects and expects positive earnings contributions from OTB from the 2011 financial year onwards.

R & D News Focus

Mitsubishi claims new solar cell performance record on thick and thin wafers

By reducing the contact resistance at the electrode, Mitsubishi Electric has increased the cell conversion efficiencies of its polycrystalline silicon wafers to 19.3%. Confirmed by the National Institute of Advanced Industrial Science and Technology (AIST) in Japan, the cell (15cm x 15cm x 200µm) is 0.2 points higher than the company's previous record of 19.1%. The company also reported an ultrathin polycrystalline silicon PV cell (15cm x 15cm x 100µm) reached efficiencies of 18.1%, a 0.7-point improvement over the company's previous record of 17.4%, also verified by AIST.

Mitsubishi's 19.3% conversion efficiency polycrystalline silicon PV cell.

Mitsubishi's approach to resistive loss uses a treatment to the wafer prior to electrode formation to improve electrical contact performance. The company said that this reduced resistive loss by 4% compared to previous PV cells. The 0.2-point improvement over the previous record of 19.1% enables the electrical output in a cell of practical measurements to increase by approximately 1%, from 4.16W to 4.2W.

The new performance results were obtained with the integration of previously developed technology, such as a low-reflection, honeycomb-textured surfacing process that reduces sunlight loss caused by reflection and a reflective structure for the rear surfaces of the cell.

Trina Solar develops high-efficiency square monocrystalline PV cell using proprietary process

Trina Solar has developed a square monocrystalline-silicon cell with enhanced power output utilizing a proprietary improved photovoltaic cell manufacturing process. Using specially designed metallization and passivation techniques, the company says that the advanced cell structure should significantly boost cell conversion efficiency, achieving up to 18.8% in test laboratory production.

According to Trina, this technology is also expected to improve module output due to increased light absorbing surface area of the square-shaped cell.

Additional details about the cell architecture and the process technology were not disclosed by the vertically integrated Chinese solar manufacturing company, nor did it reveal when it expects to have the new cell running in volume production.

Trina has said it will have between 850 and 950MW of cell manufacturing capacity online by the end of 2010.

Solarfun targets light-induced degradation in new 'ECLIPSE' solar cell

Light-induced degradation (LID) problems with boron-doped p-type crystalline-silicon solar cells has been targeted by Solarfun Power Holdings with a new cell configuration, dubbed 'ECLIPSE,' which is claimed to reduce LID impact in PV modules to about 1%. Standard cells can suffer from up to 3% degradation during the first day of exposure to the sun. Solarfun claims that module power reduction is limited to less than 2W compared to about 4W to 5W for a 180W module equipped with standard cells.

"The advance is made possible by our vertically integrated manufacturing model and ability to control the quality of raw materials throughout the production process" commented Peter Xie, President of Solarfun. "By adjusting chemical properties in both the ingot-making and cell-processing phases of manufacturing, we have achieved a low concentration of impurity while still maintaining high yields. We remain committed to our strategy of continually enhancing our technology to produce differentiated and more efficient products for our customers."

Solarfun claims that ECLIPSE modules will give an increase in electricity generation of about 1% to 2% over a one-, five-, 10-, and 25- year period when compared with standard modules.

Micron Technology, Origin Energy form solar PV joint venture; few specifics offered

In a cross-industry collaboration between major players in their respective sectors, Australian conglomerate Origin Energy and U.S. semiconductor manufacturer Micron Technology have formed a 50:50 joint venture focused on photovoltaic technology

Order Focus

Amtech's Tempress unit adds another US$19 million in solar production tool bookings

Amtech Systems said that its solar capital equipment subsidiary, Tempress Systems, has garnered approximately US$19 million in orders for its photovoltaic diffusion processing systems from several new and existing customers in Asia. The company expects the orders to ship in the second half of this year. The company said that with these most recent bookings, its total solar orders to date in FY2010 (which began Oct. 1) have surpassed $70 million.

CyberOptics enters solar market with first sale

CyberOptics, a supplier to the semiconductor and electronics assembly market, has received its first order worth US$550,000 to supply its CWA30 Solar Wafer Alignment Camera to an unidentified customer that makes solar metallization equipment used in solar cell manufacturing.

According to the company, its CWA30 platform can align a broad range of wafer technologies, including selective emitter, metal wrap-through, and print-on-print. It also has the ability to perform traditional wafer edge alignment of both monocrystalline and polycrystalline wafers. The units will delivered in the first and second quarters of 2010.

Zhejiang Hongchen places further PV1200 metallization line orders with DEK Solar

DEK Solar has received further orders for its PV1200 solar cell metallization lines from Zhejiang Hongchen. The China-based PV manufacturer first used these systems in early 2009, and then placed a follow-on order in May 2009 as it ramped cell production. Zhejiang Hongchen had plans to increase its annual production capacity to 100MW by the end of 2009 and to 200MW by the end of 2010.

DEK further commented that it is finding great demand for its high-throughput c-Si metallization lines from China-based PV cell manufacturers. The company said that it had recently completed installation of a large number of lines for another high-profile turnkey provider in the region, without identifying the customer. Its PV1200 and more recent PV3000 metallization lines are designed for also have six-sigma process rating and 12.5 micron resolution, while capable of 1200 wafers per hour throughput.

"Both our PV1200 and PV3000 metallization lines are being received extremely well by the Chinese marketplace," noted Daniel Chang, DEK Solar Alternative Energy Project Manager.

Bosch Solar to sell non-prime crystalline solar cells to ITS

Bosch Solar has signed a multi-year framework agreement with Innotech Solar (ITS) to supply the firm with the majority of its non-prime crystalline solar cells. Quantities and financial terms were not specified. Using a proprietary processes, ITS will increase the efficiency of the solar cells and use them in solar modules for power plant and special applications, the company said.

Coherent secures US$22 million in 'Equinox' solar equipment

In announcing its financial results for its first fiscal quarter, laser photonics specialist Coherent highlighted that it has received approximately US$22 million in new purchase orders for its laser-based tools for solar cell processing during the quarter. The company said that its second-quarter revenue guidance includes approximately US$8 million from the solar production systems order. Coherent guided second quarter revenue of between US$135 to US$140 million representing a 10% to 14% sequential increase from first quarter revenue of US$122.8 million.

"We are particularly pleased with orders of approximately $22 million for our 'Coherent Equinox' solar production tools, which are scheduled for delivery during fiscal 2010," said John Ambroseo, Coherent's president and CEO. "Given our backlog and outlook, we are raising our fiscal 2010 projection for net sales to US$525 to US$550 million."

Despatch sells first dryer/firing furnace tool to Chinese solar cell manufacturer

Despatch Industries has sold its first dryer and firing furnace solar-cell manufacturing system into China. The company said that the UltraFlex tool was bought by a top 10 Chinese cell producer. Despatch launched the reengineered, reduced-footprint UltraFlex platform in September 2009. It features an integral V_{OC} thermal oxidizer and has a processing capacity of 1200-2000 wafers/hr.

The Minneapolis-based company says it holds the number-one market share for metallization firing furnaces, having sold more than 200 units into China and shipped over 10GW of firing furnace production capacity worldwide. It announced in December that it had received more than $10 million in solar-related bookings in the fourth quarter.

Hanwha Chemical commissions Spire-equipped 30MW turnkey solar cell production line

Hanwha Chemical has commissioned a 30MW turnkey multicrystalline-silicon solar cell line provided by Spire. The line has exceeded both its efficiency and throughput specifications producing 15.8% efficient cells at the rate of more than 34MW per year, according to the companies.

"We are very pleased with the performance of this solar cell line," said Roger Little, chairman/CEO of Spire. "Since Hanwha put their confidence in Spire, it was important for us to deliver a line that exceeded specifications. This is Hanwha's debut to the solar cell market, and this line makes them very competitive. Spire has been providing turnkey PV lines for over 20 years and is known principally for its module lines; the success of this line continues to demonstrate our ability to provide state-of-the-art cell lines as well."

development. The companies offered few details about the venture, including its name, facility locations, financial arrangements, or technology paths.

"As we have looked to leverage our core strengths in other markets, photovoltaic energy technology is a natural area of investigation," said Mark Durcan, Micron's president/COO, in a statement. "Origin is a company with a significant interest and history in renewable energy technologies. Combining our semiconductor manufacturing expertise with Origin's solar experience could result in a strong partnership."

Origin has been working on the 'Sliver' mono-Si PV technology (see image), developed at the Australian National University's Centre for Sustainable Energy Systems, at its dedicated research and pilot manufacturing facility in Adelaide's Regency Park for several years.

Origin Energy's 'Sliver' cell technology.

Cell Production News Focus

Keithley Instruments' solar cell testing survey: the results

Keithley Instruments has conducted a survey of solar cell and PV device researchers and manufacturers working in government, universities and corporate labs and manufacturing facilities. The survey aimed to identify distinct differences in testing methods and priorities among respondents from Asia, North America, and Europe. The study was conducted during summer 2009 using a by-invitation-only online survey generating 564 responses.

The most prominent indication from the survey was that, globally, the PV industry is focused on improving device efficiencies as the dominant development priority. 'Reducing manufacturing cost' was the second most important among the respondents, although substantially less important than the need to boost device and panel performance.

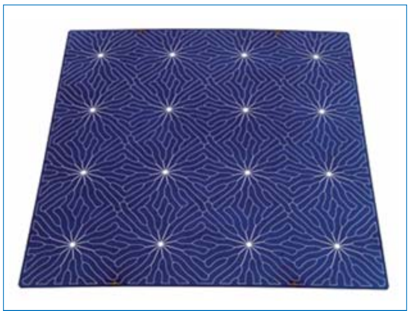
In terms of R&D, a large majority of respondents identified their 'key parameters' for measurement as short-circuit current (I_{SC}), open-circuit voltage (V_{OC}), maximum output power (P_{MAX}) and conversion efficiency.

The priority of test parameters characterized as PV moves into production returned fairly balanced results; however, there was disagreement about the most important tests in comparison to the results from the research lab. Asian respondents were far more definitive about the most valuable solar cell tests for production than for research applications.

Engineers seemed to be relatively comfortable with the solar cell industry's complicated sequence of tests.

AT&S to build back-contact cell line for Solland Solar

Solland Solar and AT&S are nearing the production roll-out of Solland Solar's 'Sunweb' back-contacted solar cells with the news that AT&S will build a prototype production line at its facility in Leoben-Hinterberg, Austria. The plan is to have the partners' line completed and operational in the summer of 2010. Objectives include full evaluation of the processes and costs as well as certification under IEC 61215 and IEC 61730.



Solland Solar's back-contacted solar cell.

The company's expect commercialization to occur by the end of 2010. The Sunweb technology is designed to improve cell conversion efficiencies as well as lower production costs. The process equipment being developed by AT&S comes from the printed circuit board industry, which could result in much lower production costs than conventional c-Si equipment.

SVTC updates progress with solar customer cell developments

Independent development foundry SVTC Technologies, based in San Jose, California has said that it has successfully completed solar cell design-to-commercialization milestones for five initial customers. In previous public announcements, Bloo Solar and JA Solar were said to be collaborating with SVTC as well as equipment supplier Roth & Rau. SVTC is well known in the semiconductor industry and branched out into the solar field in April, 2008. The new division is called SVTC Solar.

"Each customer's requirements represented a novel and complex cell design that required our engineers to modify their standard approach, but in each case a highly successful outcome was achieved," said Mike Moore, Vice President and General Manager, SVTC Solar.

Recently, Bloo Solar said that by partnering with SVTC, they had been able to develop a solid technology baseline that is now entering commercialization, which had been developed over the last three years. SVTC's development model is said to ensure customer ownership of IP developed using SVTC's services.

NREL invests US$12 million in early stage solar development

The National Renewable Energy Laboratory (NREL) will invest up to US$12 million in total funding in four companies to support the development of early-stage solar energy technologies and help them advance to full commercial scale. The money will go towards expanding the U.S. clean energy economy and the development of solar energy as a more cost-competitive source of electricity.

U.S. Department of Energy Secretary Steven Chu (pictured) announced this investment on January 21. "Expanding the solar power industry in the U.S. can create new jobs, reduce carbon pollution and save consumers money," he said. "By partnering with NREL, these companies will be able to gain from their expertise, accelerate the pace of innovation and help get technologies to market faster."

U.S. Department of Energy Secretary Steven Chu.

Companies awarded under the DOE's Photovoltaic Incubator Program will work with NREL to transition prototype and pre-commercial PV technologies into pilot and full-scale manufacturing. The anticipated subcontracts will be up to US$3 million each and will be awarded as 18-month phased subcontracts with payment made upon completion of project milestones.

The DOE is investing more than US$117 million through the Recovery Act to develop and deploy solar energy technologies.

Business News Focus

Evergreen Solar claims U.S. plant to be cost competitive with Chinese manufacturers

String Ribbon solar module producer Evergreen Solar expects its nameplate capacity to reach 170MW in 2010, based primarily on its Wuhan, China facility coming online as expected this summer. The 100MW plant, operated by Jiawei Solarchina, is expected to ramp to 20 to 25MW of capacity per quarter in early 2011 and produce a wafer for about US$0.45 per watt and a panel for around US$1.25 per watt. However, with a high cash burn rate for the loss-making manufacturer, the 70%-plus capacity increase will require the company to raise more money, according to Mike El-Hillow, Evergreen Solar's COO and CFO.

The fourth quarter proved good for the company, as demand was robust, enabling the company to ship 31.9MW – almost all of its 35MW capacity at its Devens facility. However, the company shipped 31.3 MW from its Devens facility in the third quarter, highlighting that the company is now capacity constrained until the Wuhan plant become operational.

In the fourth quarter Evergreen Solar said it had produced panels at US$2.05 per watt, down from US$2.24 per watt in the third quarter and US$2.70 per watt for the second quarter. The implementation of its quad-furnace technology is still playing-out but has already achieved a wafer cost reduction to US$0.69 per watt, down from US$0.75 per watt in the third quarter of 2009. Silicon cost was put at approximately US$90 per kilogram.

As the company scales its Wuhan facility to reach the 100MW nameplate capacity, Richard M. Feldt, chairman, CEO and president, noted that the company should expect Evergreen-branded solar panels to cost no more than US$1.00 per watt by the end of 2012, including an all-in wafer cost of about US$0.30 per watt. Module conversions efficiencies were said to be at 15%.

Sovello to be sold to new investor: key terms agreed

Business partners in 'String Ribbon' licensee Sovello, which include Evergreen Solar, Q-Cells and REC Group, have agreed key terms and conditions and signed a declaration of intent with an unidentified investor for the sale of the struggling solar module producer. Sovello said in a statement that the investor had been interested in purchasing the company for some time. The Management Board expects the transaction to be completed in the first quarter of 2010.

Sovello's module manufacturing process.

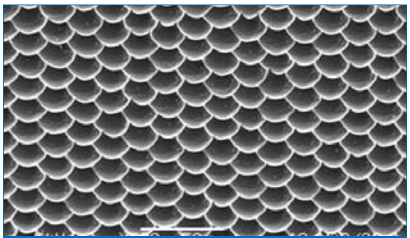
The company also said that should the sale go through, restructuring of its financial obligations with banks would be pursued. Current financing has been provided by a syndicated credit facility under which the loans drawn could be significantly reduced should the bank negotiations prove fruitful.

Sovello also noted that it had full order books for its modules and commanded a premium price due to the quality and 'Made in Germany' labelling. The company had plans to ramp capacity to 180MW in 2009 and employs over 1,200 people.

Silicon PV developer 1366 Technologies closes US$5.15M VC funding round

1366 Technologies has closed venture capital funding worth US$5.15 million, bringing the total amount raised by the silicon photovoltaics developer to US$17.55 million. The round was led by returning investors Polaris and North Bridge Venture Partners.

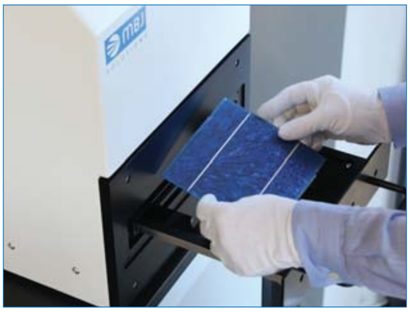
The new VC funding comes on the heels of the Lexington, MA-based company's signing of a US$4 million contract with the U.S. Department of Energy's newly established ARPA-E program. Noting that the recently closed round will accelerate the commercialization of its self-aligned cell (SAC) and direct wafer technologies, 1366 says that it has already lined up two lead development customers and is actively selling the SAC equipment and process.



Structured texture of 1366 Technologies' self-aligned cell (SAC).

Product Briefings

mbj-Solutions



mbj-Solutions' electroluminescence inspection tool designed for offline requirements

Product Briefing Outline: mbj-Solutions is focusing on the development of electroluminescence inspection systems for inline and offline use along the photovoltaic production process. The latest product from the company is an offline solar cell inspection system. The operator places a solar cell inside a drawer. By closing the drawer the system automatically applies current and voltage to the solar cell and captures an EL image, which is then displayed on the Windows user interface. The system allows the user to investigate the solar cell and to discover problems in the production process.

Problem: Crystalline solar cells are sorted at the end of the solar cell production process by using camera systems to inspect the visual appearance and a light flasher to measure the electrical performance of the solar cell. The efficiency of the solar cells can vary for several reasons, but there is little information available as to why these variances occur.

Solution: EL imaging is used to visualize any invisible defects such as shunts, micro-cracks, finger defects and many other production process-related phenomena. The mbj-Solutions SolarCell EL-basic is an offline tool used in the evaluation of the quality of the production process for crystalline silicon solar cells. The easy and safe operation of the system allows it to be used at the production line stage.

Applications: The SolarCell EL-basic is designed for the use at the end of the solar cell production line as well as in the laboratory with applications for mono- and multicrystalline silicon solar cells with two and three busbars. Back-contacted solar cell and string ribbon and EFG cell applications available on request.

Platform: All mechanical and electrical components such as power supply unit, PC, cooled NIR camera, automatic electrical contact unit are integrated inside the housing of the SolarCell EL-basic. The system comes with a compact design and a price tag of €18,900.

Availability: Currently available.

OTB Solar / Trident Solar

OTB Solar and Trident Solar collaborate on inkjet printhead integration for advanced cell processing

Product Briefing Outline: OTB Solar and Trident Solar have announced a partnership that will see Trident's proprietary '256Jet-S' inkjet printhead technology integrated into OTB Solar's 'PixDro' open architecture inkjet platforms. These will include integration into its 'LP50' research and development tool and the 'Elements' pilot or full production systems. The Trident inkjet printhead combined with OTB Solar's specialty software allows the enhanced LP50 and Elements systems to provide precise materials deposition.

Problem: Aggressive materials that are jetted for inkjet deposition of solar cell technology can quickly wear down non-inert printheads resulting in the need to frequently replace the printhead technology, increasing costs and downtime. In addition to being aggressive, the jettable materials are also expensive and non-precise deposition generates significant waste and expense.

Solution: Trident's inkjet printhead features stainless steel construction and a unique repairable design that allows the nozzle plate to be disassembled, ultrasonically cleaned and reassembled. The inertness of the 256Jet-S printhead enables jetting of the more aggressive solar processing fluids such as phosphorous dopants and alkaline etchant. These features allow the printhead to last up to eight times longer than alternative inkjet printheads, according to the company. The inert, durable construction of the 256Jet-S makes it designed for use in direct write, precision dispensing applications of etchants with PH ranging from 2 – 14.

Applications: Inkjet printing of solar cell technology.

Platform: Trident 256Jet-S printheads have been incorporated into two OTB Solar inkjet printing platforms – the LP50 and Element. The tool can handle product sizes of 5, 6 and 8 inches and has a throughput of up to 1500 wafers/hr. OTB Solar's open-architecture platforms provide enhanced flexibility in the production of solar cell technologies.

Availability: Currently available.

Roth & Rau

Roth & Rau introduces new firing furnace

Product Briefing Outline: With the acquisition of Tecnofimes, Roth & Rau has collaborated with the subsidiary to develop a new firing furnace, dubbed CAMiNI. The system is characterized by high efficiency at low operating costs. The initially offered model with two lanes (6" wafers) provides the basis for an extension, which facilitates the firing of solar cell contacts onto up to three lanes at the same time. The throughput of the CAMiNI is indicated with ≥ 6,000 wafers/h. Roth & Rau has already received its first purchase orders for the system.

Problem: Metal belt transportation in firing furnaces may introduce metallic contamination into the wafers.

Solution: The transport rolls, in comparison to former systems, are made of ceramics, which prevent metallic contamination of the wafers. Furthermore, the firing furnace needs less space than comparable earlier systems and facilitates easier handling at lower operating costs.

Applications: Fast firing application with ramp rates up to 180K/s and cooling rates of about 150K/s.

Platform: The new CAMiNI is a compact system with dimensions of 4,554 x 1,766 x 2,200mm. It is equipped with five heating zones and 44 lamps. The Uptime for the new CAMiNI is expected to be 94% and higher. The temperature uniformity is measured by TC and is ± 2K. Conveyors can reach speeds of up to 11m per minute, attaining a maximum temperature of 1050°C. This firing furnace does not require water cooling and the power consumption of a typical firing process is about 15kW.

Availability: Currently available.

Product Briefings

FANUC Robotics

The M-3iA robot from FANUC Robotics offers highly flexible handling movement

Product Briefing Outline: FANUC Robotics has introduced the new M-3iA intelligent, parallel-link robot designed to maximize speed and flexibility for assembly, small part handling and picking applications, including solar wafers.

Problem: Automating the assembly of some applications cannot be done with traditional SCARA-type robots.

Solution: The M-3iA six-axis model has a three-axis, patent-pending wrist for complex assembly tasks. The extreme flexibility offered by the three-axis wrist enables the robot to pick up and insert parts at simple or compound angles, and twist parts into place, similar to the flexibility offered by a manual operator. A four-axis M-3iA has a single-axis wrist for simple assembly and high-speed picking operations, offering speeds up to 4000 degrees per second. The 'iRVision' system is a ready-to-use robotic vision package, available on all FANUC robots, requiring only a camera and cable – no additional processing hardware. It has a 2D robot guidance tool to accomplish part location, error proofing, and other operations that normally require special sensors or custom fixtures.

Applications: Portable and compact size allows operation in small spaces. The six-axis design (three-axis wrist) enables part feeding from the sides of a work zone, increasing the useable workspace. The four-axis design (single-axis wrist) moves parts at extremely high speeds; a hollow wrist allows tooling cables to be routed internally, minimizing wear and tear.

Platform: Available in a four- or six-axis model, the M-3iA offers a unique parallel-link structure, is lightweight and portable, and accommodates payloads up to 6kg. In addition, it has the largest work envelope of any robot in its class (1350mm x 500mm). The robots operate with the company's latest R-30iA controller with integrated intelligent functions such as 'iRVision,' Force Sensing, Robot Link, and Collision Guard.

Availability: Currently available.

DEK Solar / Heller Industries

DEK Solar enhances PV3000 metallization line with drying technology from Heller

Product Briefing Outline: DEK Solar and Heller Industries have unveiled the results of a recent collaboration that enhances DEK's PV3000 metallization line. The alliance between the screen-printing and thermal technology specialists has enabled a significant breakthrough in solar cell production, incorporating precise thermal control, improved V_{oc} management and reduced power consumption, within a compact footprint.

Problem: Global demand for solar cell products means that manufacturers need high-productivity solutions delivered on a short turnaround basis. DEK Solar and Heller Industries initially joined forces in a bid to create a technology-leading metallization line that offered a distinct competitive advantage to customers manufacturing solar cells.

Solution: Heller's dryer concept is based on the principles of hot air convection drying, a process which is conducive to precision thermal control at lower drying temperatures. Offering a significant advantage over conventional IR-based dryers, the PVD3000's drying technology creates improved air exchange within the process chamber that enables the dryer to manage the increased V_{oc} volume associated with raised throughput. In addition, the specialist catalyst incorporated within the process chamber converts the V_{oc}s to simpler compounds such as carbon dioxide and water.

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

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

Availability: Currently available.

Meco Equipment Engineers

Meco's metallization line for crystalline solar cells boost cell efficiencies

Product Briefing Outline: Meco Equipment Engineers has developed its Cell Plating Line (CPL) for the metallization of crystalline solar cells to enable a fine line and thin seed layer of silver paste to boost cell efficiencies for volume production applications.

Problem: Front-side metallization of crystalline solar cells is currently done by screen-printing a thick film of Ag paste. Typically these screen-printed contact fingers are up to 120µm-wide to obtain sufficient electrical conductance. To further increase the cell efficiency, the contact finger width can be reduced as the active area of the cell increases (less shading). However, cell efficiency improvement is limited as the poor aspect ratio of screen-printed contact fingers leads to an increase of the finger resistance value at the same time.

Solution: The CPL process starts on a fine line and thin seed layer of silver paste where the electrical conductance of the contact finger is further enhanced by electroplating either Ag or Ni-Cu-Sn. This gives a fine-line contact finger while the resistance value is also improved. This leads to cell efficiency improvements of 0.3 – 0.5%, while the consumption of costly Ag paste is dramatically reduced. For the production of next-generation solar cells where the SiN layer has been opened by laser, the CPL process can be used as a direct metallization process onto silicon. With this approach, even higher cell efficiency improvements are feasible.

Applications: Metallization of silicon solar cells; frontside or backside plating. Simultaneous front- and back-side plating is also possible (e.g. for bi-facial cells).

Platform: The CPL is a turnkey line for plating of Ag or Ni-Cu-Sn. The output is either 1,500 or 3,000 cells/hour although it can also be tailored to specific needs. The CPL is delivered with automated cell loading/unloading (either stack-to-stack or cassette loading). As the cells are vertically transported through the CPL, the drag-over of chemistry is considerably lower than in case of horizontal cell transportation.

Availability: Currently available.

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

Challenges and advances in back-side metallization

Ralf Preu, **Andreas Wolf**, **Marc Hofmann**, **Florian Clement**, **Jan Nekarda**, **Jochen Rentsch** & **Daniel Biro**, Fraunhofer Institute for Solar Energy Systems (ISE), Freiburg, Germany

ABSTRACT

In today's market, crystalline silicon wafer technology dominates industrial solar cell production. Common devices feature opposing electrodes that are situated at the front and rear surface of the wafer and subsequent front-to-rear interconnection is used for module assembly. This paper reflects the functions which have to be fulfilled for the back-side contact of the solar cell as well as challenges and advances for the two basic classes: full-area and local rear contact formation. While full-area contacting has proven to be a reliable technology for industrial production, local contacting through dielectric layers has yet to be put through its paces in industrial implementation.

Introduction

The classical front-to-rear interconnection of crystalline silicon solar cells holds more than 80% of the market share of all PV technologies. Within the crystalline silicon world, Sunpower's rear-to-rear interconnected cell is the only mass produced exception.

The classical approach involves the rear contact being formed by depositing metal-containing paste to the full rear side of the cell and alloying during a subsequent high temperature process step. Most of the rear surface is covered by a paste that uses aluminium to enable high doping below the contact. Only the areas where the interconnector ribbons have to be soldered are covered by paste, which is mainly comprised of silver. In contrast, in the high efficiency world, the application of local contacting through a passivating layer has been the dominating approach for more than 20 years. The two approaches are compared in Fig. 1.

After reviewing the basic functions of the rear contact, the progress of some promising technological approaches is discussed in more detail in this paper.

The discussion focuses on issues of cell structure and the relevant technologies; more detailed information on specific process sequences is given in the literature, partly covered by the references.

Challenges for the rear contact

For maximum solar cell efficiency the rear contact should show negligible power losses due to recombination, electrical resistance, transmission and absorption of the long wave length range of the spectrum, which does not lead to the generation of carriers.

Recombination

It is quite difficult to give even relative loss values resulting from recombination at the rear contact since this effect strongly correlates to several other device parameters, most importantly to the recombination in the volume of the base. Assuming a typical minority carrier diffusion length that is several times larger than the base thickness, the rear surface recombination velocity becomes very important. If the rather lowly doped base comes into contact with a metal layer, the recombination velocity at the surface reaches its upper physical limit of ~10^7cm/s. In principal, there are two major approaches for the passivation of the rear surface.

The first option is high doping near the surface with the aim of reducing the density of the minority carriers and therefore the probability of recombination at the surface. This approach is used in most p-type cells by doping with aluminium and/or boron and is frequently called 'back surface field (BSF) since the gradient in the doping level is frequently interpreted as giving rise to an electric field that shields the minority carriers from reaching the metallic surface.

With the second option, the passivation of the rear surface is applied not within the base but on top of it by adding a passivation layer or a stack of several layers. Such passivation layers utilize two physical mechanisms:

- The density of interface states at the surface is reduced. This is reached by use of several measures, including saturation of dangling (unsatisfied) silicon bonds at the surface, the use of layers that resemble the silicon lattice in order to

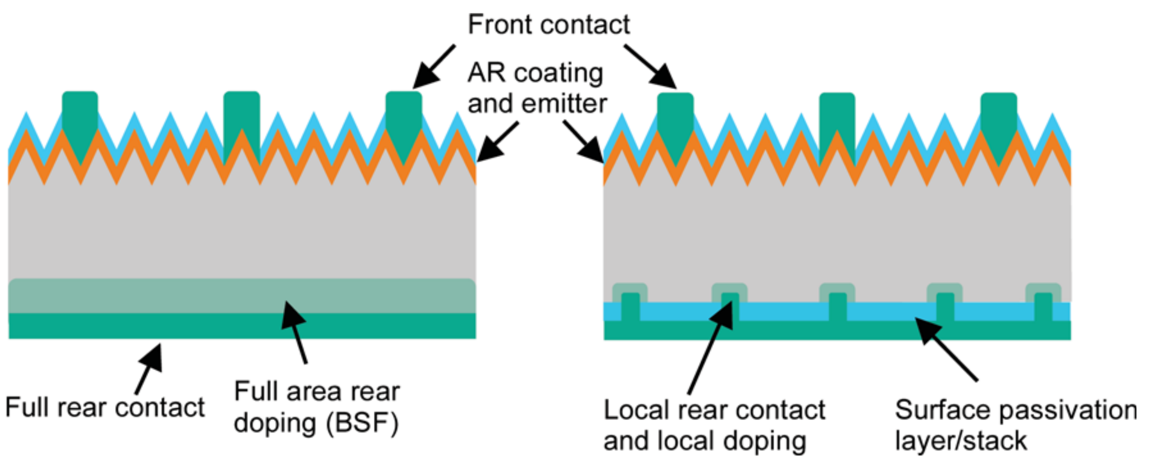
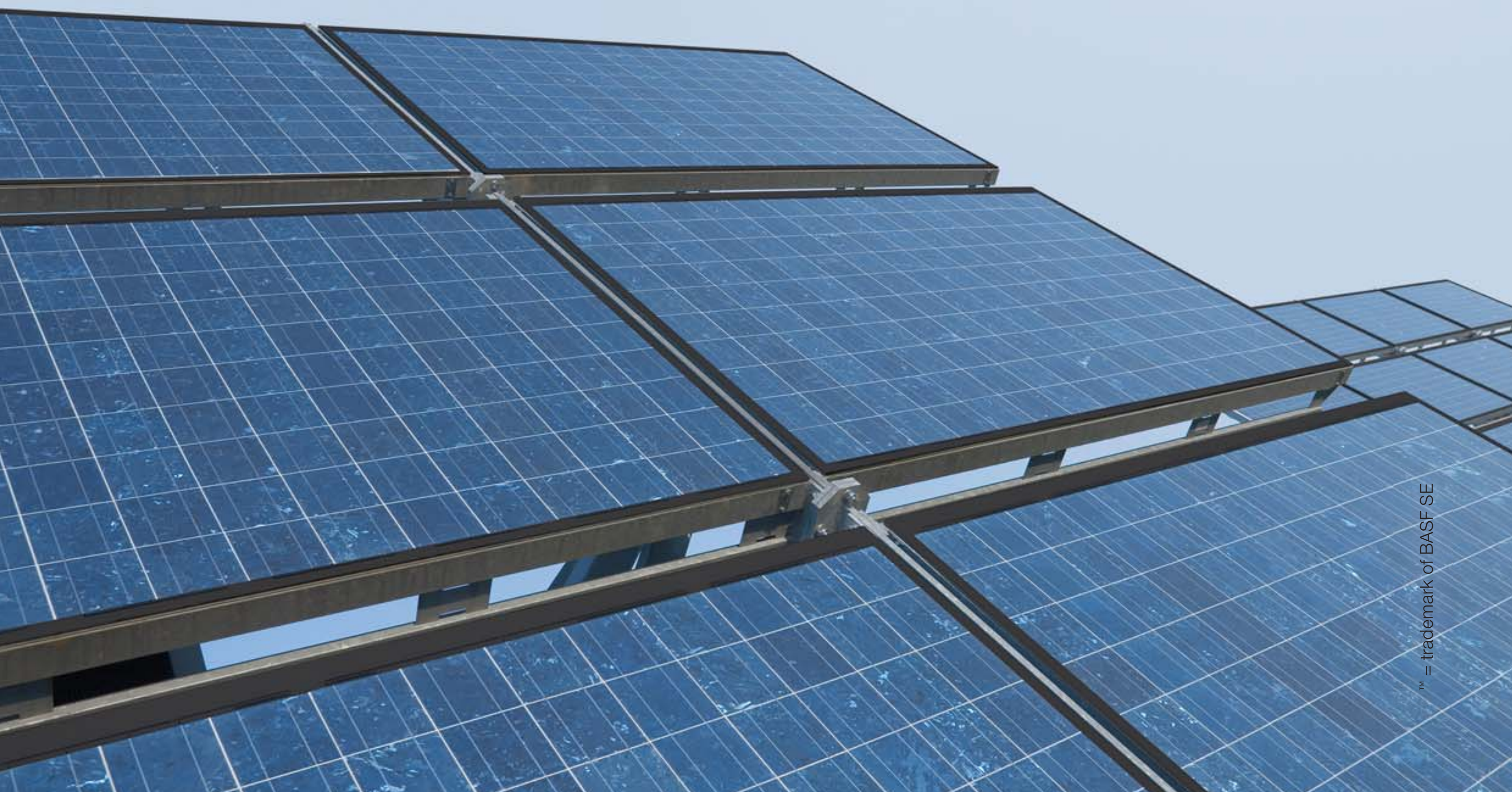


Figure 1. Two basic approaches to rear contact formation: homogeneous and local contact.



reduce structural deviations, and stress effects at the interface.

- Permanent immobile charges within a dielectric layer or at the interface induce an increased density of the opposite charge carriers near the surface, producing similar reactions to those seen in the case of high doping within the near-surface region.

A full-area BSF with direct metallic contact intrinsically cannot reach the same low effective surface recombination velocity (SRV) level as one that is based on dielectric passivation, even if contacts have to be formed through the passivating layer to allow for efficient majority carrier transport to the contacts.

"The resistance within the semiconductor base depends largely on the contacted area fraction, the contact geometry and the conductivity of the semiconductor."

Electrical resistance

To reduce the electrical resistance of the device, at least three contributors have to be considered (see Fig. 2): the resistance within the semiconductor for majorities flowing to the rear contact (R_{base}); the contact resistance between the semiconductor and the metal ($R_{contact}$); and the lateral resistance within the metallic layer to the points of interconnection ($R_{lateral}$). Introducing global area normalized resistance parameters, a useful rule of thumb holds for most relevant cases: the relative efficiency loss $\Delta P/P$ relates well to $5 \times R_{series}/\Omega cm^2$ [1] and helps to determine the relevant contributors to the resistive losses and their magnitude.

The resistance within the semiconductor base depends largely on the contacted area fraction, the contact geometry and the conductivity of the semiconductor. The set-up most applicable to the case of the solar cell is that which involves illuminated conditions, i.e. where the carriers are generated with a homogeneous lateral distribution and mostly near the front side. Thus for a fully-contacted rear surface, the area normalized base resistance is described by the expression $R_{base} = \rho_{base}\, t_{base}$, where ρ_{base}, t_{base} are the base resistivity and thickness, respectively. If a BSF is applied, this highly doped layer is typically thin compared to the base thickness. The resistance in this highly-doped region is much lower than for the rest of the base, thus the contribution of the back surface field can be neglected. For typical values t_{base} of 200µm and ρ_{base} of 1Ωcm, the respective R_{base} is 0.02Ωcm^2, which corresponds to a relative power loss of 0.1%.

In the case of local contacting, exact values can only be calculated numerically. Nevertheless, several analytical approximations have been derived to calculate the contribution of the spreading semiconductor resistance around the contacts depending on different geometrical conditions [2-4]. For most cases of local rear contacts, this spreading resistance is the dominating contributor. Typical conditions feature a point-like contact grid with a contact radius of approximately 50µm and 200 contacts per cm^2, which means that the resistance for one individual contact is 40Ω for a base resistivity of ρ = 1Ωcm [5]. This results in a series resistance contribution of 0.2Ωcm^2 and a relative power loss of 1%, both values being a factor of 10 higher than for the full contact case. This result already implies that a high base conductivity is favourable for the case of locally contacted cells. For given contact geometry, a higher base resistivity requires an increased contact area fraction, which leads to an increased recombination rate due to the much higher SRV of the metallized surface compared to that of the passivated area.

In most practical cases, the lateral carrier transport to the interconnector is dominated by the current flow through the metallic layer and the corresponding resistance loss is relatively low. For the rather standard case whereby the current flows through a metallic layer, the resistance depends mainly on the geometrical layout, the layer thickness and the resistivity. For metallic aluminium, even a few µm layers of thickness are sufficient to yield a very low lateral resistance loss. Nevertheless it must be considered that with today's pastes, the rear contact does not form a homogeneous Al layer after firing, but a sinter body with sinter necks that contribute significantly to the current transport. Thus the resistivity strongly depends on the microstructure of the paste after contact firing.

Optical performance of the rear surface

In an ideal scenario, the rear surface should exhibit 100% internal reflection if the absorption length equals or exceeds the wafer thickness. For a silicon wafer with a thickness of 200µm, this occurs for incoming photons with a wavelength above 1000nm and moves to shorter wavelengths if the thickness is reduced. Regardless, it should be taken into account that for textured surfaces the effective thickness of the wafer is increased and the incidence on the rear surface is oblique. Due to the interaction of the radiation with the free carriers within a metal layer, the reflectance of a metal layer directly situated on top of the silicon is strongly limited.

In the case of an intermediate transparent dielectric layer, the reflection increases substantially if the thickness is sufficient to prevent absorption of the evanescent wave and supports constructive interference for the reflected wave. The experimentally derived value for the angle-weighted long wavelength rear reflectance of a fully Al-covered rear surface is given in the range from 65-80%, including parasitic absorption in the highly doped layer. For a single layer system using around 100nm of silicon oxide, local contacts with a low area fraction of around 1% and aluminium as cover layer, this weighted reflectance is in the range of 95%. This difference in reflectance yields a carrier generation benefit in the range of 2 to 3% for moderate thicknesses and further increases if thinner wafers are applied [6].

In determining the importance of long wavelength radiation, free carrier absorption (FCA) in highly doped regions of the cell has to be considered, as it limits the optical path length in the cell even if the surfaces are perfect mirrors. The main contribution to FCA is introduced by the high carrier density regions of the diffused

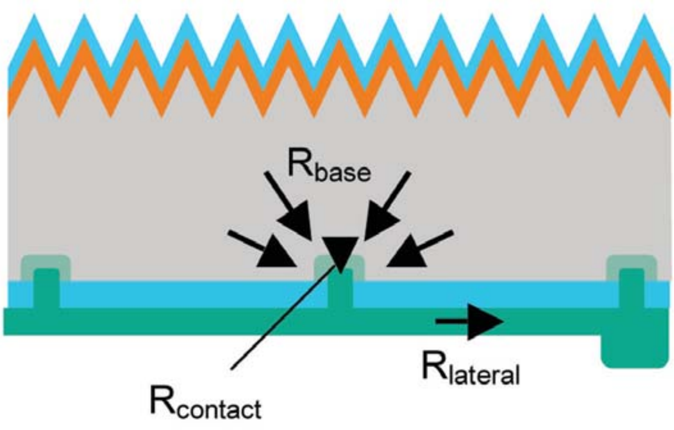


Figure 2. Dominating resistive loss mechanisms that must be considered for the rear contact of a solar cell.

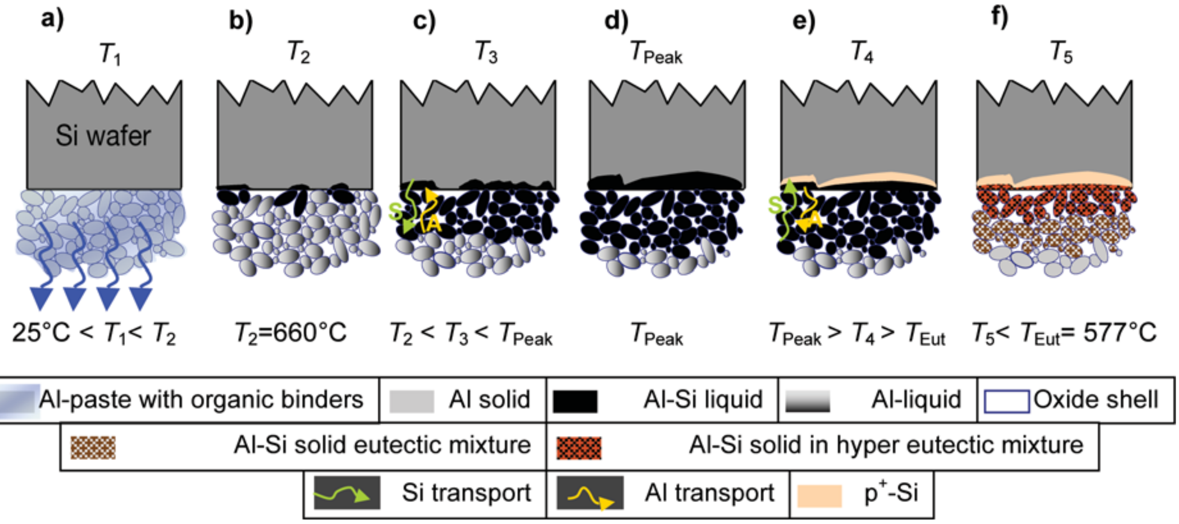


Figure 3. Current model for the formation of the rear Al-BSF (based on [9]).
a) Organic components are burned during the first stage of firing.
b) Oxide shells of the particles are enhanced due to increased temperature under oxidizing atmosphere. Al liquidizes, local contact areas between particles and wafer surface develop, start of alloying process.
c) Si is transported over the contact areas to the particles and Al is transported to the wafer surface, Si/Al concentration ratio rises as long as temperature increases.
d) At the peak temperature the maximum concentration of silicon in the liquid phase is reached. For thick Al layers and short heating times the aluminium is not fully saturated by silicon.
e) For decreasing temperature, silicon grows epitaxial from the liquid phase on the solid silicon wafer with an aluminium doping concentration determined by the liquidus curve. The transport process from c) is reversed.
f) As the eutectic temperature is reached, the remaining liquid alloy solidifies quickly. It can become hypereutectic if active and intense cooling is applied. ***J. Krause, Fraunhofer ISE***

emitter and back-surface field. Not only is the range between 1000 and 1200nm of interest, but also longer wavelength photons, since efficient back reflection of sub-band gap photons can result in lower cell temperature and thus higher open circuit voltage.

Solderability

In addition to all of its technical functions in reaching high cell efficiencies, the rear contact has to allow easy and durable interconnection. This is a delicate issue with aluminium as the contact material, which is well known for its tendency towards oxidation. Silver is used as the contact material to allow for reliable solder contact formation for standard Al-BSF cells. Many soldering contact pastes contain a small amount of aluminium to allow for improved electrical contact to the underlying silicon. Limiting the concentration of aluminium to a few atomic percent prevents the formation of a homogeneous layer of aluminium oxide at the surface, which would complicate the soldering process. However, silver pastes without any aluminium are also successfully applied to this process.

Fully-contacted rear side

Twenty years ago, in the early days of screen-printed cells, most of the industry's attention was focused on dealing with resistive losses of the rear contact, since recombination was dominated by insufficient minority carrier diffusion length of the rather thick solar-grade wafers. As a result, the rear side was contacted typically via a grid of well conducting paste. At that time, the standard conversion efficiencies of industrial solar cells were in the range of 12% for multicrystalline and 14% for monocrystalline silicon.

> "Silver is used as the contact material to allow for reliable solder contact formation for standard Al-BSF cells."

Investigations by Lölgen [7], for example, unveiled that effective surface recombination velocities down to 200cm/s can be obtained by alloying aluminium paste into the rear side of the solar cell. This work substantially contributed to the basic understanding of the alloy formation process and the adaptation of this approach to co-firing of the front and rear contacts. Further development of the contacting procedure – especially the paste formulation and firing conditions – greatly enabled the increase in efficiency to the current values with above 16% for multicrystalline silicon and above 17% for monocrystalline silicon.

Substantial progress in the understanding was obtained at the EU PVSEC in Barcelona, 2005, where Huster [8-10] published papers on his in-depth investigation of the BSF formed using an Al paste. One of the major observations of these papers was that under beneficial conditions, the BSF can be dominated by boron acting as the acceptor, which can be reached by adding boron in different forms. Furthermore, he also published a consistent model for the so-called stress-relief cooling which allows reduction of the bow being introduced by the Al-alloying process. This approach has been adapted by some of the commercially available fast-firing furnaces. Fig. 3 depicts a phase model of the formation of the pastes as introduced by Huster. Fig. 4 shows a cross-sectional scanning electron micrograph of an Al-BSF rear contact.

Locally contacted rear side

Locally rear-contacted solar cells with dielectric passivation for high efficiency solar cells were introduced more than 20 years ago by Swanson and Sinton [11] as well as Blakers and Green et al [12]. Within the past 10 years, substantial efforts and progress have been made to introduce this concept to industrial production. Compared to the dominating full Al-BSF approach, the differences in device features needed in order to successfully implement such a structure into an industrial process are quite substantial. The following section provides an overview of the different critical issues including the current status for the technological solutions to these functions as well as the main challenges that have yet to be addressed.

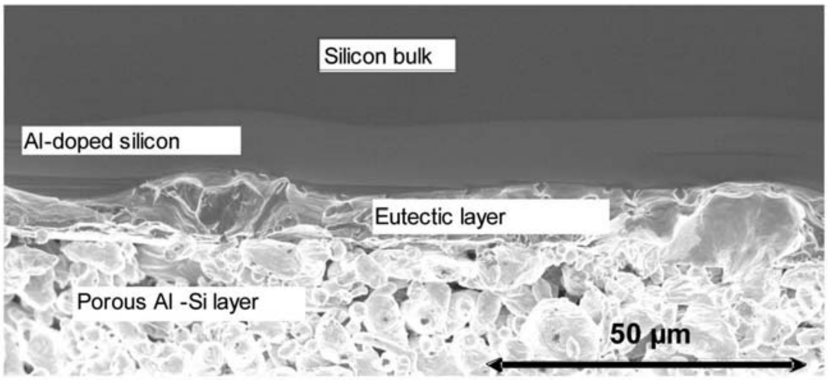


Figure 4. Scanning electron microscope image of a cross-section through the rear contact layer after Al paste deposition and firing.

High diffusion length versus cell thickness

In order to reach sufficiently low saturation current densities in the base, a ratio of at least 3 between bulk diffusion length versus base thickness should be reached. For standard boron-doped Czochralski silicon wafers at a doping level of $10^{16}cm^{-3}$ at moderate thicknesses around 200µm, this is a difficult task due to the well-known degradation effect associated with the boron and oxygen concentration.

A straightforward route is to use thinner wafers in order to reduce the volume where recombination occurs. Cells of 20% efficiency and above have been demonstrated down to thicknesses below 40µm [13] as well as efficiencies of above 18% using production and pilot production processes for less than 140µm-thin wafers [14]. The transition to thinner wafers in production will take time, since the respective developments have to take place along all individual steps of the value chain from wafer to module, and reliability of thin-celled modules have yet to be proven.

There are a number of options available to achieve a higher bulk diffusion length for boron-doped silicon, including an improved understanding of the boron-oxygen-related defect mechanism and its possible regeneration, float zone grown, magnetic and Ga-doped Cz-Si [15] as well as improvements in casted silicon.

Switching to phosphorus-doped n-type silicon makes a very high bulk diffusion length in Cz-Si easier to access. Some very high efficiencies have been obtained for the specific approaches of SunPower and Sanyo as well as passivated emitter and rear cells [16]. While a lot of progress has been made to develop simple process sequences [17], large-scale processing the latter approaches has yet to be demonstrated.

Surface conditioning

The preparation of the surface is as important as the passivation layer itself. Clean, smooth surfaces are vital features for low recombination [18]. The cleaning can be performed wet or dry. Dry etching is especially preferential in the case of plasma-deposited passivation layers since it allows integrated processing in one large vacuum system and consequently enables the substantial reduction of evacuation and handling costs. Excellent results for the preparation of the surface for subsequent passivation have been shown with both dry etch and wet chemical etch on large-scale production type equipment [19]. Nevertheless, there are waste gas treatment issues that must still be addressed.

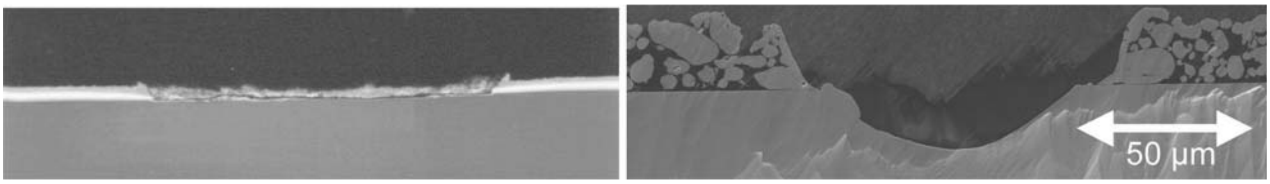


Figure 5. Scanning electron microscope image of a cross-section through a laser-fired contact on a 2µm-thin layer of evaporated aluminium (left) and a 20µm-thin layer of screen-printed aluminium (right). The depth of the LFC crater is similar to the thickness of the aluminium layer for both cases. The scale on the right side is valid for both images.

Though wet chemical single-side etching is standard for the rear emitter removal of Al-BSF cells, this can become challenging for different states within the process sequence. Process routes that allow for a low-cost etching mask on the front side are preferential. Silicon nitride, for example, can be efficiently used as a wet chemical etching and oxidation mask as has been demonstrated recently [14].

Passivation

Passivation layers can be classified into four groups that can all result in surface recombination velocities (SRV) below 10cm/s on 1Ωcm silicon. Application in PERC-like cell structures uses stacks of different layers in order to combine and produce favourable properties. In-situ or subsequent deposition of additional layers can improve internal reflectance, act as a diffusion barrier for the rear metal or even improve the passivation quality of the layer by injecting interface defect passivating hydrogen or enhancing the fixed charge density to favourable energy band conditions.

The first option for passivation is the thermal oxidation of the surface, which has been the basis for most high efficiency devices so far. It is different from all other available passivation methods in that it is a high temperature process (maximum process temperature T_{max}>800°C) and thus typically interacts more with other device structures.

An SRV below 10cm/s on p-type silicon can be reached in combination with a so-called alneal, which helps to hydrogenate the silicon-to-silicon dioxide interface and thus reduce the interface density of states D_{it}. This alneal can also be applied to recover the passivation properties after a subsequent high-temperature process as being used for firing of the contact [20]. The interface between the silicon oxide layer and the silicon is shifted inside the silicon wafer. This property has substantial advantages especially for non-uniform and increased aspect ratio surfaces as can be found in realistic process scenarios.

Substantial progress has been made in regard to the cost-effectiveness of the oxidation by preparing the transfer to wet oxides by purified steam instead of the traditional hydrogen burners. An overview of the present status of silicon oxide layers has been given recently [21].

The second group is also based on very low densities of interface traps with a low or moderate density of fixed charges, which in this case are deposited by plasma processing.

Amorphous silicon is the only representative of this group known so far. Excellent efficiencies for heterojunction and PERC-like cell structures have been reached and the use of large-area high throughput systems for the deposition has been demonstrated [22-24]. Nevertheless, the use of this approach for industrial solar cell processes yields two major drawbacks. The SRV of a passivated surface is inherently more dependent on the smoothness of the surface compared to the other passivation approaches. Secondly, amorphous silicon is very sensitive to high temperature treatments [25].

> "Excellent passivation results have been obtained by atomic layer deposited aluminium oxide, now also available as a high throughput PECVD process"

The third group is based on a deposited layer yielding a low or moderate D_{it} (well below 10^{12} $cm^{-2}eV^{-1}$) and

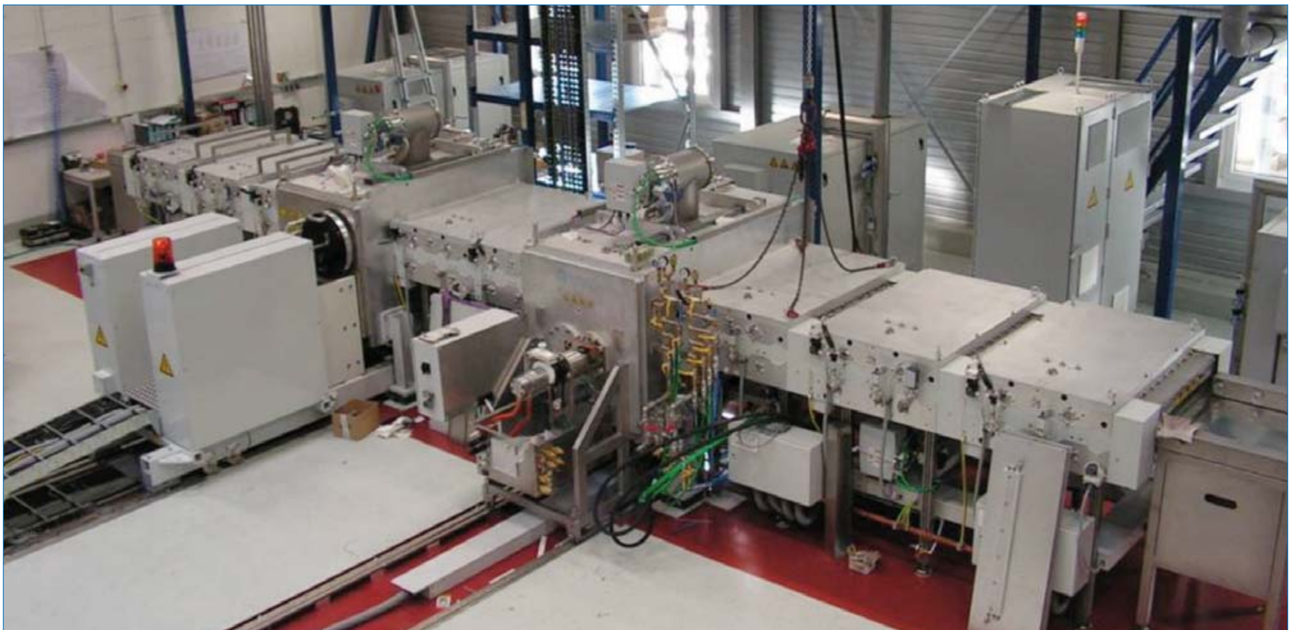


Figure 6. Pilot-line evaporation system from Applied Materials for high throughput physical vapour deposition metallization. Deposition rates for thermal evaporation are in the range of up to 500nm/s while maintaining high cell quality; up to 21.0% efficiency has been demonstrated (performed at Fraunhofer ISE).

high densities of fixed positive charges Q_f (above $10^{12}cm^{-2}$). This group holds hydrogenated layers of amorphous silicon nitride, oxide and carbide as well as metamorphic versions as siliconoxynitride [26]. The high Q_f can be maintained or even achieved by a high temperature treatment that could replace the conventional contact firing. These layers have been used to successfully passivate the surfaces of p-type wafers. But, for p-type PERC-type cells, a substantial gap of up to 1% absolute for high efficiency solar cells has not yet been overcome using these layers, which is attributed to the inversion layer induced by the positive charges in combination with non-ideal junctions of the local contacts [27]. Though this so-called inversion layer shunting has been known for several years, it seems technologically difficult to overcome this problem by production-feasible means. For n-type silicon, this group of passivation forms an accumulation layer and seems to present an adequate solution for contacted surfaces, as can also be taken from the successful surface silicon nitride passivation of phosphorous-doped emitters.

Due to the aforementioned drawbacks of passivation layers like silicon nitride, much attention has been drawn of late to negatively-charged layers which produce accumulation layers in p-type silicon. Excellent passivation results have been obtained by atomic layer deposited aluminium oxide, which so far remains a rather low-throughput deposition process [28]. Just recently we were able to demonstrate very low surface recombination velocities using a large-area PECVD system [29].

Overall, it can be concluded that wet chemical etching plus oxidation and dry etching in combination with plasma-deposited aluminium oxide are industrially viable approaches for excellent passivation of the rear surface of p-type wafers at competitive costs.

Rear contact formation

Locally defined contacts need at least two steps consisting of the application of the full-area metal layer and the local structuring process itself. Until several years ago, all rear surface passivated solar cells had been contacted by means of evaporation. i.e. physical vapour deposited (PVD) aluminium layers. Photo-lithographical removal of the passivation layer used to be the standard for structural purposes. This process can be substantially simplified using a laser to locally ablate the passivation layer [30]. After structuring, the metal layer can be deposited. Very high efficiency cells feature a local back-surface field (LBSF) below the contacts, originally applying additional photolithographic structuring. Following the introduction 10 years ago of the local laser firing of contacts (LFC), the structuring process has now been moved to after the metal layer deposition, forming a local back-surface field of medium quality compared to the diffused boron LBSF reference.

High temperature contact formation has not been feasible for aluminium deposited on silicon dioxide or amorphous silicon passivation. This is a result of the chemical reduction of the oxide in the first case and crystallization or even alloying of the underlying layer in the second case. The use of silicon nitride diffusion barriers in combination with local laser opening and the application of aluminium paste has been successfully demonstrated by Agostinelli [31]. A similar approach has been introduced by using laser-fired contacts in combination with a screen-printed and fired aluminium paste layer [32]. Applying this sequence in combination with printed front contacts has resulted in a 20.5% efficient cell, the highest efficiency reported so far for all printed contacts (2cm x $2cm^2$ cell on p-type Fz-Si) (see Fig. 5) [5].

Recent progress has shown how to overcome the throughput limitation of conventional systems for physical vapour deposition. In order to reach sufficient lateral conductivity for a back-side coating, a thickness of at least 2μm of aluminium is needed. In order to meet the resulting demand for a throughput of several thousand wafers/hour, a high-rate evaporation system was introduced in 2009 (see Fig. 6). Results from this deposition system have shown excellent static deposition rates of 500nm/s and a very good uniformity of better than 2% on the whole carrier. Equivalent cell results on a level of 21% have also been shown on high-efficiency solar cells in direct comparison to lab-type e-gun deposition [33].

In summary, two high-throughput rear-surface metallization concepts are available to form the rear aluminium layer of such cells. Metallization based on screen-printed aluminium paste is well proven and is low in investment. It can yield good BSF conditions after alloying and allows easy integration into existing lines as well as application of current interconnection technology. Evaporated aluminium layers show excellent lateral conductivity even in the as-deposited state, thus allowing a substantial reduction in the amount of aluminium used, and removing the need for firing of the deposited layer.

While the investment and running costs for the equipment are higher, the costs for consumed materials can be substantially lower compared to the screen-printed Al paste approach. An alternative option with substantial cost-reduction potential is the use of aluminium foil, which, while it has demonstrated very promising results combined with local laser firing, is still in an early stage of development [34].

"Metallization based on screen-printed aluminium paste is well proven and is low in investment."

Structuring of the contacts in combination with the formation of local laser alloying by use of LFC seems to be the most flexible approach, while local patterning and subsequent Al paste deposition and firing allows use of conditions similar to the standard Al-BSF formation. Local printing of paste with subsequent firing through the passivation layer is a third option, but has not yet yielded any outstanding results.

Other cell designs

In principle, it is possible to form a hybrid of the two basic approaches (BSF and dielectric passivation). This idea has been formulated to address the problem of high resistive losses that ensue from manufacturing high efficiency solar cells on lowly doped silicon with local contacts. In this approach, a highly conductive area is formed at the rear surface, which helps to substantially improve the lateral conductivity within the semiconductor. Nevertheless, the surface is still passivated with a dielectric layer, which also ensures high performance. Technologically this area

Function	Approach	Status	Main challenges
Surface conditioning	Wet chemical etching	• Inline single side etching is available • Simplified RCA-clean was demonstrated to work well on pilot wet bench	• Further simplification/reduction of chemical consumption • Improved single sidedness, homogeneity of process • Polishing of surfaces.
	Dry etching	• Very low surface recombination velocity (S_{eff}<10cm/s on 1Ωcm p-type Si) after dry etching on large area plasma etching system demonstrated	• Waste gas treatment • Improved single sidedness and homogeneity of processes • Polishing of surfaces
Passivation	Wet Thermal Oxidation, thick	• Excellent and firing stable passivation, if combined with alneal at the end of process • High throughput demonstrated, substantial cost reduction by the introduction of wet oxides using purified steam	• Integration of high temperature process and double sided growth of oxide in total process flow • Development of low-cost high quality inline oxidation
	Firing stable vacuum-deposited stacks of silicon oxide/nitride/ carbide	• Very low S_{eff} on high throughput systems demonstrated, based on large positive fixed charge density	• High positive fixed charge density ($Q_f > 10^{12}$ cm^{-2}) of layers led to substantial efficiency losses for locally contacted cells on p-type silicon, well suited for n-type Si
	Amorphous silicon	• Very low S_{eff} on high throughput system demonstrated	• Relatively low Q_f, so far very smooth surface required, still most sensitive to high temperatures • Firing stability on cell level
	Firing stable vacuum deposited stacks of aluminium oxide	• Very low Seff for atomic layer deposition (very dense and homogeneous) and PECVD (high throughput system) demonstrated • High negative Q_f of layers allows beneficial carrier accumulation on p-type silicon	• So far only little experience in cell processing
Point like local contact formation	Laser-fired Contacts	• High efficiencies and high throughput demonstrated for a variety of approaches	• Further improvement of local back surface field quality • Up-scaling to industrial application
	Laser ablation	• High efficiencies demonstrated for screen printed cells	• Local back surface field formation depends on subsequent firing step
	Screen printing	• Simple approach, frequently tested	• High efficiency to be demonstrated
Metallization rear	2-3µm Al-PVD-layer	• LFC has proven to be a high throughput process, high throughput Al-PVD-deposition system set-up with excellent results under development	• Interconnection demands for additional contact layer
	10-30µm screen printed and fired Al layer	• High throughput for LFC process • Easy implementation module inter-connection using screen printing of pads	• Simple introduction of firing stable rear stack
	15-30µm thin Al foil	• Good cell results demonstrated	• Very early stage of development
Annealing	Forming gas anneal	• Tube furnace process is a standard for high efficiency cells	• First forming gas inline furnace for PV cells to be investigated

Table 1. Overview of the most critical process functions to implement a solar cell with passivated rear and local contacts, including the most promising approaches, their status and the main challenges for a process transfer to industrial scale.

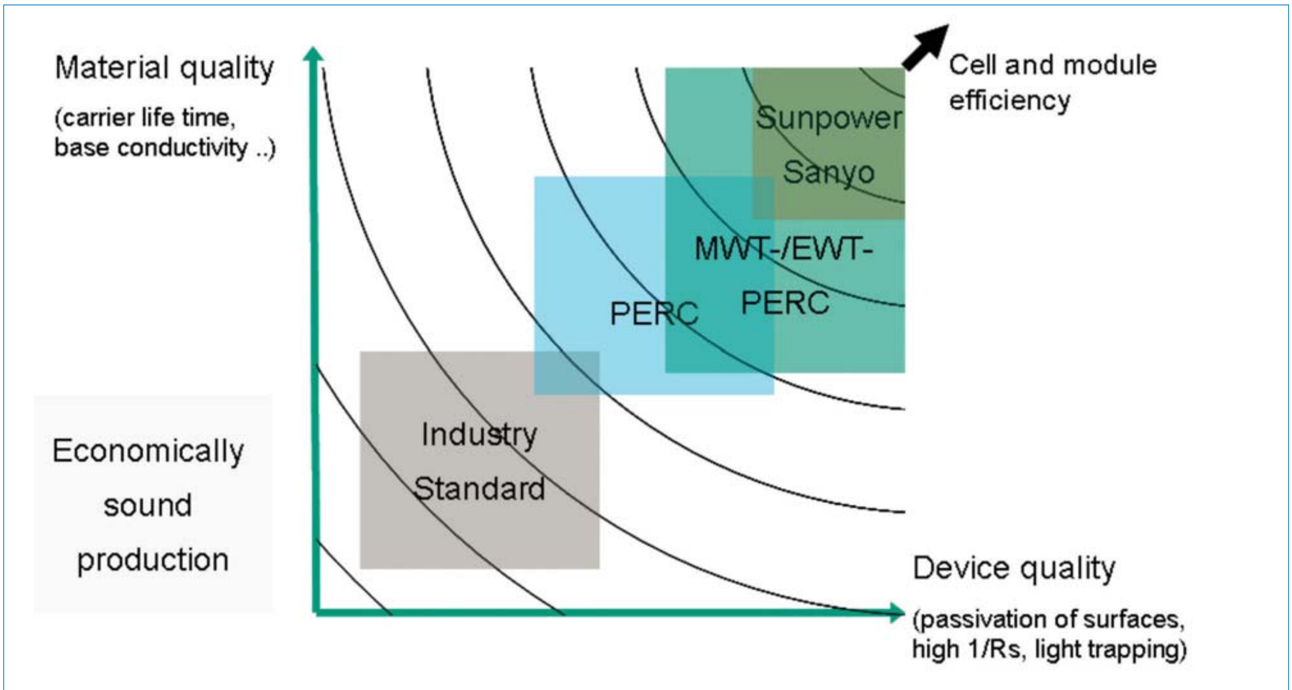


Figure 7. Portfolio for economically sound production of passivated solar cells. Combination of high quality material and device structure will enable filling of the gap between today's standard screen-printed cells and the premium cells of Sanyo and SunPower.

can be prepared like a BSF. Zhao et al. have taken the so-called passivated emitter and rear totally diffused (PERT) cell approach, which has resulted in efficiencies up to 24.5% [35].

Adaptations of the two basic approaches are necessary for rear contact formation if both polarities are placed on the rear side as is the case with Metal Wrap Through (MWT), Emitter Wrap Through (EWT) and Rear Junction Back Contact (RJ-BC) cells. In each of these approaches, the junction area is situated more or less directly at the surface. High quality junction passivation is vital to reach high efficiencies. For RJ-BC cells like SunPower's A320, the use of dielectric passivation in the junction areas is mandatory [36].

EWT cells have been produced without a dielectric passivation of the junction areas, but the difference in efficiency is substantial, and junction passivation also seems to be essential and can lead to efficiencies of up to 18.8% for screen-printed solar cells [37]. Most MWT cells are based on an Al-BSF, and junction passivation is less important since the junction area at the rear is about one order of magnitude smaller than for EWT and RJ-BC cells. But recent results have shown that the dielectric passivation of the p-n junction area is also very helpful to reach higher efficiencies [38].

In summary, it can be said that for all rear-contacted cells, dielectric passivation of the rear surface is even more important than for the classical cell architecture itself.

Summary and outlook

The boundary conditions for the back contact of crystalline silicon solar cells are well known. Screen-printed Al-BSF technology has advanced substantially over the years and represents a very widespread and robust technology. Nevertheless, achieving further efficiency increases on this route is a challenge. In particular, the implementation of an increased internal reflection requires new approaches. Substantial further reduction of the wafer thickness relies on the use of dielectrically passivated layers to yield mechanical and efficiency benefits.

The solar cells with the highest efficiencies feature local rear contacts. In the field of local contacts through dielectric layers, a lot of progress has been made during the last three years in terms of industrial feasibility. The first silicon solar cell-dedicated PVD equipment has proven its high throughput and efficiency potential. Similarly, screen-printed contact formation and dielectric passivation, which have been regarded as a contradiction for a long time, have shown to harmonize very well.

The respective approaches allow an introduction of passivated rear-side cell design to industrial processing of boron-doped silicon wafers, with the first implementations expected this year. Application of high diffusion length material and other enhancing techniques such as fine line contacts and selective emitters will result in industrial solar cells featuring efficiencies above 20%. Further combination with rear-contact approaches like MWT or EWT is expected to then fill the gap between the upper limit of standard screen-printed and the premium but complex cells of Sunpower and Sanyo (see Fig. 7).

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Improving cell efficiency and reducing costs: applying experiences in microelectronics

Kris Baert & **Jef Poortmans**, IMEC, Leuven, Belgium

ABSTRACT

The PV industry is expected to eventually reduce its manufacturing costs well below €1/Wp. Major technological changes lie ahead of us for manufacturing wafers, solar cells and modules if this cost target is to be met. In order to focus R&D efforts amongst the myriad options, and to speed up the learning curve, the PV industry (equipment vendors, material suppliers and PV manufacturers) may benefit from collaborative efforts guided by an ITRS-like roadmap. In this paper we present the IMEC roadmap, the target of which is to reduce drastically the amount of pure Si needed per Wp by combining efficiencies beyond 20% with aggressive reductions in wafer thicknesses.

Introduction

In 2008 the first PV systems were revealed to have reached grid parity [1]. Grid parity is now predicted to be within reach for the whole of southern Europe by 2012 [2], and may already have been reached in certain parts of Italy. Widespread introduction of PV will require a price level well below €1/Wp, bringing with it the possibility that crystalline silicon modules at this price level will look different from their current appearance. In many scenarios it has been predicted that in order for c-Si PV modules to reach costs < €1/Wp, great changes will be required [3]. Improved manufacturing practices, vertical integration, economies of scale (fabs may scale by a factor of 10 or more), increase of areal throughput, and standardization are essential to reduce costs, but will continue to require constant technological innovation.

With Si representing about 40% of the cost/Wp at module level [3], the amount of Si used per Wp has to be reduced drastically from the present 8-9g/Watt. Higher cell efficiencies are equally essential to reduce the contribution of the module fabrication costs.

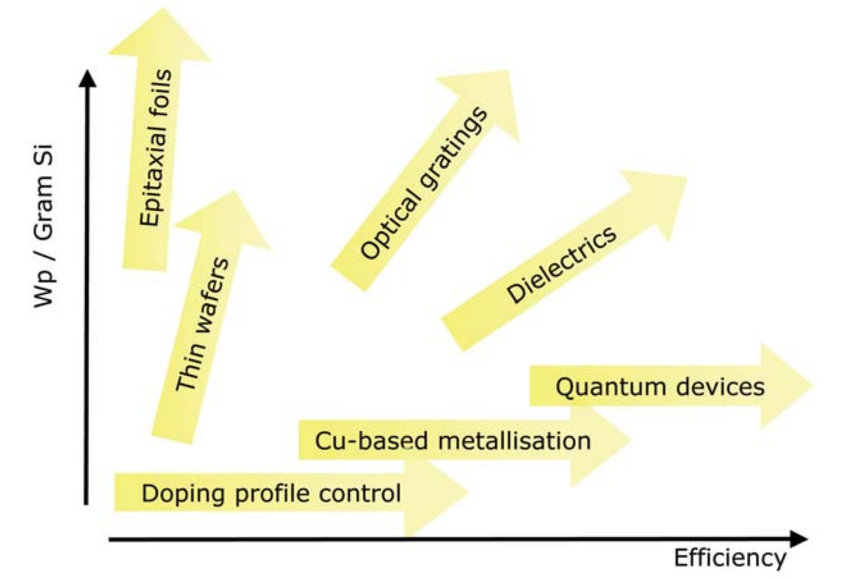

Figure 1. Indication of potential contribution of various novel process technologies to higher efficiencies and lower Si wafer consumption.

ICT technology for PV: where are the opportunities?

There is a wide range of process technologies available for advanced Si-based devices and microsystems that have not yet found their way into PV production, but this is about to change. Fig. 1 suggests a classification of a number of technologies according to their potential to contribute to efficiency increases and/or reduced consumption of Si.

- Obvious gains are available by **improving emitter-doping profiles** beyond what can be offered by $POCl_3$ diffusion. The highest flexibility in this respect is offered by the use of epitaxial technology: near-ideal profiles can be grown starting with a lowly-doped emitter (enhancing the UV response) plus a highly-doped 'spike' at the very surface (acting as a Front Surface Field and reducing contact resistance) (Fig. 2). An important step towards throughput as required by PV is taken by batch type CVD systems for epitaxy [4]. Ion implantation can also offer the required degree of precision, and is (again) being explored for PV applications [5]. Lattice damage is often quoted as a concern but recent research shows that appropriate dose, energy and annealing conditions can effectively contain lattice damage and is certainly compatible with processing of high-efficiency devices in monocrystalline Si. In the case of implanters, we expect high throughput tool concepts (e.g. P3i) to come about soon in order to address the 'productivity gap' between IC and PV production.
- The opportunities for efficiency improvement by doping are all the more relevant when combined with improved metallization schemes such as those based on **laser ablation and Cu plating** (Fig. 3). Such a scheme allows an almost independent optimization of a shallow emitter profile and the metallization scheme – in contrast with the intricate compromises typical for screenprinted Ag metallization. Cells with efficiencies up to 18.5% have been demonstrated [6]. The remaining challenge is to develop self-aligned seed/barrier layers with the appropriate reliability properties to warrant 25+ years of performance. Several diffusion barrier layers are known to be effective against Cu diffusion into Si.
- Quantum device technology may eventually be essential to exceed the efficiency limitations of single-junction solar cells – for example by larger


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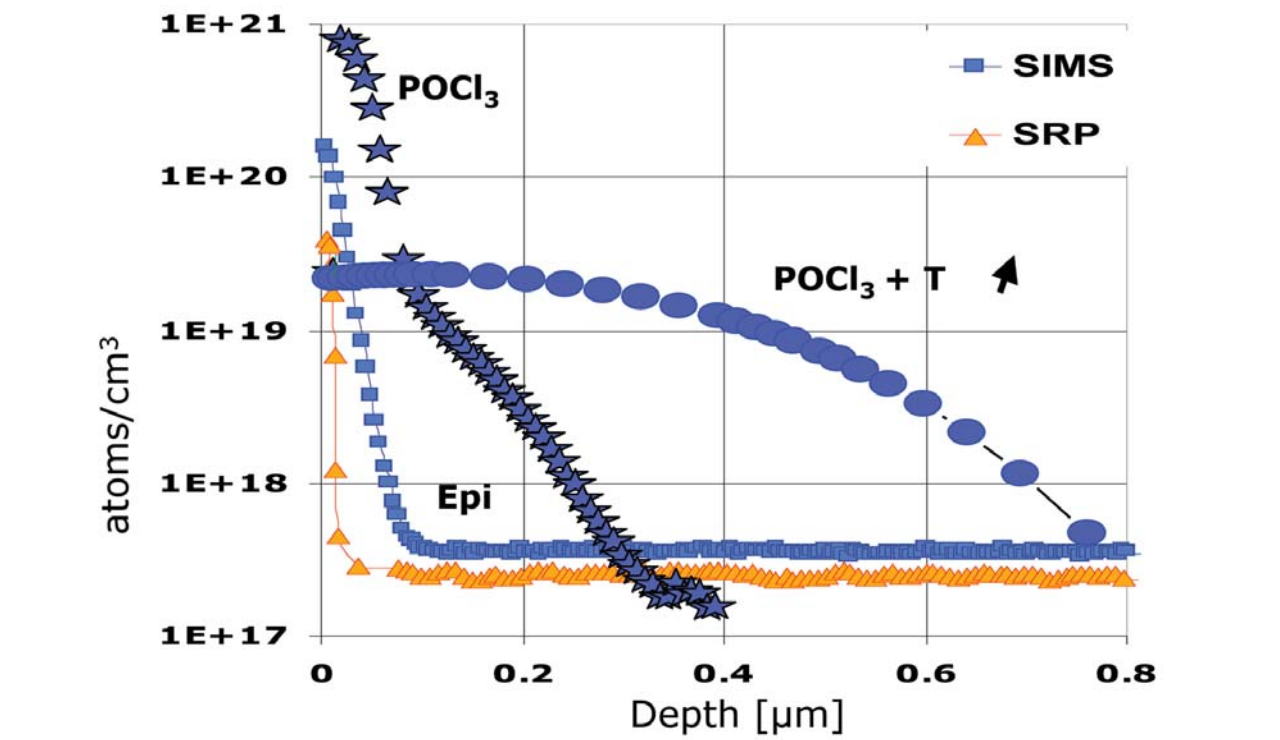

Figure 2. By using CVD epitaxy for the emitter, a very shallow emitter profile with a surface spike can be implemented as compared to the typical Gaussian distribution of a diffused layer.

bandgap (1.7eV) **nanowire solar cells** in all-Si tandem cells [7].

- Improved dielectrics are of paramount importance to increase the efficiency while reducing the amount of active Si. Typical silicon nitride layers as a surface passivation layer do not provide very low surface recombination velocities. **Atomic layer deposition** technology (e.g. Al_2O_3 deposited by thermal ALD) is heavily pursued in view of its unique combination of chemical and electrical passivation, and the repetitive nature of the process is seen as compatible with in-line processing. Recombination velocities as low as 10cm/s have been demonstrated [8] and the layers have been implemented in industrial solar cells [9].
- For very thin cells, optical enhancement schemes beyond texturization are instrumental in keeping high collection efficiencies in the infrared – for example **optical (submicron) grating**s may be put to use.
- Arguably the most important barrier today to using thin wafers in production is the lack of equipment handling below 150µm. This problem is not new, however. **Thin wafer transfer and handling** schemes have been developed in 3D integration that allow processing of Si wafers as thin as 50 or even 20µm. Several of these carrier and transfer techniques are applicable to the PV area.
- A way to circumvent the use of thin wafers altogether is to make use of high quality fully **epitaxial solar cells**, which are grown on low-cost Si substrates. The main challenge for industrialization of this approach is the availability of high throughput epitaxial systems. However, different reactor concepts and prototypes for high throughput epi-systems are currently under development.

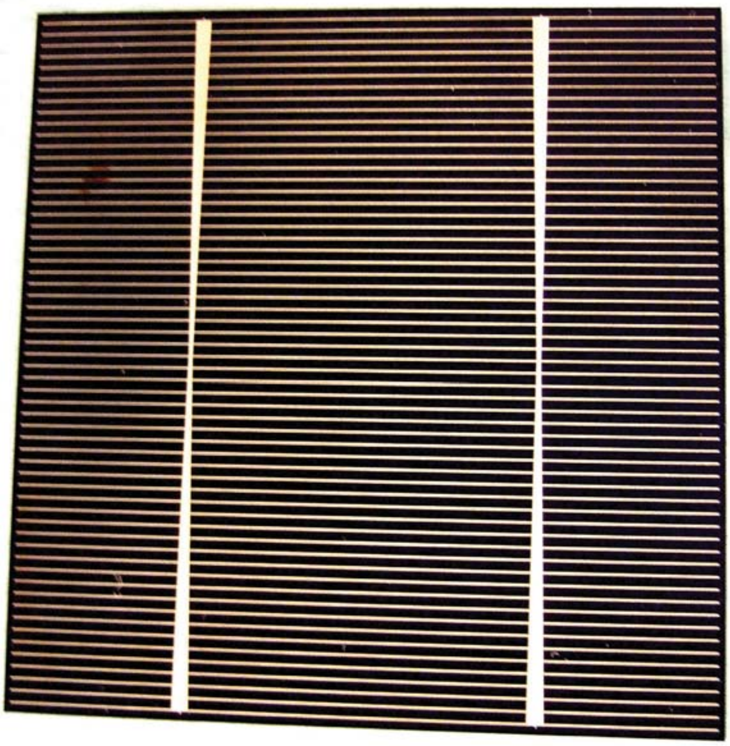

Figure 3. Large-area solar cell with efficiency of 18.3 % [6] made by laser ablated vias and Cu metallization at the front side.

A roadmap towards thinner Si solar cells

While the technical potential of the above technologies is clear, the challenge for their cost-effective introduction in PV production lines is tremendous and requires a concerted industrial effort. To focus R&D efforts amongst the plenitude of options, and to speed up the learning curve, the PV industry (equipment vendors, material suppliers and PV manufacturers) may benefit from collaborative efforts guided by an ITRS-like roadmap. Fig. 4 presents a possible roadmap showing a drastic reduction of silicon thickness over the next decade.

Today's wafer-based processing concepts look set to be further pursued for a long time; such processing may potentially be extended down to 40µm cells. Several steps will lead to this end goal.

PERL and back-contact solar cells

We expect PERC and PERL-like concepts to enter the market first since these are a logical next step from today's front-side contacted cell manufacturing lines to industrial efficiencies of 20% for wafers of about 120µm ("**i-PERL**").

However, we believe BC cells may dominate further on the road in view of their inherent efficiency advantages (no shadowing) and their 'planar' processing nature (most processing is at one side of the wafer which facilitates integration of thin cells into modules). Today, BC solar cells made in 180µm wafers still require very high diffusion lengths and therefore costlier wafers. However, as thin wafers become more widely used, Si may overtake front-side cells in terms of market share (**i^2-BC**).

Ultrathin wafers, cells and module integration

For U-cells (ultrathin cells of 40µm), there is as yet no cost-effective technology for the production of high-quality ultra-thin wafers. Wire sawing may be limited to 100µm, with a kerf loss equal that width; ribbons are limited either by material lifetime or by industrial throughput. Several technologies are under investigation worldwide, such as that developed by Silicon Genesis [10]. Another possibility currently under investigation at IMEC, may be SLIM-Cut (Stress-induced Lift-Off Method) for fabricating thin foils below 100µm thickness without kerf loss [11]. This kerf-loss-free wafering method has demonstrated promising results down to 50µm, which amounts to savings of a factor of 6.

The challenge is that manufacturing such thin Si layers – with yield – will also require novel wafer handling concepts whereby the wafer is somehow supported during processing. This requires a review of the cell process since the use of a support has its own constraints. Carrier support techniques exploited in the field of 3D integration may be put to use here.

Cells with reduced wafer thickness will also impose specific requirements on the integration into modules. The conventional tabbing and stringing process used today is prone to creating cracks in thinner cells due to the thermo-mechanical stress of this assembly process. For back-contact cells, module integration schemes based on 'flip-wafer' mounting the cells with conductive adhesives or solder balls on a laminate substrate have been demonstrated but are still not widely used. An attractive alternative is a superstrate interconnection technology where back-contact thin cells are embedded on module glass by planar processing, an approach that is based on concepts that have successfully been demonstrated for ultra-thin ICs [12]. This approach can lead to material and manufacturing cost savings as compared to a substrate-based integration.

In view of the critical role of module integration technology on the operational lifetime of any PV system, innovative cell-module integration concepts can only be introduced successfully into the market if due consideration is given to reliability aspects. This requires the availability of ageing models for PV modules, which can be generated based on measurements of thermal/mechanical properties, Failure Mode and Effect Analysis, Finite Element Modelling, and accelerated ageing tests.

Thin-film epitaxial solar cells

But how thin can cells really be made before light trapping becomes elusive? Very encouraging results are obtained by use of **epi-cells** (see lower line in Fig. 4) where only a thin layer of (epitaxially grown) Si is acting as the solar cell. Elaborate optical enhancement schemes are put to work here, with a porous Si grating at the back-side of the cell (between the epi-layer and the substrate). This reflector strongly improves the optical confinement of light in the active part of

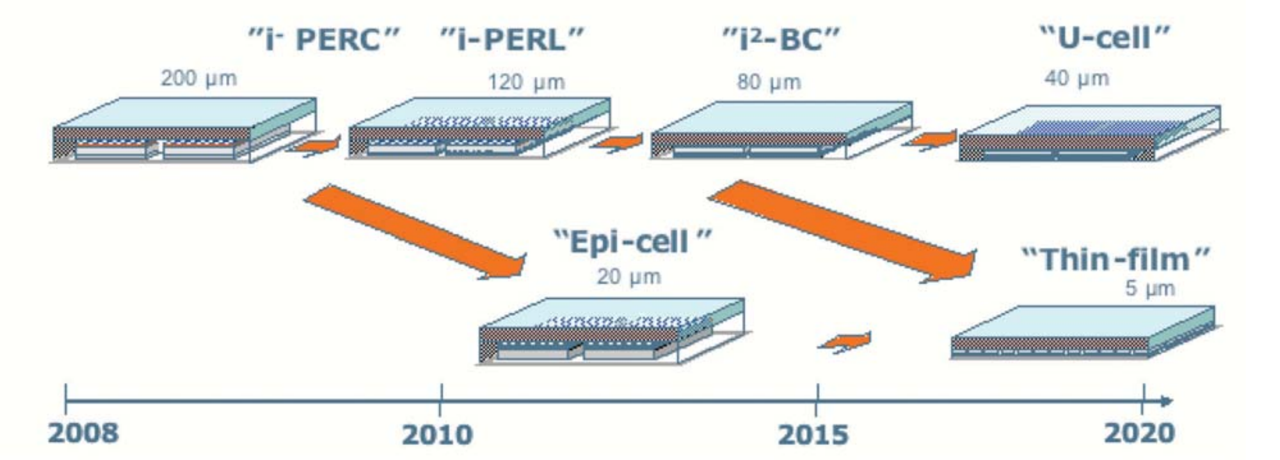

Figure 4. IMEC's crystalline silicon solar cell roadmap, predicting a continuous reduction of active layer thickness.

the cell. Lab efficiencies of 34.6mA.cm^{-2} (corresponding to an efficiency of 16.9%) have already been achieved [9] using a rear-emitter n-type cell with an active Si layer of only 25µm. These results bring industrial implementation of such epi-cells within the realm of possibility. It should be pointed out that this technology can also be used for growing thin-film solar cells on glass, and could one day form the ultimate thin-film Si solar cell.

Open innovation for the PV industry

In the past, introduction of process changes in existing solar cell lines was a relatively slow process, certainly when compared with the rapid technology evolution within the microelectronics sector. Apart from the already mentioned reliability problem, return on investment was also an issue. Due to the increasing size of the existing industrial PV players and the entrance of new players stemming from the microelectronic sector with their strong background in semiconductor processing and the rapid implementation of new processes, the introduction of new technologies is surely going to be accelerated. Thanks to the increased size of the industry, the development of PV-dedicated equipment becomes economically more viable

IMEC has launched a wafer-based silicon solar cell (Si-PV) Program around this Si-PV roadmap. The program aims to deliver the key process technologies required for the next generations of crystalline-Si-wafer-based solar cells. The concept is an 'open innovation' collaboration model, based on sharing of intellectual property and resources. This model has become an established means in the IC industry for enhanced collaboration between IC manufacturers, equipment vendors and material suppliers. Applying this model to the PV industry requires that particular attention be paid to differentiation possibilities for the PV manufacturing partners in the program.

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Examining cost of ownership of crystalline-silicon solar-cell wet processing: texturization and cleaning

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ABSTRACT

This paper, the second in a series covering cost of ownership studies for photovoltaics [1], examines the need for saw damage removal and the follow-on processes of precleaning, texturization, and cleaning. The process considerations for wet and plasma approaches are further discussed before taking a detailed look at texturization using random pyramid formation. The paper will conclude with a view of current and future wet process techniques and a cost of ownership case study using Akrion Systems' GAMA-Solar as an example.

The need for saw damage removal, precleaning, texturization, and cleaning

In practice, there are four operations that are performed as part of the surface conditioning process in cell manufacturing. These are saw damage removal, precleaning, texturing, and cleaning. Saw damage results from the wire sawing process used to slice silicon ingots into wafers. As a result of this mechanical process, cracks of about 1-10µm deep are introduced into the surfaces of the wafer (see Fig. 1). Removing the saw damage from the wafer surface improves the mechanical strength of these thin wafers and increases the recombination at the surface region.

Precleaning removes surface contaminants on the wafer that can lead to differences in texturization feature sizes, which can have a direct effect on surface reflectance. Texturization is a light-trapping technique that increases light absorption, thus increasing energy production over a given surface area. Increases in light absorption can be accomplished through a variety of texturization techniques and/or through the application of antireflective coatings. Cleaning is the removal of metal, particulate, and organic contaminants that can negatively impact the performance of the solar cell in the short or long term. Ultraclean wafers are critical for obtaining high yields in the solar cell fabrication process.

Saw damage removal

Saw damage induced at the wafer-sawing level (Fig. 1) can be removed with either wet alkaline or acidic solutions that etch away at the top layer of silicon. Dry damage removal by plasma etching is also possible. Conveniently, the saw damage removal step can be combined in the same tool with the texturing step (Fig. 2).

Precleaning

Examinations of surface morphology indicate that reflectance variations are associated with the lack of homogeneity of texture features, as shown in the left-hand image in Fig. 3. Further analysis by scanning electron microscope (SEM) shows that this results from an abrupt change in pyramid sizes from one area to another, as shown in the right-hand image in Fig. 3. The area of low reflectance was found to correspond to the area of small pyramids, a texturing inconsistency that appears to have been caused by surface contamination on the wafers. Such contamination can be demonstrated by intentionally touching a precleaned wafer with a cleanroom glove and noting the dark patterns at the corresponding areas after texturization.

Texturization

Light management in the solar cell is critical. Silicon, a material with an indirect band gap, has a relatively low absorption coefficient. Efficient surface texturization, coupled with an antireflectance coating (ARC) (see Fig. 4), can reduce reflectance losses from 35% to below 10% [2,3].

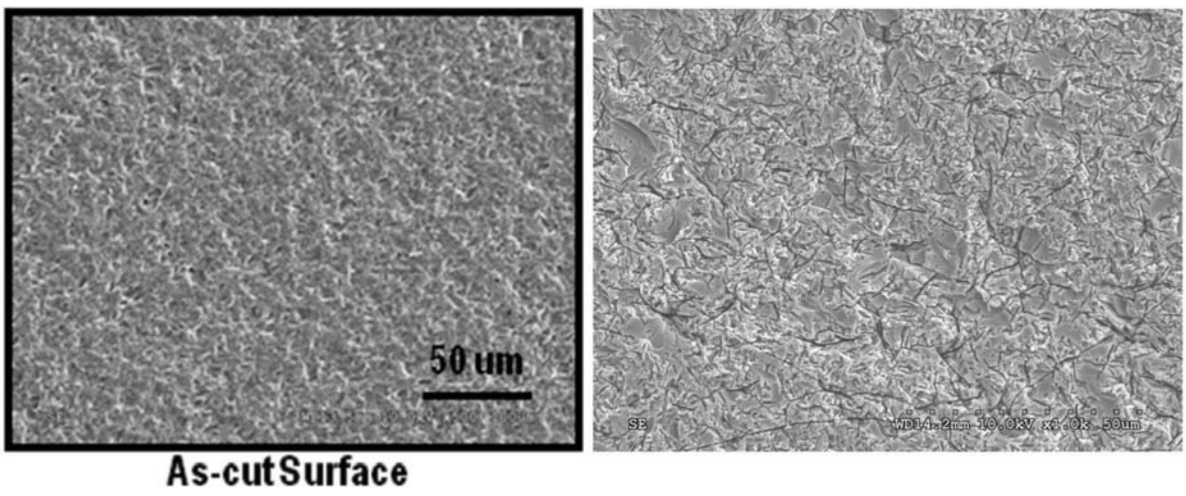

Figure 1. Wafer surface after ingot sawing.

Figure 2. Integrated saw damage removal, precleaning, texturization, and cleaning equipment.

As shown, a well-texturized surface reflects only 9.5% at 950nm compared to greater than 20% reflectance for an as-cut (untreated) surface.

The bonding energy of silicon atoms is different for each crystal plane – a characteristic that turns out to be very useful. Alkaline etching is not diffusion limited, instead it is driven by the differences in etch rate for the crystal planes. The result is that silicon etching is highly anisotropic and well understood in the industry. The <111> plane is more densely packed than the <100> plane and, thus, the etch rate of the <111> orientated surfaces are much less than those in the <100> orientation. An alkaline etchant exhibits an etch rate approximately 100 times faster along <100> than along <111> and, hence, the <111> facets are developed and form at 54.7 degrees to the horizontal plane. This result is the formation of small pyramids with a square base, randomly distributed over the wafer surface (see Fig. 5).

The degree of anisotropy (etch rate selectivity between different crystal planes), the etch rate, and homogeneity depend on the etching temperature, chemical concentration, and bath impurities. An additional factor to consider is that the typical etch bath creates residual etch byproducts. These silicates act as seeds (or nuclei) that initiate the pyramid formation and also act as an etch mask (or micro-mask) at that location. However, once these silica seeds exceed a critical concentration, they act as a contaminant, suppressing the etch rate sufficiently that the bath will no longer be effective in creating the random pyramid structures.

Cleaning

After texturing, the wafers are rinsed with deionized water, cleaned in HF and/or HCl to remove metal impurities on the wafer surface, and then dried in hot air (heated clean dry air or nitrogen). HCl removes surface impurities while HF removes the native oxide and any embedded impurities in the oxide, leaving the wafer surface free of trace metals and increasing the minority carrier lifetime. A metal signature of $<5x10^{10}$ atoms/cm^2 could be obtained for Al, Cu, Fe, Mg, Mn, and Zn with this clean [4], increasing the minority carrier life time and improving the sheet resistance. This HF-last process renders the surface H-terminated and is highly desirable prior to high temperature phosphorous diffusion.

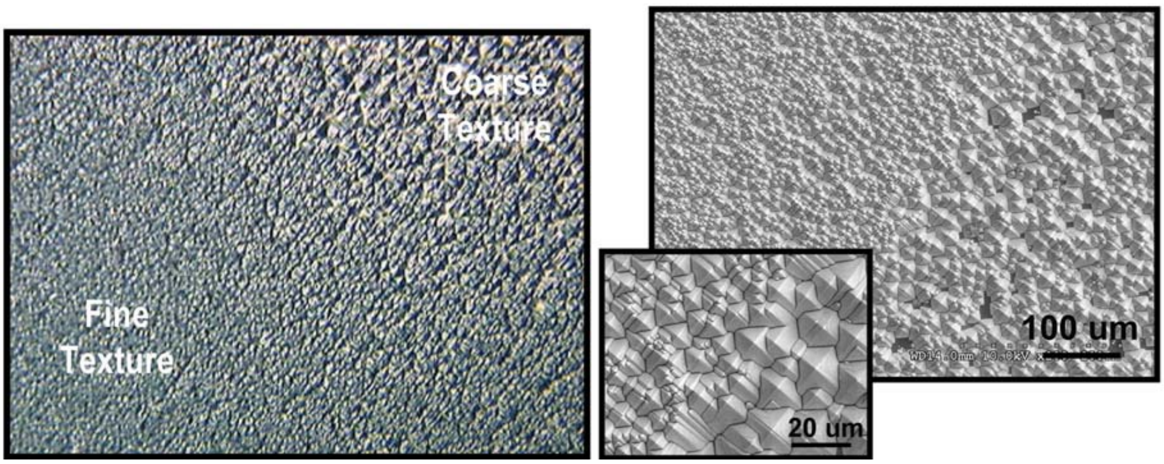

Figure 3. Surface morphology of an inconsistently textured area showing (left) optical microscopy image and (right) SEM image.


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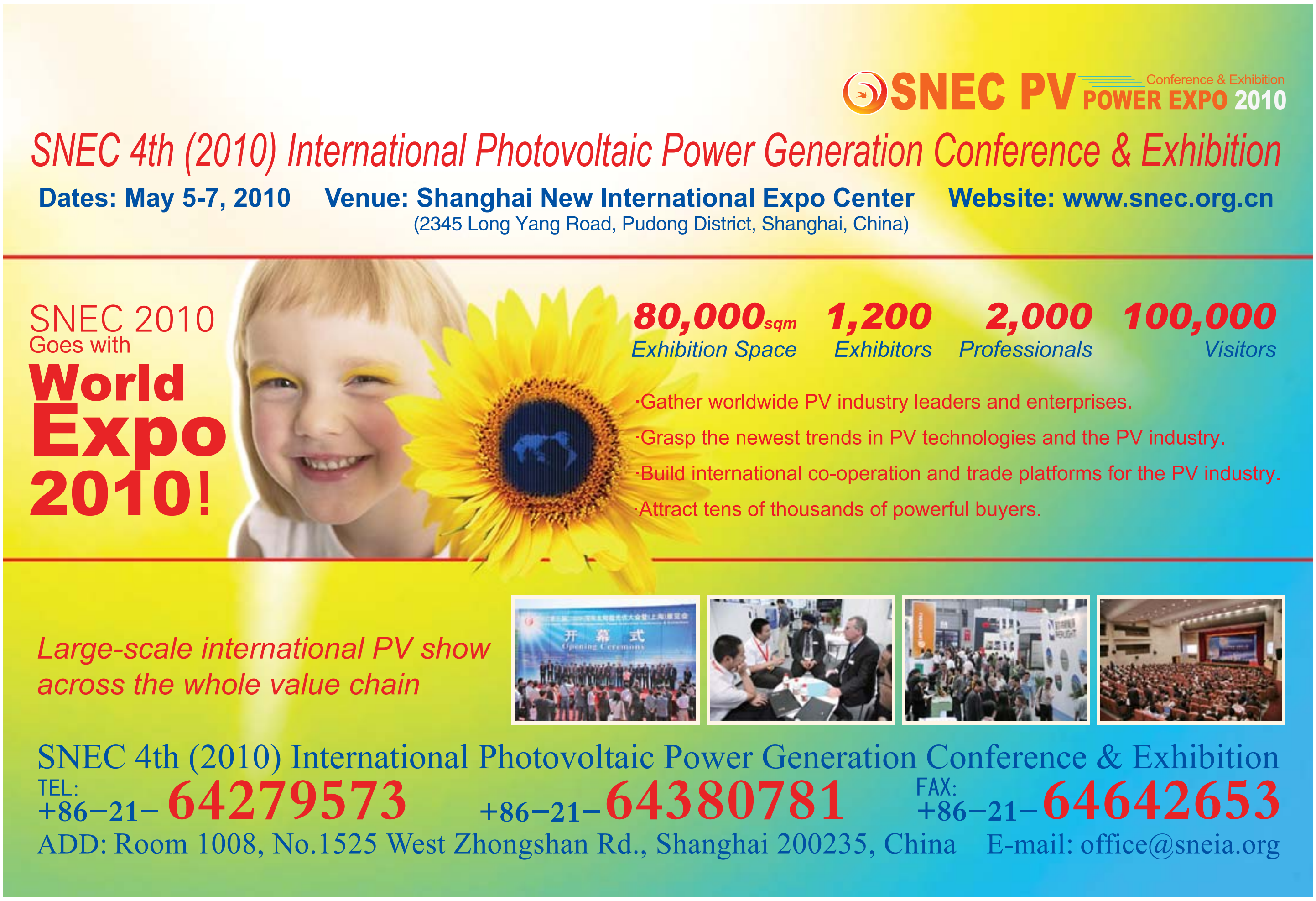
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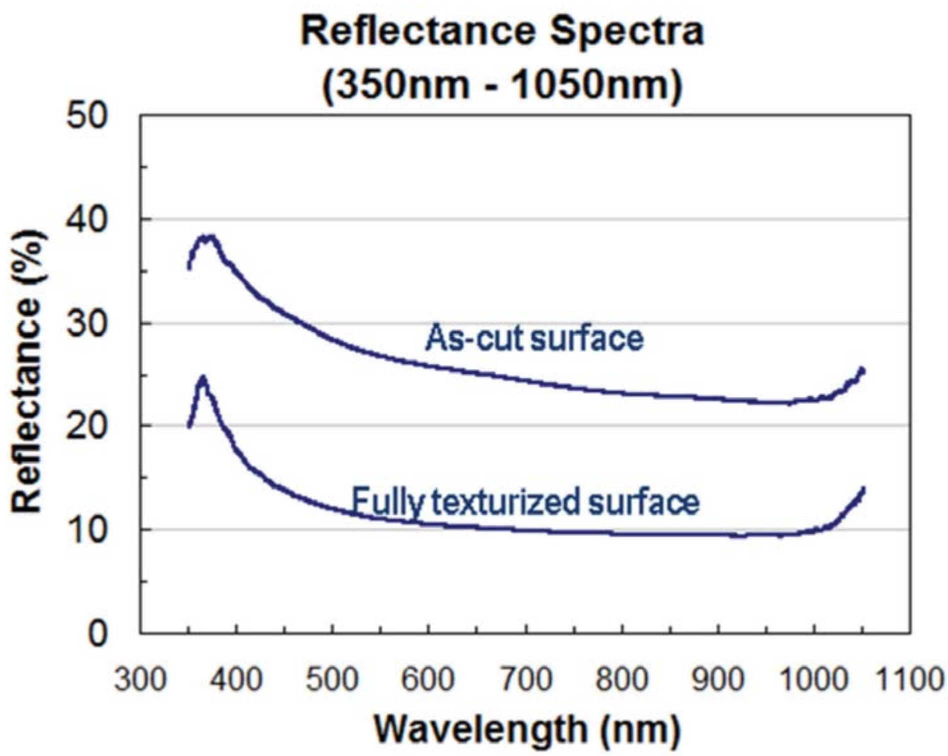

Figure 4. Reflectance with and without texturization.

Process choices: wet vs. plasma

Commonly used chemicals for this texturization are mixtures of KOH/IPA or NaOH/IPA. The IPA is a wetting agent for improving the lateral uniformity and anisotropy of the etching process. Alkaline concentration can vary from 2-5% to 10-20% by weight, while process temperatures can vary from 70-90°C. Depending on the desired results, process time can vary from a few minutes to an hour.

With increasing price pressure and COO concerns, tools can be specified to produce in excess of 3000 wafers/hour (wph). Tools are typically configured with multiple baths for the same chemistry and batch sizes of 200 wafers, which are held in cassettes and moved automatically from bath to bath. Wafers are typically exposed to this harsh chemistry for 30 minutes to produce these random pyramids. Inline processing has met with limited interest due to the length of the equipment needed to support such long process times.

It is worth noting that wet processes dominate the manufacturing base. Extensive learning that has been applied to wet processing has paved the way for high-quality, reliable, and productive tools. The materials themselves are readily available at high purity levels. While some might suggest this is a 'mature' process and thus has limited remaining upside, nothing could be further from the truth. In practice, it is this depth of understanding that allows for improvements to be made on a rapid basis, resulting in immersion batch tools like GAMA-Solar that incorporate the following features:

- Advanced process control (APC) using concentration sensors, ensuring repeatability, robustness and tool uptime needed for volume manufacturing.
- Low defects using advanced drying techniques leaving no streaks on the wafers. Ultrasonic/megasonics are often employed to further reduce defects in process and rinse tanks.

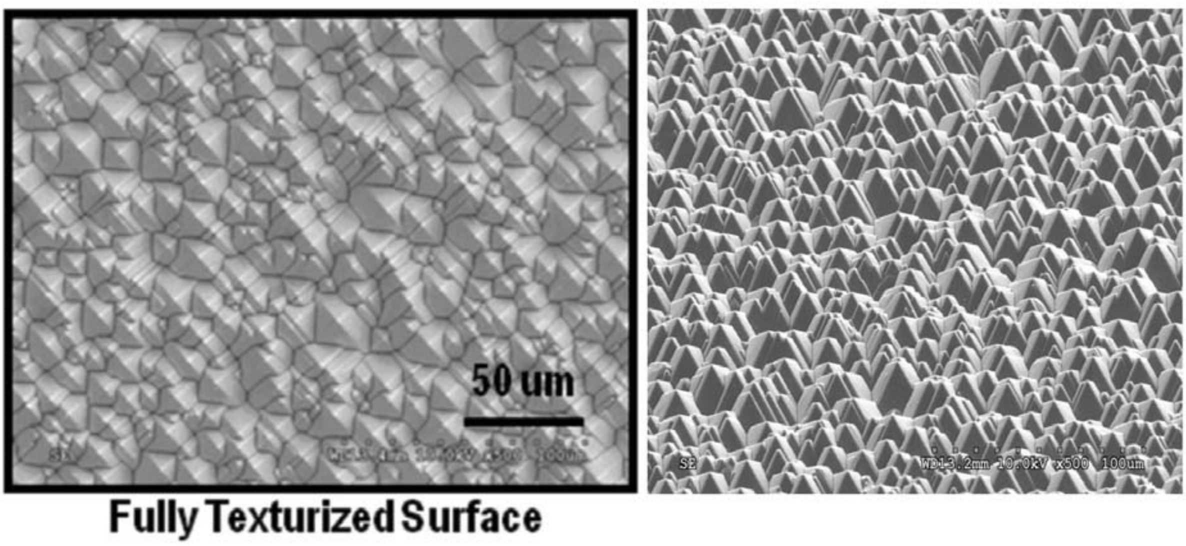

Figure 5. Random pyramid structures.

- Etch and texturization uniformity across the wafer, within wafers, and lot-to-lot by optimizing tank design for more uniform fluid flow.
- Tool reliability and flexibility by using modular designs that offer better control on water and chemical usage, exhaust volumes, and future upgradeability.
- Smaller footprint.
- All of the above having a positive impact on COO.

Plasma processes are relatively recent entrants into texturing. These processes have certain advantageous attributes when compared to wet processing, including reduced handling, reduced waste disposal, and reduced consumption of wet chemicals, such as DI water. In addition, as plasma etching is single-sided, it creates new possibilities for treating the backside of the wafer. These possibilities include the use of multicrystalline materials without saw damage, such as edge-defined, film-fed growth (EFG), which cannot be processed using common chemical bath texture methods.

A distinction has to be made between reactive ion etching (RIE) and other types of plasma texturing. RIE relies on the ion bombardment texturing, which results in a formation of so-called 'black silicon' and creates surface and subsurface damage that has to be removed for further cell processing (dopant diffusion).

RIE process chemistry is based on SF_6/O_2 or Cl_2. This technique has been proven to yield low reflectance with good uniformity, resulting in superior response in the long wavelength region. However, the defects induced by the ion bombardment can severely degrade the internal quantum efficiency (IQE). A possible solution is to use a damage removal etch (DRE), a wet chemical processing comprised of alkaline and acidic etch followed by modified acid-peroxide cleaning and final HF dip. DRE can partially diminish the results of texturing in terms of reflectivity; however, this is a necessary trade-off in solar cell processing to keep a low surface recombination velocity.

A second dry texturing alternative is a process based on microwave-powered antennas. 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 a radio frequency bias is applied. The process, which uses gases such as SF_6, N_2O and Cl_2, is self-masking in that the residues of the etching process are temporarily deposited on the surface, leading to a local etch block and the formation of a texture.

A third dry texturing process for silicon wafers was developed using a remote plasma source chemical downstream etcher, where the plasma is ignited by a microwave source situated above the reaction chamber that allows the ions to be trapped before reaching the wafer. In contrast to RIE, there is no acceleration of ions by a bias voltage as reactions on the silicon surface are carried out by radicals. Gases used are SF_6 and O_2; no ensuing wet chemical processing is required.

When plasma texturing is applied as a replacement for wet texturing in standard, thick (200µm) screen-printed solar cells, it yields similar or only slightly higher conversion efficiencies. In practice, the significant benefits of plasma texturing are most likely to be realized with advanced structures, with very thin wafers, and with specialized substrates such as silicon ribbons and epitaxial layers on low-cost silicon substrates. For these specialized substrates, plasma texturing is an enabling technology, as there is no straightforward wet chemical texturing process.

One important issue associated with plasma texturing is gas abatement. While replacing wet texturing by plasma texturing would reduce the amount of wastewater, the release of greenhouse gases could offset the environmental advantage associated with solar panels. SF_6, for instance, has a huge global warming potential (GWP) of 24,000. Just a small percentage 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 is common to several processes in microelectronics and increasingly to thin-film PV (reactor etching). Producers of gas and abatement systems have responded to the challenge and are 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 [5].

In discussing the various trade-offs associated with texturing, it is apparent that there are numerous considerations. Nevertheless, the ultimate requirement is not a technical requirement, but a business necessity. It is critical to consider the trade-offs in processing not simply as a series of technical trade-offs, but as a series of business trade-offs. COO is a tool that can be applied to this analysis, resulting in a disciplined, objective analysis of the technical trade-offs.

Given the number of processes for saw damage removal, texturization and cleaning, a complete COO analysis of each technology along with each configuration is well beyond the scope of this paper. Instead, a configuration for a wet processing sequence will be evaluated, which the authors perceive as being commonly used in production today. The remainder of the paper will discuss this process and the associated cost of ownership.

Current state of wet processing

In considering a 30MW solar-cell production line, an analysis was performed to determine the required capacity of the texturization process step. The results showed a need to process 1200 wph using the following tool configuration:

- **Preclean**: using an alkaline etch to remove saw damage and preclean wafers prior to the texturization step.
- **Texturization**: using KOH/IPA tanks, with multiple tanks needed to support the throughput requirements.
- **Postclean using HF/HCl**: removing chemical residues and rendering the wafer surface metal-free.

Typical conditions

A 25-minute process time is achieved with 80°C in each KOH/IPA tank. Bath life is estimated to last for 24 hours with a feed-and-bleed mechanism, which permits the addition of small volumes of fresh chemicals and bleed of similar volumes of used chemicals. This helps keep the etch byproducts below the maximum threshold. Accumulation of etch byproducts will eventually work as an etch mask and heavily contaminate the wafer surface with silicates. Post clean typically comprises a 1:1:200 HF/HCl/Water at ambient temperature for five minutes, which achieves a bath life of five days.

Future process changes

The PV industry has enjoyed rapid and profitable growth. With increased competition and cost pressures, solar cell manufacturers are competing to produce high-efficiency solar cells at the lowest possible cost. Areas of opportunity in the wet processing arena include:

- **Chemistry change**. Efforts have already been made to develop texturization chemistries to replace IPA in the KOH/IPA mixtures [4,6]. Surfactants could replace IPA and provide equally texturized surfaces. In addition, plasma processes have shown promise to replace acidic texturing. However, the issue of gas abatement may offset the environmental advantages of less wastewater.
- **Automation**. Further automation can be employed to reduce wafer breakage and minimize/eliminate contamination.
- **Statistical process control (SPC)**. Recent trends show the need for process control. Tool manufacturers are offering sensors and technologies to monitor and control the concentration of chemicals over the bath life, which can lead to an accurate prediction of the chemical concentration required to produce the desired results. It also enables the extended use of chemicals and, hence, lowers COO and increases process robustness, and can contribute toward further reduction of the installation time as well as reducing rework and wafer misprocessing.
- **Tightened specifications**. This would require more sophisticated techniques for surface conditioning to eliminate foreign contaminations on the wafers. This may mandate that equipment makers build tools with stringent contamination (particles, metals) and etch uniformity specifications. It may also require including features like minienvironments for the tools, filtration of chemicals, and high-purity materials of construction, which would oblige solar cell manufacturers to adopt many of the same cleanroom protocols that are already in use in the IC industry.
- **Water consumption**. Just like the IC industry, wet cleans and etch processes use large volumes of water to remove chemicals from the wafer. Cost drivers and environmental pressures will force solar cell manufacturers to find ways to use less water by using dilute chemicals, for example, thereby needing less rinsewater.

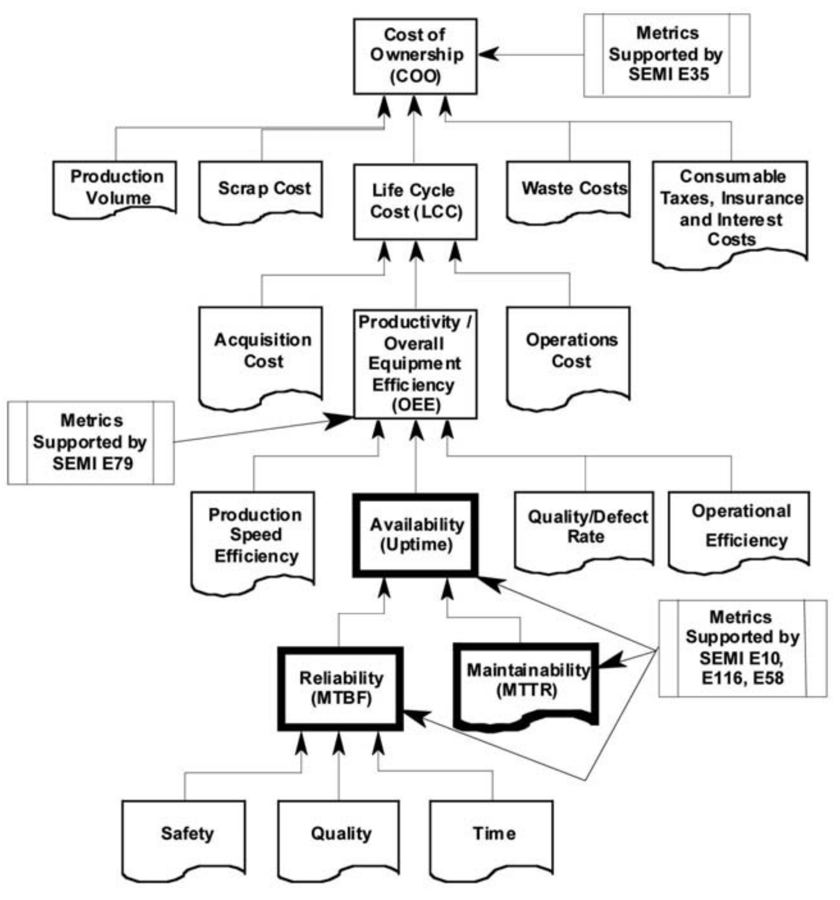

Figure 6. Hierarchy of equipment performance metrics [9].

Case study

As noted previously, a complete COO analysis of each technology along with each configuration, given the number of processes for saw damage removal, texturization, and cleaning, is well beyond the scope of this paper. Instead, a configuration for a wet processing sequence will be evaluated, one which the authors believe is commonly used in production.

Basic COO review

A more detailed discussion of COO can be found in the first paper in this series [1]. To review, the basic COO algorithm is described by [7]:

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

Where:

C_U = Cost per good unit (wafer, cell, module, etc.)

C_F = Fixed cost
C_V = Variable cost
C_Y = Cost due to yield loss
L = Process life
TPT = Throughput
Y_C = Composite yield
U = Utilization

Overall equipment efficiency (OEE) review

One of the most popular productivity metrics is OEE [8], based on reliability (MTBF), maintainability (MTTR), throughput, utilization, and yield. All these factors are grouped into the following four submetrics of OEE.

- Availability (joint measure of reliability and maintainability)
- Operational efficiency
- Throughput rate efficiency
- Yield/quality rate.

Calculating OEE requires many parameters. If the accuracy requirement is not a critical factor, the following formula can be used to calculate an approximate OEE value:

OEE = Number of good units output in a specified period of time/(theoretical throughput rate × time period).

There are many equipment performance metrics at different levels. Fig. 6 depicts the hierarchy tree of the equipment performance metrics.

Parameter	GAMA-Solar
Throughput	1,200 wafers/hour
Wafer size	156mm
Wafer cost	$3
Mean time between failure (MTBF)	1,500 hours
Mean time to repair (MTTR)	4 hours
Equipment cost	$1,500,000
Equipment yield	99.96%
Utilities	$30,700/year/system
Consumables	$103,563/year/system
Maintenance	Owner provided

Table 1. Major COO inputs.

Wet processing for texturization and cleaning

As stated previously, an obvious requirement for high efficiency in photovoltaic modules is low reflectance. Single-crystal silicon solar cells achieve very low reflectance through use of textured surfaces and/or antireflection coatings [2-4,6,10]. These principles have been understood and employed for more than a decade. The rest of this paper will examine the current cost structure and potential for cost reductions in a state-of-the-art, production-proven wet processing tool from Akrion Systems: the GAMA-Solar.

COO inputs

The following are the results of the COO analysis run on the GAMA-Solar wet processing station, based on the major input parameters shown in Table 1.

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

Cost drivers

Examination of the detailed TWO COOL cost-of-ownership model in Table 2 highlights the main cost and productivity factors (TWO COOL is a commercial software package from Wright Williams & Kelly). Recurring costs are approximately 1.5× initial capital costs over the life of the process.

Table 3 takes a closer look at the cost breakdown according to the 13 categories specified in SEMI E35. The top pareto costs are labour; depreciation, which is impacted by equipment costs, throughput rate, and utilization; materials/consumables, which includes utilities, supplies, consumables, and waste disposal; maintenance, including repair parts and technician labour; and floor space.

The top three cost drivers account for almost 90% of the total cost of ownership. For this reason, attention will be focused on those areas as cost sensitivities to input parameters are examined that drive labour, depreciation, and material/consumables costs.

Cost driver sensitivities

The first factor to be examined is labour content, which represents 40% of the total cost of these integrated process steps. Labour is defined as direct operator labour and the model is based on one operator overseeing one machine. Since these are highly automated machines with sufficient throughput to support a 30MW line, it is not likely that the factory would be significantly larger in order to allow for further amortization of labour content. However, Fig. 7 does examine COO sensitivity to labour content, should such opportunities present themselves.

If the factory can scale to accommodate two machines (or an equivalently larger single machine), increasing the labour efficiency from one to two machines would improve COO by 20%. Given such a significant sensitivity, looking at scaling and automation issues would be a major opportunity for cost reductions.

Next, the factors impacting depreciation, purchase price and throughput are examined (see Figs. 8 and 9). Purchase price has a modest impact on COO in high throughput tools, especially those with higher variable costs. The cost impact in this case is approximately \$0.004 (6%) per \$300,000 (20%) change in purchase price. However, as can be seen in Fig. 9, improvements in throughput can have a significant impact

Cost per system	\$1,500,000
Number of systems required	1
Total depreciable costs	\$1,532,500
Equipment utilization capability	96.72%
Production utilization capability	96.72%
Composite yield	99.96%
Good wafer equivalents out per week	194,908.54
Good wafer equivalent cost	
With scrap	\$0.07362
Without scrap	\$0.07242
Average monthly cost	
With scrap	\$62,353
Without scrap	\$61,336
Process scrap allocation	
Equipment yield	100%
Defect limited yield	0.00%
Parametric limited yield	0.00%
Equipment costs (over life of equipment)	\$1,664,627
Per good wafer equivalent	\$0.02340
Per good cm^2 out	\$0.0001
Recurring costs (over life of equipment)	\$3,573,012
Per good wafer equivalent	\$0.05022
Per good cm^2 out	\$0.0003
Total costs (over life of equipment)	\$5,237,639
Per good wafer equivalent (cost of ownership)	\$0.07362
Per good wafer equivalent supported	\$0.07362
Per good cm^2 out	\$0.0004
Per productive minute	\$1.47

Table 2. COO results.

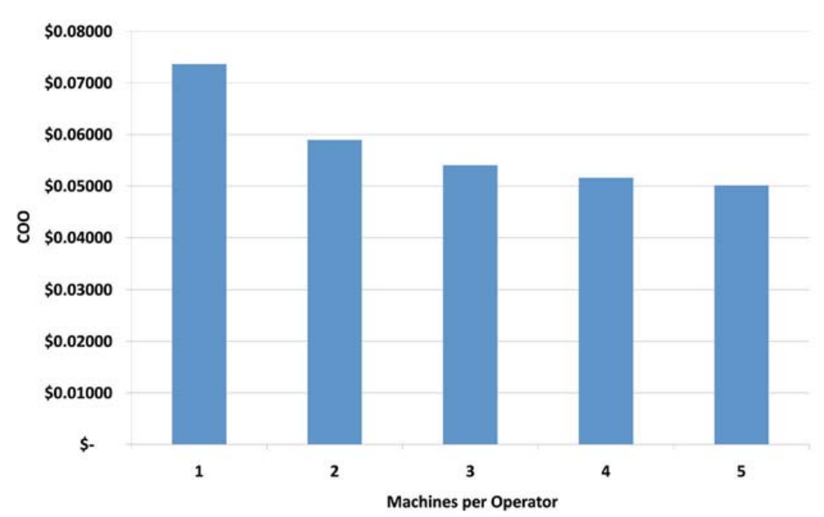

Figure 7. Sensitivity analysis of labour vs. COO.

Cost drivers per good wafer equivalent	
Labour	\$0.02940
Depreciation	\$0.02154
Material/consumables	\$0.01491
Maintenance	\$0.00338
Floor space costs	\$0.00167
Support personnel	\$0.00134
Scrap	\$0.00120
Training	\$0.00010
System qualification costs	\$0.00009
ESH preparation and permits	\$0.00000
Moves and rearrangements	\$0.00000
Other materials	\$0.00000
Other support services	\$0.00000

Table 3. Pareto of cost drivers.

on COO, with a $0.006 (7%) change for a 100wph change (8%) around the nominal value.

Assumed in this sensitivity analysis is that the amount of chemistry consumption per wafer remains the same across all throughputs. If higher per-wafer chemistry consumptions are needed to achieve the increased throughput (increased consumption of acids, bases, and IPA), then this becomes a multivariable analysis and beyond the scope of this paper.

The last area of examination for cost sensitivities is supplies and consumables. Table 4 shows the annual costs per system by supply item. One of the issues in defining a sensitivity analysis for any of the listed items is their interrelationship with other factors. Increasing or decreasing KOH concentrations, for example, will have an impact not only on throughput, but also caustic drain costs. Likewise, IPA is volatile at typical process temperatures (up to 90°C) and that has a significant impact not only on IPA refresh but also exhaust volumes, which require oxidation. It is less likely that KOH concentrations can be significantly impacted due to the fact that it is the etchant; it is more likely that IPA can be impacted since it is acting as a wetting agent.

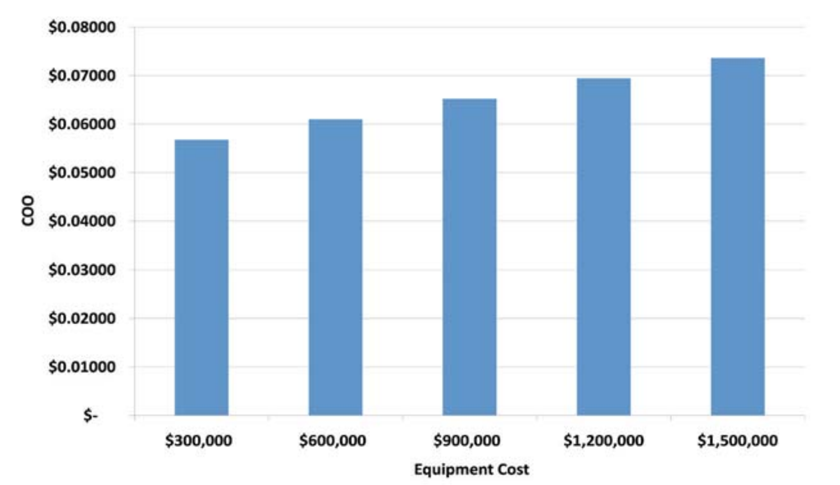

Figure 8. Sensitivity analysis of purchase price vs. COO.

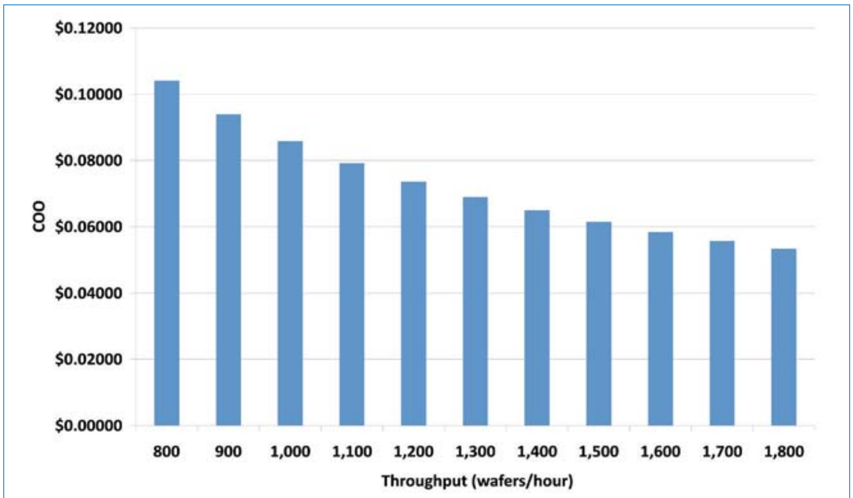

Figure 9. Sensitivity analysis of throughput vs. COO.

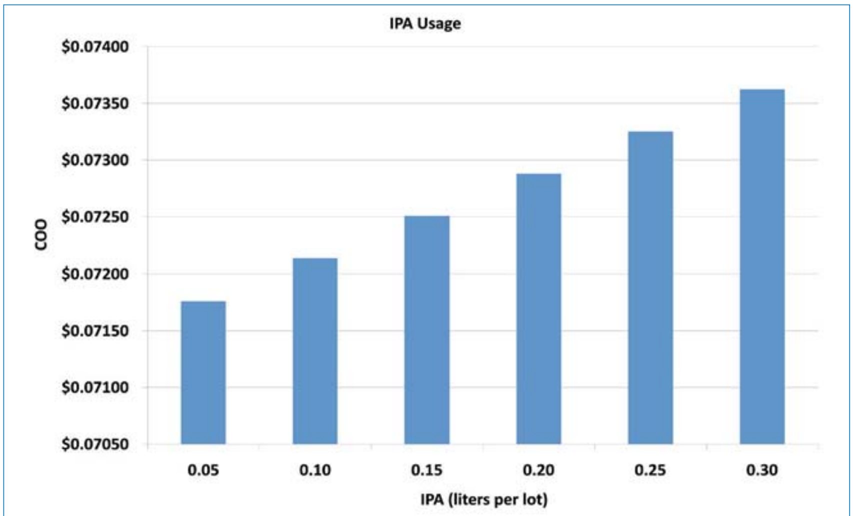

Figure 10. Sensitivity analysis of IPA usage per lot vs. COO.

Fig. 10 looks at the COO impact of reducing IPA consumption. In preparing for this paper, the survey of end-users indicated that their perception was that IPA was a major cost driver due to its volatility at operating temperatures. As a result, Fig. 10 was a surprise based on these initial comments and shows that efforts solely focused on IPA usage reduction will not drive a major cost reduction.

However, reducing the volumes of IPA or even eliminating it remains an industry concern. Studies show that alternatives can be found although no solution has been endorsed yet by manufacturing sites. If the assumption is that an alternative surfactant can be used at 50% the cost of IPA and at 10% the volume (with a corresponding 90% reduction in exhaust), a COO of $0.07035 is calculate, or a reduction of 4.5%. Again, unless there are environmental or other strategic reasons, it appears replacement of a relatively inexpensive chemical like IPA is not a highly leveraged investment.

When using COO, a proposed improvement can often result in an impact on multiple inputs. For example, a feed-and-bleed approach to refreshing chemistry results in longer bath life and, hence, higher tool utilization. The benefits of this approach can be quickly analyzed as follows: a typical tool uses a bath for about 8-10 hours, at the end of which the bath has to be changed. The time needed for the change-out is approximately 1-2 hours, including the time needed to verify the right chemical concentration and the desired etch rate. A typical feed-and-bleed rate is to add additional chemicals of about 50% of the initial mix, extending bath life and reducing chemical consumption. COO calculations indicate that a feed-and-bleed system reduces the cost per wafer by nearly 16%.

Overall equipment efficiency

Table 5 shows the OEE of the GAMA-Solar; the OEE is in excess of 95% which leaves little room for improvement, with only five hours per week dedicated to preventive maintenance.

Conclusion

This paper has examined the need for saw damage removal and follow-on

Supply/Consumable	Annual Cost per System
DI water	$16,046
HCl	$433
HF	$518
IPA	$20,131
KOH	$28,966
CDA	$234
H_2O_2	$1,638
Acid drain	$7,127
Caustic drain	$7,729
Exhaust	$20,741

Table 4. Annual supply/consumable costs.

Overall equipment efficiency	96.68%
Availability efficiency	96.72%
Engineering usage	0.00 hr/week
Standby	0.00 hr/week
Hours available/system (productive time)	162.49 hr/week
Downtime	5.51 hr/week
Scheduled maintenance	5.04 hr/week
Unscheduled maintenance	0.47 hr/week
Test	0.00 hr/week
Assist	0.00 hr/week
Non-scheduled time	0.00 hr/week
Equipment uptime	162.49 hr/week
Total time	168 hr/week
Performance efficiency	100%
Throughput at capacity/system	1200 layers/hr
Theoretical throughput	[1200 layers/hr]
Operational efficiency	100%
Rate efficiency	100%
Quality efficiency	99.96%
Equipment yield	99.96%
Defect limited yield	100%
Parametric limited yield	100%
Alpha error factor	100%
Beta error factor	100%
Redo rate	0.00%

Table 5. OEE results.

processes including texturization in both wet and plasma-based systems. While the technical approach to reducing reflectance at the wafer's surface is well understood, the results show that initial industry concerns over the cost of IPA may have been misplaced. Through the use of COO, the photovoltaics industry has at its disposal a quantitative methodology which can help it make the best choices as it continues down its rapid cost decline curve.

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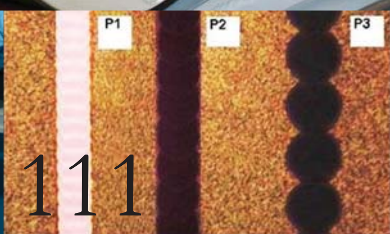
Thin Film



First Solar takes 2009 revenue past US$2 billion: guides close to US$3 billion for 2010

Module production at First Solar's Frankfurt (Oder) plant in Germany.

Financial results for First Solar in 2009 clearly place the CdTe thin-film solar producer as the number-one photovoltaics manufacturer by revenue in the world in 2009. This is the first time that the company has reached this position. Revenues topped US$2,066.2 million in 2009, up from US$1,246.3 million in 2008. Fourth-quarter revenue reached US$641.3 million, up from $480.9 million in the third quarter. Module production for the quarter reached 311MW, a new record for the company, resulting in 2009 production levels of 1.1GW, a record for the industry. Annualized capacity per line reached 53.4MW.

The company also announced that it was expanding production at its Malaysian facilities with plans to add eight new lines. Shipments will start in the first half of 2011. Capital spending for 2010 was said to be between US$500 and US$550 million.

Conversion efficiencies of its CdTe thin-film modules reached 11.1% in the quarter and the module manufacturing cost was US$0.84 per watt. Production cost per watt was lowered to US$0.80. The company is confident of a 3.5% per annum reduction through 2014.

First Solar also updated capacity plans for its Ohio facility and its joint venture in France with EDF. Combined with the Malaysian fab expansions, First Solar expects to reach a production capacity increase of only 54MW in 2010, due mainly to improved line optimization and line expansion at its Ohio fab, which is already underway. However, capacity is expected to reach 1.7GW in 2011 with lines 5 and 6 coming online in Malaysia by midyear. The planned EDF manufacturing partnership will provide a 107MW boost to capacity in 2012, with a total capacity reaching 1.816MW by the end of 2012.

With a high exposure to the German market, executives noted that they expect installations to be approximately 3GW in 2010, basically flat with what they believe was installed in 2009. In 2010, despite efforts to open other geographical markets such as the U.S., the company still expects approximately 40 to 50% of its module sales to come from Germany. Because of the planned feed-in tariff changes due for implementation on June 1, First Solar expects shipments to Germany to be first-half-year loaded.

Module Production News Focus

Oerlikon Solar claims US$0.70 cost per watt for 'Micromorph' thin-film modules; full production planned for 2012

Many of the amorphous (a-Si) thin-film users of turnkey production lines have had to hunker down during the current recession and strictly limited access to capital. Hit by a perfect storm that saw polysilicon prices plummet and now reaching sub-US$50/kg for c-Si users, a-Si producers need higher conversion efficiencies to compete competitively with other technologies, not least CdTe leader, First Solar.

According to Oerlikon Solar, many of its a-Si thin-film customers are targeting 2012 and beyond to gain significant market share when their next-generation 'micromorph' factories will be in full production at production costs that enable grid-parity level PPA prices. Oerlikon Solar recently claimed that its tandem-junction technology would be capable of producing modules for US$0.70/W by the end of 2010.

The company said that one of its most recent customers, Gadir Solar, has been ramping its 40MW a-Si thin-film line in the bay of Cadiz, Spain in record time since October 2009. Heliosphera, another Oerlikon Solar customer, announced last year that it had received TUV certification for micromorph-based modules.

The micromorph turnkey thin-film production lines are claimed to be on track to produce a further 30% reduction in production costs in 2010. The company says that it has already driven down module cost 25%, via improved cell efficiencies and greater line throughput, which means that a line capable of producing 60MW in 2008 can now produce 100MW, without additional equipment.

Oerlikon Solar said that incorporating an advanced fab design, its turnkey tandem junction technology would be capable of producing modules for US$0.70/W by the end of 2010.

Oerlikon Solar's Fab 1200.

SoloPower abandons flat-plate strategy, embraces flexible CIGS PV module

CIGS start-up SoloPower has abandoned its efforts to string its electroplated flexible stainless-steel solar cells into flat-plate PV panels and is proceeding directly to the production of flexible CIGS modules. In a phone interview with the two SoloPower principals, Lou DiNardo, company CEO, confirmed that SoloPower has decided to get out of the commodity business of classic form-factor glass modules, a market dominated by a combination of low-cost First Solar CdTe and Chinese and other crystalline-silicon entrants.

A strategic move was made to accelerate the development and commercialization of the more value-

SoloPower's flexible module.

added flexible product, with the industrial and commercial metal rooftop sector as the primary target market. DiNardo is confident that his company will be the first to market with a low-cost, high-efficiency, certified 20-year-plus lifetime product. This is largely due to a concerted and apparently successful effort to solve the moisture seepage issue with a combination of new barrier materials, as well as improved top and backsheet layers and tweaks in the buffer and TCO layers that "ease the burden of the moisture barrier," he explained.

The recent efficiency and reliability test results do offer some credence to DiNardo's assertions. SoloPower says it has seen small-area conversion efficiencies of 13.76%, with $12cm^2$ and $178cm^2$ cells hitting 13.4% and 11.7%, respectively, and more importantly, metre-long flexible module reaching 10.75% efficiencies. The cells and modules all came off the company's 10MW roll-to-roll production line, not from lab-generated PV materials.

In damp-heat IEC testing, the modules did quite well after enduring more than the requisite 1000 hours at 85°C and 85% RH, showing minimal power degradation of $<5\ P_{max}$. The company expects ultimate approval of the modules to be completed by July 2010.

China Solar Power to build 200MW a-Si thin-film plant with Suzhou Industrial Park

An Ulvac turnkey a-Si thin film customer, China Solar Power (CSP), will build its third production plant with an investment from the Suzhou Industrial Park (SIP). The 200MW nameplate capacity facility will be the first of its kind in at the Suzhou Industrial Park. SIP was established in the mid-1990s as a joint venture between Suzhou and Singapore. The cost of the new plant was put at US$180 million.

CSP was founded in 2007 by Tano China Capital Management, a subsidiary of Tano Capital. CSP's first thin-film PV manufacturing plant is located in the city of Yantai, Shandong Province in Northern China.

Roth & Rau to jointly own CdTe thin-film production lines with Chinese partner

Photovoltaics equipment supplier Roth & Rau is becoming a production partner with an unidentified China-based company to establish a joint venture firm responsible for cadmium telluride thin-film (CdTe) module production. Roth & Rau CTF Solar, a subsidiary of Roth & Rau, will be the partner in the new enterprise. The JV will use Roth & Rau's turnkey CdTe equipment and technology and will first establish an 80MW 'specimen' line in Brandenburg, Germany at a cost of €100 million. Based on the relevant production milestones, the JV will then build production plants in China, with the Brandenburg line becoming the reference site.

Roth & Rau said it would hold a 49% share of the capital in the new JV, contributing €19.6 million to the new company's capital reserve. Roth & Rau will then have the opportunity to hold a 32% stake in production plants built in the future in China.

First module out for centrotherm's Taiwan-based CIGS thin-film customer

The first CIGS thin-film modules using centrotherm photovoltaics' new turnkey production technology have rolled out at the site of its unidentified customer in Taiwan. The company reiterated that it expects conversion efficiencies to reach 10% on the line by the end of 2010. The turnkey line, now in ramp-up mode, has a capacity of 30MW per annum. According to centrotherm, the modules being produced rank as the largest CIGS modules in mass production, with a surface area of $1.5m^2$.

R & D News Focus

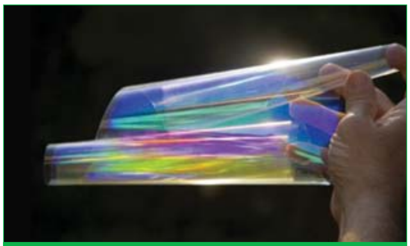
Silicon thin-film triple-junction cell boosts efficiencies to 14.8% for Mitsubishi

A triple-junction thin-film silicon cell structure that utilizes the majority of the solar spectrum is in development phase at Mitsubishi Electric. A 5mm x 5mm cell is claimed to have produced conversion efficiencies of 14.8% in the lab. High-quality film-deposition processing of each layer was required. Mitsubishi said that first layer absorbs short wavelengths and the third layer absorbs long wavelengths. Texture fabrication was also applied to transparent electrodes for optimal confinement of light.

Mitsubishi said it intends to continue its R&D of the triple-junction cell with the aim to raise conversion efficiencies further. Work will focus on improving cell structure and materials as well as processing conditions.

Prism Solar, PPG partner to test different glass for standard, holographic PV modules

Prism Solar and PPG Industries have joined forces to test the performance of different types of glass in both standard and holographic photovoltaic modules



Prism Solar's holographic PV module film.

at various incident and direct angles. The companies say that the tests will compare PPG's Solarphire antireflective high-transmissive glass to patterned glass to ascertain the increase in energy yield.

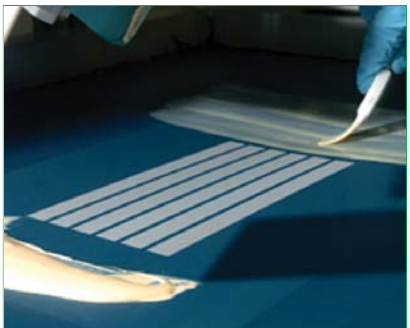
The holographic solar module developer will be characterizing the performance of PPG's AR glass and patterned glass to determine the increased energy yield in relation to angular performance.

By measuring energy yield from a series of modules characterized to be equivalent in terms of peak watt rating, the added value of AR properties for monofacial modules as well as Prism's bifacial holographic planar concentrator modules can be determined, according to the partners. Test arrays with tilt angles from 0° to 90° will be explored to provide data on a full range of possible array tilt angles.

Prism Solar has holographic film and module production facilities as well as significant R&D capabilities in Highland, NY, and Tucson, AZ, with capacity expansion plans under way.

Dyesol establishes German subsidiary to pursue dye solar cell development

Australia-based materials provider Dyesol has established a German subsidiary in Bavaria to pursue commercialization of dye solar cell (DSC) technologies. The company said that due to Germany's leading position in the solar industry it would seek collaboration and partnerships with industrial and government partners to bring DSC products to market. The new subsidiary will be operated by Dr Keith Brooks, currently Managing Director of Dyesol's Swiss subsidiary Greatcell.



Pasting process in the production of Dyesol's dye solar cell (DSC) technology.

Semprius, Siemens enter agreement for solar technology development

Semprius and Siemens Industry have entered into a joint development agreement to co-develop plug-and-play demonstration systems based on Semprius's solar module arrays and Siemens's automation and control components. The systems will be installed at test sites around the world, including major utilities, commercial sites, international test locations and government facilities.

Siemens will integrate its components with Semprius PV module arrays, and together the companies will implement the test systems to validate performance of the combined technologies.

ECN to coordinate EU-funded 'HIFLEX' program on organic ultra-flex roll-to-roll PV

A three-year program is underway to commercialize highly flexible organic photovoltaics (OPV) modules using inexpensive materials produced with compatible roll-to-roll printing and coating techniques. The European research project, dubbed 'HIFLEX,' is being coordinated by Energy Research Centre of the Netherlands (ECN) and includes several universities as well as industrial partners, Dr Schenk and Agfa-Gevaert. Commercially, the technology is being developed for a wide variety of ICT products in the mobile electronics market.

The flexible thin-film technology will be free of indium tin oxide (ITO) using scalable, reproducible and commercially viable printing and coating techniques. Dr Schenk has experience in the inline process and quality control of R2R techniques, while Agfa-Gevaert is known for developing silver (Ag) grid lines, and PEDOT antistatic coatings as well as developing innovative coating solutions.

Based on their expertise in the field of device and module engineering, upscaling and large-area printing, and long-term lifetime testing, the universities involved in the program include ECN, Fraunhofer Institute for Solar Energy Systems (ISE), Risø National Laboratory for Sustainable Energy (Risø DTU), TNO/Holst Centre, and UK Materials Technology Research Institute (MaTRI).

Testing and Certification News Focus

NREL confirms new 15.1% conversion efficiency record for Avancis' CIS thin film module

The U.S.-based National Renewable Energy Laboratory (NREL) has confirmed a new conversion efficiency record for CIS thin-film modules fabricated by Avancis. Published in the journal 'Progress in Photovoltaics,' NREL confirmed a 15.1% conversion efficiency for a 30 x 30cm^2, fully encapsulated CIS solar module, based on the aperture area of 668cm^2. Avancis produced the results in its R&D lab in Munich, Germany. The thin-film start-up has produced 11% efficiency levels at its 20MWp/pa capacity plant in Torgau, Saxony.

Concentrix Solar's CPV modules get IEC certification

Concentrator photovoltaics company Concentrix Solar has received the IEC 62108 certification for its CX-75 Flatcon CPV module generation. The industry standard confirms that

Concentrix Solar's Flatcon CPV modules.

the modules and assemblies have passed the required battery of tests and are suitable for long-term operation in a wide range of outdoor climates.

The assessment was performed by the Spanish accredited testing institute CENER and certified by the Spanish Association for Standardization and Certification. The Concentrix module successfully passed all the necessary IEC performance and accelerated aging tests and therefore received design qualification and type approval.

According to the testing standards for conventional PV modules, the IEC 62108 norm simulates environmental conditions and influences for CPV modules to verify the performance reliability and aging resistance, including testing of hail impact, mechanical load, insulation, and wet insulation as well as outdoor exposure.

Odersun's PV modules.

Odersun receives IEC certification for CIS-based modules

Odersun has achieved International Electrotechnical Commission (IEC) certification for its standard CIS-based solar modules. The German Engineering Association VDE has awarded the certification for Odersun's 1.0 x 1.70m framed glass-foil modules built of Odersun's CIS-on-copper-tape cells.

The IEC 61646 and 61730 certifications are awarded to companies producing modules that meet the IEC's strict norms regarding function, quality and safety.

Odersun will now begin the ramp-up of its 20MW manufacturing facilities in Fürstenwalde, Germany.

Business News Focus

Uni-Solar installer adds Solyndra's CIGS modules to product offering

A long-standing user of Uni-Solar a-Si thin film laminates in the U.S., Advanced Green Technologies (AGT), has signed a distribution agreement with CIGS thin film producer, Solyndra. The two technologies compete in the commercial rooftop markets. ECD produces the Uni-Solar branded products.

Solyndra's founder and CEO, Chris Gronet, noted that gaining AGT as a distributor was a great addition to its North America distribution network. Further contract details were not disclosed and Solyndra declined to comment based on it being in the quiet period before its expected IPO.

Applied Materials acknowledges challenging times for 'SunFab' users: 30MW of modules installed

High upfront capital costs, a financial crisis that starved start-ups of capital injections, and plunging polysilicon prices were only some of the key challenges that Applied Materials 'SunFab' a-Si thin-film customers faced in 2009. The strong emergence of First Solar with its alternative thin-film technology with much higher conversion efficiencies and lower manufacturing costs

Order Focus

BudaSolar wins first phase of 1GW turnkey thin-film complex in Dalian, China

Silicon thin-film equipment supplier BudaSolar Technologies has secured a contract with China City Investments Limited, a project company set up by Chinese investors to supply an 85MW turnkey a-Si thin-film line. The agreement is the first phase of the Dalian City Industrial Park Project targeting the development of a vertically integrated production complex that will include a glass factory set up by Harcon Co. of Hungary.

The plans call for a cumulated PV production capacity of 1GW, ramped in 10 phases. The construction of the complex is to begin in the second quarter of 2010, with initial production starting in the second half of 2011. BudaSolar Technologies has previously supplied a turnkey thin-film line to Grupo UniSolar SA in Spain.

Smit Ovens wins follow-on order for CIGS vapour transport deposition

Smit Ovens has received a follow-on order from an existing, unidentified customer for its vapour transport deposition (VTD) systems for mass production of thin-film CIGS (copper indium gallium diselenide) cells. The order also includes a scaled-down system for deposition of selenium and crystallization of CIGS precursors, suitable for research into process optimization.

Singulus wins €19 million thin-film equipment deal

In what the company's CEO hailed as a major breakthrough, Singulus Technologies has received an order for its recently developed thin-film processing equipment. The order is worth €19 million and underlines attempts to broaden its product portfolio and enter new markets. Singulus said that it had been developing the technology in close cooperation with this customer during 2009. The news comes on the back of its recent 2009 financial results and its planned development of complete turnkey 'front-end' production lines with recently acquired Stangl.

Sunfilm integrates in-line metrology systems from Basler

Sunfilm, the first Applied Materials 'SunFab' thin-film customer to switch to tandem junction silicon cell structures, has also integrated three 'Sensic' in-line metrology tools from Basler Vision Technologies to provide required quality inspection throughout the process flow. Basler is best known for inspection systems used in the LCD industry. The systems have now been adapted and optimized for the thin-film industry.

Mike Splinter, Applied Materials' chairman, president and CEO.

has put a squeeze on a-Si market penetration. Mike Splinter (pictured), Applied's chairman, president, and CEO, finally acknowledges that many of its SunFab customers have found the current environment challenging. However, in its latest quarterly conference call, Splinter was adamant that the company had full belief in the technology and that the key market for its large substrate panels was only just starting, that of large-scale utility plants.

"The price declines in crystalline silicon modules have exerted margin pressure at some of our thin-film customers, in some cases lowering their demand and factory utilization to very low levels," remarked Splinter in the conference call. "When you look at the temperature coefficient, when you look at the incident light, when you look at ambient particles in the air versus the efficiency of these panels, installation costs are huge advantages over other technologies. The utility-scale solar has to develop, it's still a very nascent market; it's a very small percentage of the total."

Putting a positive spin on recent customer developments, Splinter highlighted that it had signoff at two new lines during the quarter, bringing the total to nine. He also noted that two customers announced large development projects this year and that customers now have 30MW of modules installed in the field, providing field performance data to demonstrate the capabilities of the technology.

Singulus to push new technologies in c-Si and thin-film markets

In a major effort to boost its position within the solar equipment market, Singulus Technologies is planning a suite of new product introductions in 2010 that will include technologies to lower PV manufacturing costs and boost cell efficiencies for both 'front-end' c-Si production and CIGS and CdTe applications. Another import move will be the development of complete integrated turnkey lines for 'front-end' c-Si production, leveraging technologies and systems from its recent acquisition of Stangl. The company noted that due to continued pricing pressures on PV manufacturers this was a key driver to focus on such solutions.

The company is also cooperating with leading cell manufacturers targeting both improved cell concepts with higher efficiency and production technology that offered lower production costs. Several new production concepts have also been under development at the company for the thin-film production, which will be launched in 2010. New developments include the application of its ILGAR technology or ovens for selenization deposition and diffusion.

Duke Energy to start first solar power plant; buys juwi/First Solar 'Blue Wing Solar' project

A 16MW solar power plant under development by juwi solar, using 214,500 ground-mounted cadmium-telluride thin-film PV panels from First Solar, has been acquired by Duke Energy. The 'Blue Wing Solar' project in San Antonio, Texas, which was originally planned to begin construction in the first quarter of 2010, with completion and grid connection by the end of 2010, is unchanged, with CPS Energy remaining the customer. The Blue Wing projects will be the first commercial solar power project Duke Energy will own and operate.

"Demand for power from renewable resources continues to rise," said Keith Trent, Group Executive and President of Duke Energy's Commercial Businesses. "Our entry into the commercial solar power industry reaffirms Duke Energy's commitment to generating emissions-free electricity for customers."

Duke Energy Generation Services (DEGS), a Duke Energy Commercial Businesses unit that owns and develops renewable power assets, will purchase the Blue Wing Solar Project from juwi solar. Financial details were not disclosed.

ECD revenue rises but so do losses: factory usage taken down to 25% of capacity

Energy Conversion Devices is still struggling to sell its flexible thin-film laminates in a market that is only slowly recovering, according to its latest second quarter financial year results. Revenues increased slightly Q-on-Q to US$52.9 million, compared to US$42.9 million in the first quarter of fiscal 2010. However, losses of US$39.1 million were reported, which are much higher than the first quarter loss of US$11.8 million. Revenue in the same period a year ago had topped US$103.1 million with income of US$13.0 million.

The company is still feeling the impact of its acquisition of Solar Integrated Technologies and recent workforce reductions. It is also impacted by lower utilization rates, which the company noted had negatively impacted the quarterly results to the tune of US$7.4 million.

"We reduced our inventory balances, continued to restructure our company and are encouraged by the early results of the business initiatives undertaken in the second quarter," commented Mark Morelli, ECD's President and Chief Executive Officer. "We've signed more than 35 megawatts of new projects and agreements since the end of the quarter, and we expect to build on this momentum in the second half of the fiscal year."

Morelli went on to claim that he was confident the company would be able to achieve 12% laminate conversion efficiencies and less than US$0.95 manufacturing cost per watt, though did not give a timeline to these milestones in statement.

During a conference call with financial analysts, executives of the company noted that it would be lowering production to only 25% of capacity in the current quarter, due to an inventory (finished goods) glut of approximately 44MW. The company had previously reduced utilization rates to 50%.

Production costs are running higher than current ASPs, forcing a high cash burn rate, which was put at approximately US$40 million per quarter by executives. The lower utilization rates are designed to burn-off inventory at a higher rate and generate cash for the company.

MiaSolé receives $101.8 million in tax credits to advance solar manufacturing

MiaSolé has received two Advanced Energy Manufacturing tax credits totaling US$101.8 million from the Obama Administration for the manufacture of low-cost thin-film cells and modules. A total of US$2.3 billion in tax credits is being allocated for investments in 183 manufacturing facilities for clean energy products across 43 American states.

In order to achieve this goal, MiaSolé will add jobs to ramp up its manufacturing facility based in Santa Clara, CA. The number of employees at MiaSolé was already increased in 2009 from 150 to 300.

"We believe the award is a reflection of the Department of Energy's confidence in MiaSolé's technology and business model," said Dr. Joseph Laia, CEO of the company. "The strong show of support by the Obama Administration is encouraging, and we look forward to ramping our manufacturing capacity and creating jobs aided by these funds. We also view the commitment of the Administration to create green manufacturing jobs as important in positioning the United States towards the future."

More than 500 applications were submitted for the tax credits. The winners were selected based on their commercial viability, domestic job creation, technological innovation, potential for reducing air pollution and greenhouse-gas emissions, and the speed at which the projects would be completed.

Product Briefings

BrightView Systems

BrightView's InSight M Series in-line metrology system optimizes thin-film processes

Product Briefing Outline: BrightView Systems has unveiled the InSight M Series, an in-line process control and optimization tool developed specifically to address the challenges faced by thin-film solar cell manufacturers. The Wide Area Metrology (WAM) system provides continuous monitoring and whole-panel mapping of critical material and process parameters at full production throughput and for 100% of manufactured panels.

Problem: Solar cell performance depends on a complex interaction of photoelectrical effects, material properties, and layer interface characteristics. Optical and electrical parameters must be balanced to achieve optimal conversion efficiency, and maintained within narrow process windows.

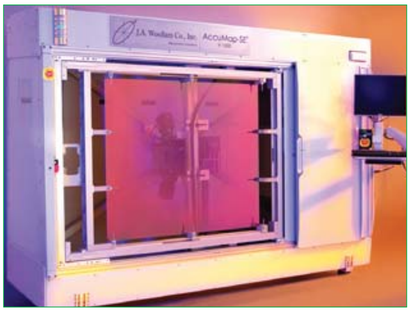
Solution: By combining an in-line metrology technology and matching spatial data analysis solutions that are driven by in-depth knowledge of thin-film PV process and volume production, the InSight M Series is the integral solution for improving thin-film PV panel efficiency and long-term reliability. Easily integrated at key steps in any thin-film production line including single-junction and multi-junction silicon, the system allows panel producers to implement process optimization solutions that enhance average panel efficiency, improve line productivity and verify full compliance with the strictest durability and quality requirements. With its 'True Cell' technology, the InSight is able to measure and map critical layers on-the-fly within the actual product stack.

Applications: All thin-film modules. Complete panel mapping of critical material and process parameters.

Platform: The system architecture allows for easy integration into the design of new production lines or insertion into existing ones, including Gen 5 and Gen 8.5 lines. The BrightView tool is complemented by an intuitive operating interface and state-of-the-art software modules that allow easy implementation and customization of intelligent line monitoring recipes, spanning all production stages.

Availability: Currently available.

J.A. Woollam



J.A. Woollam's new AccuMap-SE provides accurate thin-film measurement of panel uniformity

Product Briefing Outline: J.A. Woollam Company has integrated its Flying M-2000 Spectroscopic Ellipsometer into a mapping tool for thin-film uniformity measurements over the entire PV panel. The high accuracy and wide spectral coverage of the M-2000 ensure that every layer in a thin-film stack can be measured, while new automation has been designed to ensure fast, precise measurements over the entire panel.

Problem: The performance of thin-film PV depends on the thickness and optical properties of many different layers. Research ellipsometers are used during product development and have helped improve PV designs. There is currently a need to move research-grade ellipsometry into pilot and production lines to characterize the thickness and optical constants for the various films. In addition, fast measurement speed is necessary to determine thin-film uniformity over the entire panel.

Solution: The AccuMap-SE combines the latest spectroscopic ellipsometry technology into an affordable platform for use in research, pilot and production lines. Measurements are performed with Woollam's Flying M-2000 technology that provides accurate spectroscopic ellipsometry from the ultraviolet to the near infrared in a fraction of a second. The ultraviolet spectrum is important when characterizing the crystallinity and optical properties of semiconductor layers, while the near infrared provides film thickness and conductivity measurements for transparent conductive oxide layers. The Flying M-2000 also incorporates a proprietary head with fast, automated alignment to measure films on either the front or the back of the panel.

Applications: Amorphous and microcrystalline silicon or silicon-germanium films; CIGS, CdTe, CdS, any TCO material, including doped SnO_2, ITO, ZnO_x, etc.

Platform: For use with any panel size up to 1.1m by 1.5m.

Availability: Currently available.

Nordiko Technical Services

Broad Ion Beam Milling tool from Nordiko handles nanoscale R&D requirements

Product Briefing Outline: Nordiko Technical Services' '7500' Broad Ion Beam Milling system is designed around a new 50cm plasma source and a new high reliability rotary substrate table that allows in repeatable milling performance with very good within wafer non-uniformity from a very low divergence collimated ion beam. The tool can be used in thin-film development through to pilot production of a wide variety of materials.

Problem: Ion-beam milling (etching) has been developed and used in R&D to evaluate the influence of interfaces on solar cells. With nanoscale structures being deposited in advanced cell structures, Broad Ion Beam Milling systems offer excellent etch uniformity and control of etch feature geometries. Ion-beam sputter deposition also offers significant advantages in the density, crystallinity, grain size and thickness control – characteristics that can sometimes be a problem with similar systems.

Solution: The ion source is the largest from Nordiko's series of RF excited ion beam generators. By matching the attributes of the large plasma generator to a very robust accelerator, the ion source delivers ground-breaking performance in terms of beam quality. The ion accelerators used in these systems are customized to achieve maximum benefit to the application. All are characterized by a robust structure and class-leading beam quality delivering matched beams with optimized emittance to deliver tight low divergent broad beams. The system can also perform self-organized pattern formation for nanoscale applications.

Applications: Wide variety of thin-film materials, substrate size up to 225mm².

Platform: The variable angle rotary substrate table provides effective sample cooling. End-point detection using secondary ion mass spectroscopy (SIMS) is optionally available for precision milling applications. Wafer handling and process supervision is controlled by the Nordiko automation system.

Availability: Currently available.

Scaling single-junction a-Si thin-film photovoltaic technology to the next level

Mohan K. Bhan, **Rahul Kapil**, **Indu Shekhar Bajpai**, **Rajesh Kumar**, **Vineet Jain** & **Sudheer Kumar**, Moser Baer PV Technologies India Limited, Greater Noida, India

ABSTRACT

The recent photovoltaic industry shakeout which started around Q3 2008 has faced the overcapacity, credit crunch, and economic crisis that significantly declined the average selling price by 50–65%, including the price of thin-film photovoltaic modules. The changing business environment has put significant pressure on all PV manufacturing technologies but more candidly on amorphous silicon thin-film single-junction module manufacturers to advance and scale up the device efficiency and aggressively drive cost reduction. This paper outlines the technical approach taken at Moser Baer Photovoltaic Technologies India Limited (PVTIL), including process optimization and device management strategies, to enhance the efficiency (total area) of the thin-film single-junction amorphous silicon module as manufactured using Applied Materials' SunFab line.

Introduction

Moser Baer Photovoltaic Technology India Limited (PVTIL) was formed in February 2007 with the main objective to become one of the leading thin-film module manufacturers in India with the capacity to compete in global markets. The production plant was constructed with the initial annual manufacturing capacity of 40MW using the Applied Materials Gen 8.5 SunFab Line applying a stable efficiency of ~6%. The reported efficiency is determined after applying the total module/glass area to the calculation. The Factory Acceptance Test (FAT) of the single-junction amorphous silicon (a-Si) thin-film plant was completed in December 2008. The line is capable of producing modules in three different sizes: 1.43m^2, 2.86m^2, and 5.72m^2, respectively. These modules find various applications ranging from rooftop installations to larger solar farms.

For the solar industry, 2009 was a difficult year for a variety of reasons. Financing dried up completely in all major markets. Weakening economies and job outlook increased the liquidity premium, while bankability issues coupled with an imbalance in module supply-to-demand ratio significantly decreased the module price by more than 50–65%. This has placed a severe pressure on PV module manufacturers to aggressively drive their technology improvement roadmap to lower the cost of modules.

At PVTIL, we have taken a systematic and innovative engineering approach to scale up the single-junction a-Si process

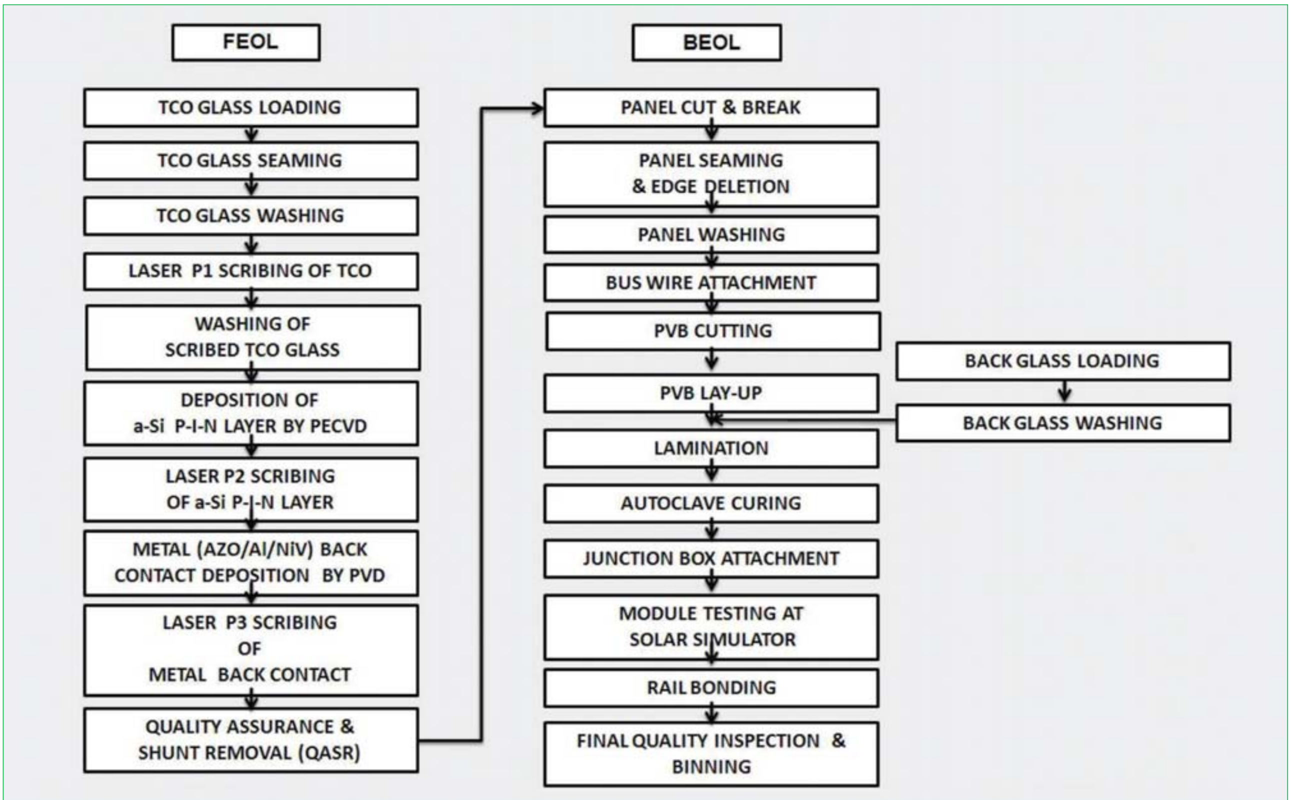


Figure 1. Flow chart of PVTIL single-junction 50MW production line, comprising both the FEOL and BEOL technologies and processes.

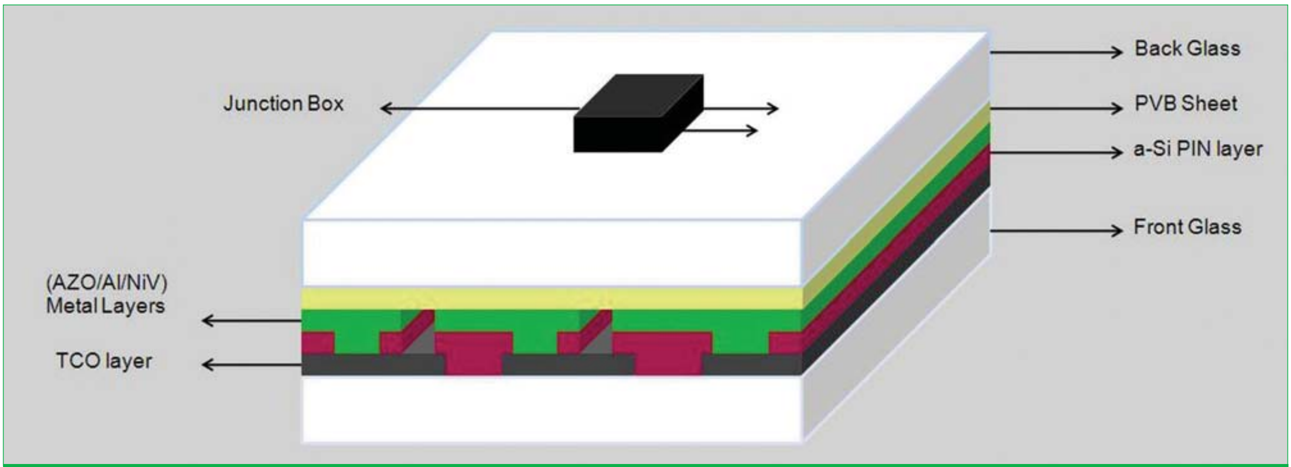


Figure 2. Cross-sectional view of the single-junction a-Si p-i-n module.

and technology from a stable efficiency of 6% to ~7%. The enhanced device and module performance has been derived by following a four-pronged strategy: better photon management/light absorption; improvement in the extraction of charge carriers; enhancement of device stability; and achievement of a stabilized daily production with consistent process control.

Enhancement of stable efficiency to ~7% and improvements in yield and equipment uptime have resulted in the readjustment of the annual manufacturing capacity of the production line to >50MW. With the scaling of a-Si single-junction technology, the old product portfolio such as MBTF85, MBTF170 and MBTF340 are now being replaced by MBTF100, MBTF200 and MBTF400, respectively, with higher wattage per module. The modules are frameless with glass-PVB-glass encapsulation and are available with and without bonded rail options.

Module production line

A general flow diagram of the fabrication steps of the production line is shown in Fig. 1. The line is divided into front end of line (FEOL) where front glass is processed as the panel and back end of line (BEOL) where a front glass-PVB-back glass encapsulant is integrated into a module. The first step of the module manufacturing involves loading of transparent conducting oxide (TCO) glass substrate in FEOL. TCO glass is manually edge-seamed before the washing and drying step. The building of the cells starts with Laser P1 scribing of TCO, which results in the formation of 216 cell isolations with ~1cm width over the glass length of 2.6m.

Next, the washing step is performed before depositing the new PVTIL proprietary a-Si p-i-n device (Fig. 2) using AMAT's Gen 8.5 plasma-enhanced chemical vapour deposition (PECVD) cluster tools. A second laser P2 is then scribed in the a-Si layer in parallel to the first scribe in the TCO, leaving a P1-P2 gap of 150–200µm to allow a monolithic interconnection of the solar cells later on in the process. A three-layer (AZO/Al/NiV) rear contact is deposited using the sputtering tool on top of the p-i-n device. Following the sputter deposition, a third laser scribe (P3) is performed. The P2-P3 scribe width is kept at 150–200µm with the P1-P2-P3 gap fixed from the 300-400µm range, respectively. In addition, an edge isolation line is scribed using P3 at a distance of ~15mm from the glass edge which defines the active area of the cell/module. The final FEOL step involves removing shunts by reverse biasing the cells and burning/curing the defects. The shunt busting is an important step to achieve P_{max} (peak module power) performance and consistency from module to module processing. This completes the processing of the solar panel.

The full-size (5.72m^2) panel is further processed through the back end of the line for manufacturing a complete integrated module, where based on laser design, the panel can be cut into quarter size (1.43m^2), half size (2.86m^2), or processed as a full-size (5.72m^2) glass. After the cut and break step from the BEOL, the panel is further processed through auto-seaming equipment for ~12mm edge deletion where all excess films are removed to achieve edge isolation on all four sides. Next, the panel goes through the final washing step. Thereafter, the side bus lines are soldered at the two end segments (cells) of the panel, at which point the cross bus bars are attached to the side bus lines which run through the centre of the module (Fig. 3).

Before the lamination step, the module is integrated in a layup room where the

Figure 3. Back-side view of the quarter-size MBTF100 module with bonded back rail.

front panel (glass), polyvinyl butyral (PVB) foil and back glass (with hole for attaching junction box) are sandwiched. The module then passes through a laminator where a combination of heated nip rollers removes the air and seals the edges. At the exit of the laminator conveyer, the modules are collected and stacked together on a rack for batch processing through the autoclave where they are subjected to an anneal/pressure cycle to remove the residual air and completely cure the PVB. Finally, a junction box is attached to the cross bus wire and sealed on top of the hole of the back glass and is filled with the pottant to achieve a complete module integrity. The fully processed module is flashed in a solar simulator (AM 1.5 Global intensity) with an NREL-calibrated c-Si reference cell covered with KG1 filter.

"Although the single-junction a-Si solar cell has limited scope in terms of efficiency improvement, it has multiple advantages."

Strategies and new process development experiments

A cross-sectional view of the a-Si single-junction p-i-n device made with various layers is shown in Fig. 2. A technology transfer at an initial and stable efficiency of 7.18% and 6%, respectively, was made from AMAT to PVTIL. Although the single-junction a-Si solar cell has limited scope in terms of efficiency improvement, it has multiple advantages such as 1) it is almost independent of wafer price fluctuation; 2) it can be processed in larger glass sizes ($5.72m^2$), resulting in higher wattage modules even with low conversion efficiency; and 3) the technology can be upgraded to tandem junction (TJ). However, upgrading to TJ technology requires substantial capital investment. Therefore, we decided to look for the device and material engineering of the existing a-Si single-junction technology to improve the device efficiency from a stable value of 6% to the next level.

In order to form strategies for the enhancement of device efficiency, one must understand the basic limitations of the a-Si single-junction p-i-n diodes, which are established from thermodynamical considerations on radiative recombination and semi-empirical considerations on the classical diode equations. An upper limit for the short circuit current density Jsc can be computed by considering the normalized AM 1.5 spectrum (IEC 904-3) and assuming that all photons with $h\nu > E_g$ (h is Planck's constant, $\nu = c/\lambda$ where c is the speed of light, λ is the wavelength, and E_g is the energy gap of the semiconductor material considered) are absorbed and converted into electron-hole pairs that can, in principle, be collected at short circuit conditions. According to this equation, for a-Si solar cells with the E_g of 1.75eV, the corresponding limitations [1–3] to J_{sc} is ~21.1mA/cm^2. For the single-junction a-Si solar cell technology that was transferred to PVTIL at a typical stable efficiency of 6%, the measured average J_{sc} was about ≈ 12.23mA/cm^2. In order to achieve the major efficiency gain, we looked into the CVD and PVD process development and optimization strategies to increase the short circuit current density through better light trapping and absorption.

We also looked for improving both V_{oc} and FF by reducing the recombination losses in the I-layer, achieving low series resistance and high isolation resistance in between the cells, and improving the extraction of charge carriers with reduced recombination losses at various device layer interfaces. Fig. 4 describes the four-pronged strategy for device performance management.

Results and discussion

As a first step towards increasing the module efficiency, we investigated and developed the new CVD process regimes and deposition conditions which resulted in a much better film uniformity across the entire $5.72m^2$ area of the module. A detailed design of experiment (DOE) around the key deposition parameters

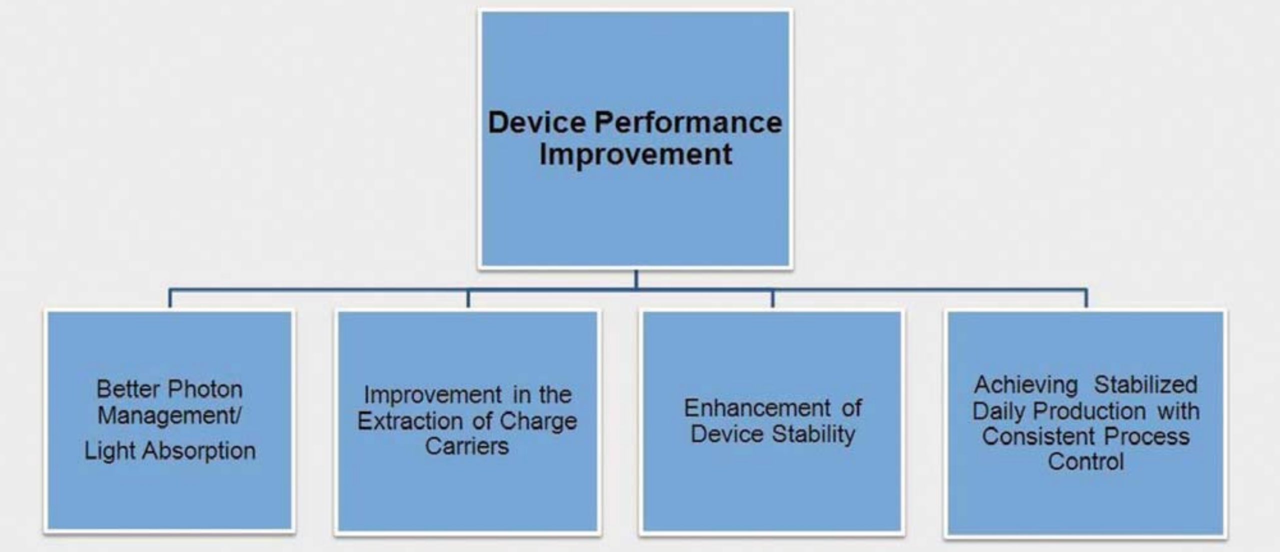


Figure 4. Description of the four-pronged strategy for device performance management.

such as gas flow ratio, power, pressure and susceptor to diffuser plate spacing conditions for all the p, i and n layers were conducted. The new optimized CVD process improved film uniformity to the ≤10% range over the entire panel area for all amorphous layers. Fig. 5 shows a typical a-Si intrinsic (i) layer thickness mapping. Good film uniformity of all deposited layers of the solar cell structure is essential to achieve a consistent and much improved module efficiency both within the entire substrate and from module to module.

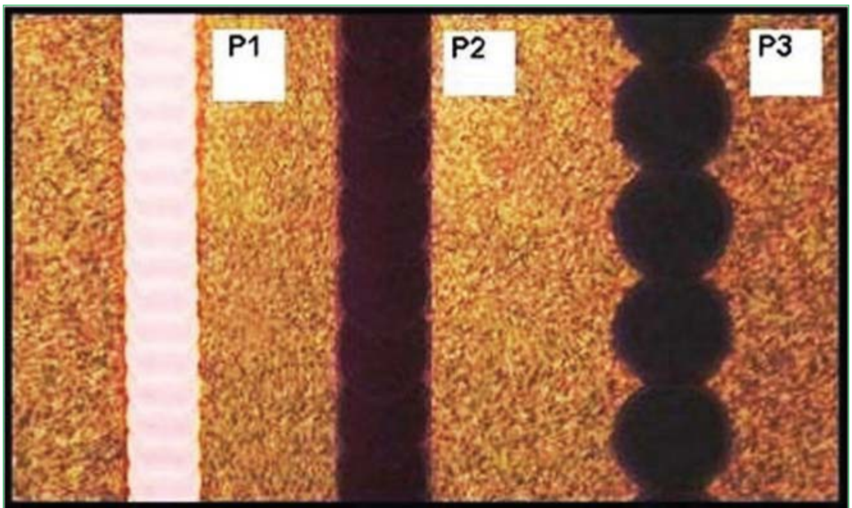


Figure 5. Typical photo by optical microscope of the laser P1-P2-P3 scribe used for panel fabrication.

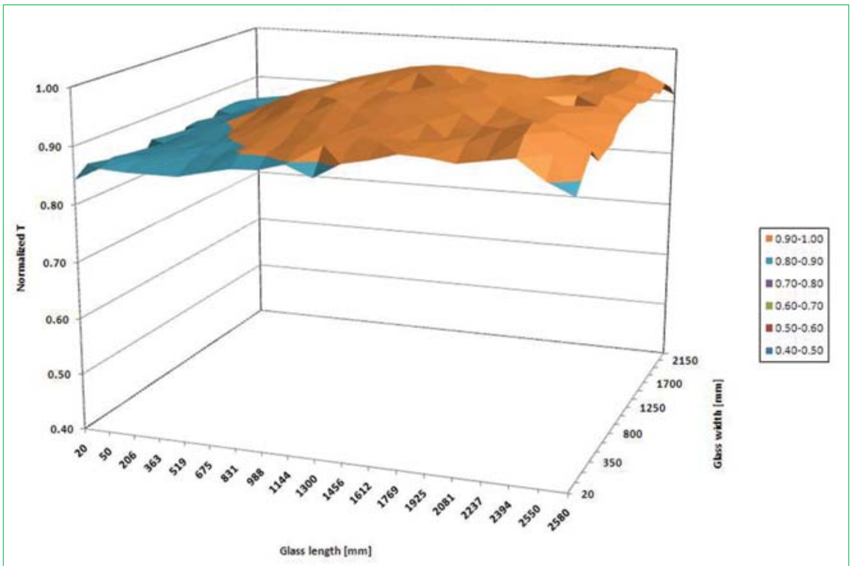


Figure 6. Typical thickness variation of the new proprietary PVTIL a-Si:H based i-Layer, with improved film uniformity of <10%.

Next, emphasis was placed on the optimization of all the laser P1, P2 and P3 processes and improvement of the scribe quality. This was done to optimize and achieve low series and contact resistance in the monolithic interconnection design and to reduce the active area losses. Fig. 6 shows the photo of the laser P1 - P2 - P3 scribe pattern taken from the module with optimized conditions. It is critical to achieve the right P2 scribe: an 'over and under' P2 scribe will yield high series resistance and low shunt resistance and hence will lower FF and device efficiency. For all three lasers, we optimized the beam frequency, energy and spot size conditions to achieve maximum gain in efficiency and overall gain in the device's electrical parameters such as V_{oc}, I_{sc} and FF. The laser design was also optimized to minimize the active area losses.

In order to improve the current density from the device, we further optimized the p layer energy gap (E_g), doping concentration and film thickness while maintaining the film uniformity at below 10% target variation. The optimization brought about substantial gains in J_{sc} and some improvements in V_{oc} and FF. A further optimization of the process conditions was achieved to minimize the recombination losses and absorption of charge carriers at the p/i interface.

Next, we focused on i-layer deposition conditions to achieve maximum gain in J_{sc} and V_{oc} without sacrificing the light-induced degradation (LID) factor. The new and optimized process showed a better LID factor, as verified by certification agency TÜV. In order to further enhance the light trapping and reduce recombination in the n layer and at the i/n interface, we further optimized the entire deposition conditions and film thickness. Similarly, we improved the quality and transmission of the AZO layer through development of the new process. The AZO layer has a special role in controlling the light transmission and light scattering back to the device to improve its absorption in the i layer to increase the J_{sc}. At PVTIL we have followed multiple designs of experiments to leverage and combine different process gains to develop a new PVTIL proprietary single-junction a-Si manufacturing process.

After the development of the new process, it was successfully validated for production worthiness on our manufacturing line. During the production trials on the stabilized manufacturing line, the new PVTIL process recipe has consistently demonstrated gains in module efficiency, hence establishing its performance.

Fig. 7 shows the illuminated current voltage curves (both initial and stabilized) of the quarter size modules made with the new PVTIL proprietary single-junction a-Si process. The measurements were conducted on the flash solar simulator calibrated using the NREL 2cm x 2cm reference cell covered with the KG1 filter. The illumination level was adjusted over the whole panel area with the calibrated 30cm x 30cm a-Si module to an illumination level of $1000W/m^2$ and the module I/V measurement temperature was maintained at 25°C.

> "Optimization brought about substantial gains in J_{sc} and some improvements in V_{oc} and FF."

Table 1 gives a summary of the stabilized electrical data for the two types of quarter size ($1.43m^2$) modules produced using old BKM (Best Known Methodology) and new PVTIL Proprietary BKM process. It is clearly visible that the new PVTIL single-junction a-Si process gives much better and enhanced values of J_{sc}, V_{oc}, FF, η and P_{max}. A maximum increase in current density, J_{sc}, from 12.23 to $13.53mA/cm^2$ is achieved using the new process. The observed stable efficiency and power on the $1.43m^2$ module processed with the new process recipe is ~6.91% and 98.8W, respectively. The reported electrical values are factored with a light-induced degradation factor of ~15-20% to arrive at the stabilized values. For the full size module ($5.72m^2$), as a result of gain in area and reduction in process losses, which incur on quarter size modules, the estimated average stable efficiency and P_{max} are anticipated at ≥7% and ≥400W, respectively. The new recipe trials on full size substrate are in progress and we expect to establish the results in the first quarter of 2010.

Process Type	Module size	Initial efficiency	Stable efficiency	V_{oc} [V]	I_{sc} [A]	J_{sc} [mA/cm2]	V_{mpp} [V]	I_{mpp} [A]	FF[%]	R_s[ohm]	P_{max} [W]
Old BKM	$1.43m^2$	7.19%	6.00%	91.7	1.47	12.23	70.4	1.29	63.3	7	85.8
New PVTIL Proprietary BKM Process	$1.43m^2$	8.28%	6.91%	93.3	1.63	13.53	72	1.37	64.7	7	98.8

Table 1. Comparison of the stabilized electrical data of $1.43m^2$ modules deposited with the Old BKM and New PVTIL Proprietary BKM process.

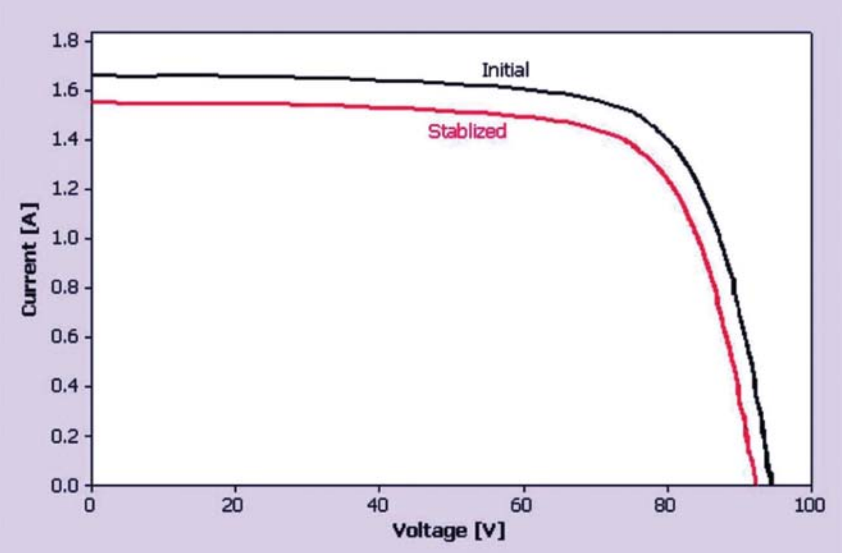


Figure 7. A typical initial & stabilized I-V curves of the ~7% efficiency quarter size MBTF100 module.

Following the modules' manufacture, application of the new proprietary process and verification at TÜV Intercert, the old module types are now being replaced with the new product types such as MBTF100, MBTF200, and MBTF400, respectively with higher wattage per module. Modules prepared with the new process steps are undergoing further evaluation and certification at TÜV Intercert.

"The new PVTIL single-junction a-Si process gives much better and enhanced values of J_{sc}, V_{oc}, FF, η and P_{max}."

Further process development work is ongoing and new strategies are being investigated with the aim of taking the single junction a-Si technology of the 5.72m^2 module to the ≥7.5% stable efficiency range.

Conclusions

The changing business environment has put significant pressure on all PV manufacturing technologies, but more so on amorphous silicon thin-film single-junction technology to advance and scale up the device efficiency and drive cost reduction. At PVTIL, we have developed new processes for the enhancement of stabilized efficiency of the modules. Through both device and process engineering, we have been able to increase the quarter size (1.43m^2) module efficiency performance from a stable 6% to ~7% with improved P_{max} ~ 99W. The superior module electrical performance has been achieved through gains in current density to 13.53mA/cm^2 and improvements in V_{oc} and FF. For full size (5.72m^2) modules, the gain in active area and reduction in process losses are expected to yield a stable efficiency ≥ 7% and power ≥400W, respectively. With the enhancement of stable efficiency to ~7% and improvements in yield and equipment uptime, the annual manufacturing capacity of the production line has been readjusted to >50MW.

Acknowledgements

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Taking thin-film technology closer to the lowest possible manufacturing cost

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ABSTRACT

It is widely acknowledged that, without government subsidies, solar power still cannot compete effectively with conventional sources of electrical energy. As the industry strives to make solar electricity affordable and as a viable alternative to fossil fuels, solar power technology companies are diligently moving towards reducing the manufacturing cost for solar modules. In the case of thin-film solar cells in particular, as a benchmark, the cost of for solar power must be reduced for it to be competitive or to attain grid parity. This paper presents a number of opinions from industry leaders on how best to decrease this vital cost.

In terms of progress, First Solar continues to maintain the lowest manufacturing cost in the industry and was the first company to break the $1/watt price barrier last year. In its third quarter results released in October 2009, the company shared that the combination of higher watt throughput and a number of other operational improvements drove manufacturing cost reduction to $0.85 per watt. This was down 2% quarter-over-quarter, 21% year-over-year.

The long-term financial models which the company has previously discussed suggest manufacturing cost targets of $0.65 to $0.70 a watt by 2012. Its manufacturing costs have declined two-thirds from over $3 per watt to less than $1 per watt since First Solar began full commercial operation of its initial manufacturing line in late 2004.

Trends

Jim Cushing, managing director of Applied Materials' SunFab Products Group says industry costs are coming down due to three major trends: line integration, selection, cost and optimisation of direct materials, and efficiency gains.

"Over the last 30 years, solar technology has consistently been driving towards lower costs and higher efficiencies and closer to direct competitiveness with grid sourced electricity. Over the last 18 months, this trend has been accelerated as poly costs have dropped, thin-film companies have scaled, and larger, more capable equipment manufacturers have entered the market. Given the increased levels of investment in this industry, we see these trends continuing as factory productivity increases, economies of scale drive cost, and efficiencies improve", Cushing explained.

Cushing shared that the three main focus areas for Applied Materials are factory operation (primarily throughput, uptime, and yield), technology (efficiency), and direct materials costs.

"Our factory metrics are up across the board, and we have continued to deliver efficiency improvements to our factories. For direct materials, we recently had our second generation module IEC Certified. The approach to this module was to engineer lower cost. We changed the front glass, thinned the PVB [laminate], developed low gas flow processes, and negotiated lower direct material prices. The overall module material cost saving was 22%", Cushing added.

From the industry's perspective, **Dr. Harin Ullal** (pictured right), who works for the National Center for Photovoltaics at NREL, says First Solar has done an outstanding job in demonstrating how a PV company can systematically drive down the cost of PV modules over the years.

"One of the strategies they adopted very early in the game is the concept of 'smart copy'. At the same time, they improved the name plate rating of their individual manufacturing line, which was rated at 25MW a few years ago. Today, the same line is rated at 53MW without any replacement of hardware, but improving on the variables. So this is an excellent model for the other thin-film PV industry companies to follow if they would like to be a successful PV company in the future. Going forward, cost reductions will be more challenging in the future", said Dr. Ullal.

Rival companies acknowledge First Solar's performance and attribute its cost reduction-related results to the volume of manufacturing.

For instance, United Solar Ovonic's president **Subhendu Guha** (pictured right) mentioned that First Solar produces very large volumes, and has done an excellent job in lowering the module cost.

"We believe we can substantially reduce our costs from the current $1.76/watt to about a dollar/watt. This will be achieved through material cost savings, improved manufacturing throughput and yields, and improved conversion efficiency for our product", Guha said.

NREL's Dr. Harin Ullal.

Manfred Bächler, CTO, Phoenix Solar, underlined that the cost reduction roadmaps are still on track. "We as a company were focused on BOS (balance-of-system) cost reductions. However, for the second half of 2009 and probably also for 2010, we will suffer from increasing material prices", he said.

United Solar Ovonic president Subhendu Guha.

Critical factors

Direct materials account for around 50% of the total production cost, which explains why a company such as Applied Materials has dedicated teams focusing on engineering lower-cost solutions.

"We achieved over 22% reduction to date, and are currently working on another 20%-30% reduction. Additionally, we have an aggressive efficiency roadmap to 10% which will reduce our overall production cost to <$1/W. For a fully automated factory, labour cost is not a major factor, enabling more flexibility on factory location", continued Cushing.

In a thin-film product, the active material cost is very low. The encapsulants and the substrate dominate the cost, and prices decrease as the volume increases.

Last year, a study indicated that paying attention to lesser-known non-active materials can yield positive results. According to Lux Research, while active semiconductor materials garner wide attention in solar technologies, the lesser-known non-active materials significantly impact module efficiency, and account for 15% to 48% of module manufacturing costs. It was revealed that new non-active materials that can lower the overall cost per watt ($/W) of module manufacturing costs will be required. It added that thin-film modules see greater margin potential, but longer development cycles. Non-active materials comprise 36% to 48% of standard thin-film module manufacturing costs. New entrants with improved non-active technologies will have a greater edge in thin-film than in x-Si. The caveat: longer development cycles.

With the rapid growth in the PV industry, many companies are now coming up with fresh ideas and evaluating new materials.

> "Non-active materials comprise 36% to 48% of standard thin-film module manufacturing costs."

"Encapsulation is one where we feel there are a number of excellent potential solutions in the works. The key issue is proving reliability. Panels need to last 25-30 years under a wide range of environmental conditions and so a significant amount of data must be generated before a new technology can be adopted. That is why Applied built the SunFab Module Reliability and Test lab in Xi'An, China. This lab enables us to screen a variety of new materials and device designs under highly accelerated environmental conditions", said Cushing.

NREL's Dr. Ullal agreed that non-active materials are an important component of the cost structure for all PV technologies, such as encapsulations/packaging, Al frames and mounting structures. A lot of the future cost reduction for PV modules will come from the non-active materials, he said.

According to Dr. Ullal, PV companies that do not make a reliable PV product that will last 25 years in the field and meet the companies' warranties of 80% of rated module performance at the end of 25 years may not survive in the long term. There is a huge amount of development work underway to reduce the cost of non-active materials that contributes directly to cost-reduction of PV modules, he said.

Progress

For some time now, it has been highlighted that thin films must be less expensive at the module level to compensate for lower efficiency as more area, be it on the ground or on the roof, and more balance-of-system (BOS) is required to attain the same efficiency reached by most crystalline technologies. For instance, the costs for the supporting structures, DC cabling and inverters (power conditioning units – PCU) are higher than for c-Si modules.

> "Thin films must be less expensive at the module level to compensate for lower efficiency."

Efficiency is one of several components that affect total system cost, says Cushing. He also shared that his company has taken an integrated system-level approach to driving down these costs. One example of this approach is the module architecture including size, mounting and technology. The 5.7m^2 size of the panel maximises the number of watts installed per module, which significantly decreases labour time and cabling requirements. In addition,

Figure 1. Solarion AG's foil-based solar cells.

a back rail is bonded directly to the module in the factory. This further saves installation time in the field and reduces the number of BOS components required. The technology, thin-film silicon, has the added value of generating more energy-kWh per rated kW compared to c-Si due to the lower temperature coefficient. This integrated solution lowers total BOS costs and increases energy out which effectively offsets the 'penalty' due to the lower efficiency.

Phoenix Solar's Bächler mentioned that due to the significant price reductions in c-Si modules, thin-film module prices came under pressure. For some of the thin-film module manufacturers, the price reductions required by the market had been higher than the cost savings they could achieve due to improvements in manufacturing process and efficiency increase – i.e. they are facing lower than expected gross margins. But the same is also true for many c-Si manufacturers, he added.

Thin-film technology companies acknowledge that customers and project developers are getting more sophisticated, and are increasingly looking beyond cost-per-watt of solar modules to LCOE as a key buying criterion.

"This is a better measurement of the cost of energy from a particular system, measured by the energy yield and all the costs over its lifetime. We can compete on LCOE, even with low-priced Chinese poly", said Guha. Citing an example, he said, "When applied to an existing rooftop, our costs can be anywhere from 30-70c/watt below most polysilicon systems, and compared to our competition, our laminates have a proven capability to generate more energy per rated watt in real-world conditions. Having lower total installed costs and higher energy yield makes us competitive on an LCOE basis while continuing to offer features and benefits that glass panel products can't match".

Leipzig, Germany-based Solarion's sales and marketing director **Stefan Nitzsche** pointed out that there has been a reduction in BOS costs but that this rate was not as extensive as the module price decrease.

> "Customers and project developers are getting more sophisticated, and are increasingly looking beyond cost-per-watt of solar modules to LCOE.

"But the component suppliers are doing a good job and they are continuously improving that. A lot of potential is also in the mechanical and electrical design of the module. Considering the larger area required for less efficient [thin-film] modules the system price per installed kW has to be somewhat lower than for c-Si systems. Especially for large PV installations, the valuation of the system is not done by the module power alone; the trend is going to a performance ratio valuation of the entire system", said Nitzsche.

Manufacturing

Some companies highlight that although a-Si, like CIGS, can be deposited on a flexible substrate, its conversion efficiency, which already is generally much lower than that of CIGS, measurably degrades when it is exposed to ultraviolet light, including natural sunlight. To mitigate such degradation, manufacturers of a-Si solar cells are required to implement measures that add cost and complexity to their manufacturing processes.

According to United Solar Ovonic's Guha, this is really a myth. He says while amorphous silicon products show initial degradation on exposure to light, the efficiency stabilises after only a few hundred hours.

"Most manufacturers rate their product at the stable value, that is after the product has 'settled in' and is producing electricity at a consistent rate," commented Guha. "Regarding deposition of CIGS on flexible substrates, apart from demonstrating good production yield using the roll-to-roll deposition, degradation

Figure 2. Solarion's low-cost roll-to-roll manufacturing technology.

caused by moisture ingress is a big issue. Many companies are working to develop a moisture-barrier coating, but price and availability are not yet clear".

In order to further reduce the manufacturing cost of PV modules, Guha's company has pioneered the development of and has the fundamental patents on a unique approach utilizing proprietary continuous roll-to-roll solar cell deposition processes.

Elaborating on this development, Guha said: "We deposit the triple-junction amorphous silicon solar cell using an automated processor that takes six rolls of stainless steel, each 1.5 miles long, and deposits nine miles of solar cells on 6 rolls of stainless steel in 60 hours. We have built several generations of roll-to-roll processors, and have now perfected the process to obtain great uniformity, consistency and yield. Looking ahead, we are working on new manufacturing advancements that could substantially improve the product throughput from our existing lines and decrease our costs".

It is said that historically, manufacturers have formed PV modules by manufacturing individual solar cells and then interconnecting them.

In the roll-to-roll approach, manufacturers typically cuts cells from the finished substrate, complete thermal processing, and then cells are then assembled together, says Cushing. Further work is being done to come up with fully-automated roll-to-roll manufacturing solutions. "Thin-film technology deposited on glass already has the advantage of fully integrated processing. The manufacturing process uses laser scribe lines to create interconnected cells from the absorber and metal layers. This means that there is no extra interconnection step", added Cushing.

Solarion is using a proprietary coating technology for the deposition of the CIGS absorber based on a low-cost roll-to-roll process (see Fig. 2). Nitzsche declined to give details of the cost structure. However, he shared that the company process is a very competitive one.

"We have less energy consumption, better materials usage, higher process speeds and better process control than conventional CIGS evaporation technologies. This enables us to achieve appropriate efficiencies at lower deposition temperatures while using a plastic substrate. The insulating substrate enables us in the future to make monolithically integrated devices which decreases costs and increases product reliability", said Nitzsche.

"Furthermore, our roll-to-roll process drives down our capex requirements to set up a plant. A big advantage will be to get rid of the glass. To make flexible modules with a conversion efficiency of about 10% drives costs down dramatically... A flexible product allows for a significant decrease in system costs because for certain applications separate subconstructions will not be necessary anymore", Nitzsche added.

Going forward

First Solar has already demonstrated that their thin-film manufacturing cost is down to $0.85/watt and NREL's Dr. Ullal is confident that other thin-film companies will follow once they have economies of scale of installed production, and comparable module performance. First Solar says most of the conversion efficiency and cost initiatives are event-driven rather than time-driven.

Dr. Ullal says this might be true to some extent. He explains that a good example of this is the oversupply of polysilicon feedstock material which has driven down the cost of silicon modules by almost 50% in the last year.

Dr. Ullal says there is a lot of price pressure on thin-film PV technologies to drive down the cost of their modules. These price reductions will come from improving performance (efficiency of the modules), yield (electrical and mechanical), up-time, throughput and capital expenditure in the manufacturing lines. Other factors that affect cost are standardisation of processing equipments, capability of equipment to produce state-of-the-art efficiency modules, long-term supply chain contracts with vendors, etc. In addition, it is also important to work with countries and states that give you preferential incentives in terms of land, taxes (extended period of tax holidays), etc.

"The challenge is finding out how to drive down cost in the overall supply chain."

From Applied's perspective, Cushing says while many companies are focused only on how to reduce cost at the module level, his company is looking at it from the systems level. The challenge is finding out how to drive down cost in the overall supply chain – from raw materials to installation and ultimately energy out. Material choices, mounting methods, and energy yields are examples of ways to drive down cost beyond pure production cost.

Guha says his company has made excellent progress over the past two years, and still has a lot of opportunity to reduce costs further.

"Our manufacturing cost-per-watt declined 12% in the fiscal first quarter as compared to the average for the full fiscal year 2009. When we are operating at our 150MW nameplate capacity, we expect to get our cost-per-watt down to about $1.50, and we have a path to get to about a $1/watt," concluded Guha.

About the Author

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Using novel spectroscopy and spectrometry techniques for the quantitative analysis of photovoltaic thin films and materials

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ABSTRACT

Chemical stoichiometry along with depth profiling and metallic contamination is of considerable interest for photovoltaic thin films. Conversion efficiency can be affected for example if primary components, e.g. Cd and Te, are not present at proper ratios. Moreover, amorphous silicon can vary substantially between sources and deposition technique, and qualitative comparison of trace metallic contaminants may not be sufficient to ensure final thin-film quality. This discussion presents data from atomic emission and mass spectrometry techniques that quantitatively and accurately describe both bulk and trace elemental compositions in photovoltaic materials, various thin-film matrices, and the final thin-film cell and module.

Introduction

Characterization of photovoltaic thin films is a wide-ranging subject that starts and ends with the all-important photovoltaic efficiency, and encompasses every aspect of the thin film and complete solar module. All of this characterization is needed simply to understand what properties enhance photovoltaic efficiency and how to improve it. As analytical chemists working traditionally for integrated device manufacturers in the semiconductor industry, it is normal to measure and quantify various materials and species concentrations. Examples include a chemical composition for a liquid chemistry used in process, or a contamination amount on the wafer surface that might affect properties of the final integrated circuit. Similar quantitative figures of merit have also been identified and are needed within the photovoltaic industry where accurate measurement of compositional bulk elements, depth profiles of multiple elements, and determination of metallic species in thin films, different module layers, and the complete stack are required as technologies and processes evolve.

As briefly suggested by the term 'wide ranging,' chemical characterization for PV thin films is a topic where the authors give apologies to too many researchers and techniques that cannot be adequately referenced here. Impurities entrained in solar materials have long been recognized as a potential problem for effective photovoltaic conversion. Beginning with crystalline silicon (c-Si), neutron activation analysis (NAA) has been used for years [1], and glow discharge mass spectrometry (GDMS) more recently in an effort to qualify silicon materials as suitable for PV applications [2]. Several studies have probed the required purity levels of crystalline silicon on ultimate photovoltaic performance [3].

> "Impurities entrained in solar materials have long been recognized as a potential problem for effective photovoltaic conversion."

With amorphous silicon (a-Si), the impurity levels are not as restrictive as with c-Si [4]; however, the presence of alkali and transition metals has been reported to affect solar cell performance

Constituent	NIST Standard			Glass-Powder	Soda-Lime Glass
	Certified value	Uncertainty	ICP-OES	ICP-OES	ICP-OES
	% (w/w)	% (w/w)	% (w/w)	% (w/w)	% (w/w)
SiO_2	82.77	0.40	82.97	84.10	59.15
Fe_2O_3	0.24	0.01	0.25	0.00	3.11
TiO_2	0.11	0.02	0.12	0.00	0.09
Al_2O_3	9.90	0.13	9.97	9.75	14.6
CaO	0.74	0.04	0.76	0.73	0.53
MgO	0.06	0.01	0.07	0.00	3.78
Na_2O	1.75	0.06	1.69	1.62	12.7
K_2O	3.94	0.09	3.90	3.90	3.94
BaO	0.12	0.01	0.13	0.00	0.02
B_2O_3	N/A	N/A	0.00	0.00	2.12

Table 1. Compositional analysis of glass materials by ICP-OES indicates excellent agreement with NIST standards. Starting glass powder material and glass backing material for thin films can also be analyzed quantitatively via ICP-OES.

[5,6]. Ubiquitous alkali elements such as sodium and potassium are mobile ions and common transition elements including iron, nickel, and chromium can cause diffusion issues. All of these metals may be analyzed via depth profile studies and secondary ion mass spectrometry (SIMS) [6]. Beyond a-Si, polycrystalline thin films may also be affected by the presence of metallic ions. Sodium has long been understood as a positive influence species in copper-indium-gallium-(di)selenide (CIGS) films [7], while more recently iron diffusion behaviour in CIGS and zinc incorporation in $CuInS_2$ films have also been studied [8,9].

These are just a few examples and a few types of thin films where measurement of metallic species has been performed to understand ultimate solar cell performance. SIMS is one common technique for these types of analyses and provides real utility in its results. With SIMS however, different ionization conditions, ion sources, or mass spectrometers are needed to cover all elements of interest.

Measurement of trace metallic species, either through desired incorporation in a thin-film process or as an unwanted impurity, is just one measurement need for thin-film solar cells and modules. Compositional analyses in tandem with a depth profile of the thin film and/or conducting oxide material has been performed via a number of techniques and summarized recently [10]. In this case numerous techniques, including SIMS, Rutherford back-scattering spectroscopy (RBS), and energy dispersive x-ray spectroscopy (EDS), are used to analyze a CIGS film for Cu, In, Ga and Se distribution profiles. As shown, the results differ from technique to technique because of the different sensitivity factors associated with the measurement calculation. In order for engineers to be able to make direct comparisons of the results, it is highly desirable to perform these measurements against the same traceable calibration standards.

In this discussion, techniques are presented that can be used for quantitative measurement of metallic elemental species, overall elemental compositions, and depth profiles of various thin-film PV materials. Inductively coupled plasma optical emission spectroscopy (ICP-OES), RF glow discharge optical emission spectroscopy (RF GD-OES), and laser ablation inductively coupled plasma mass spectrometry (LA ICP-MS) are not traditional surface analysis techniques, and in fact have been used more prominently in non-high technology fields. However, by utilizing the inherent merits of each technique combined with simultaneous detection of elements across the periodic table, quantitative and comparable results are achieved. The result is a better understanding of some thin-film properties and an ability to solve specific thin-film issues.

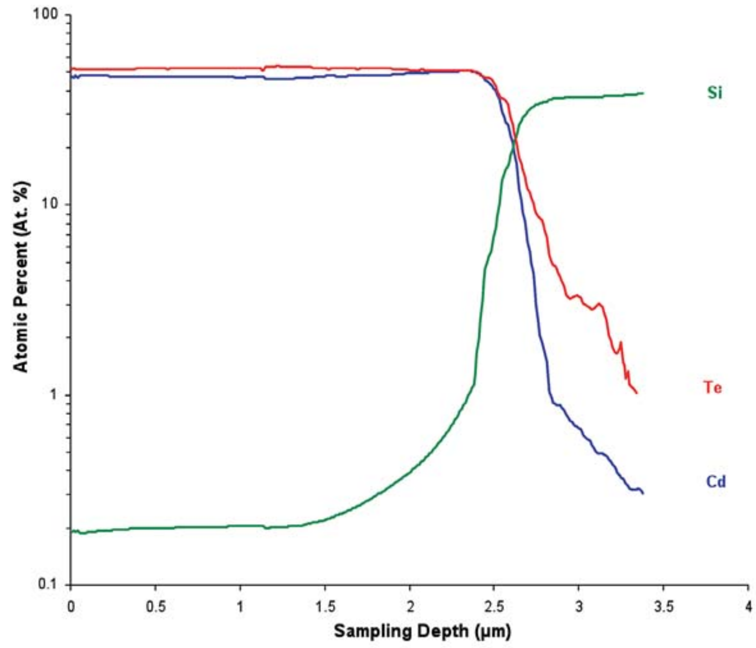

Figure 1. GD-OES depth profile for a CdTe film on silicate glass substrate.

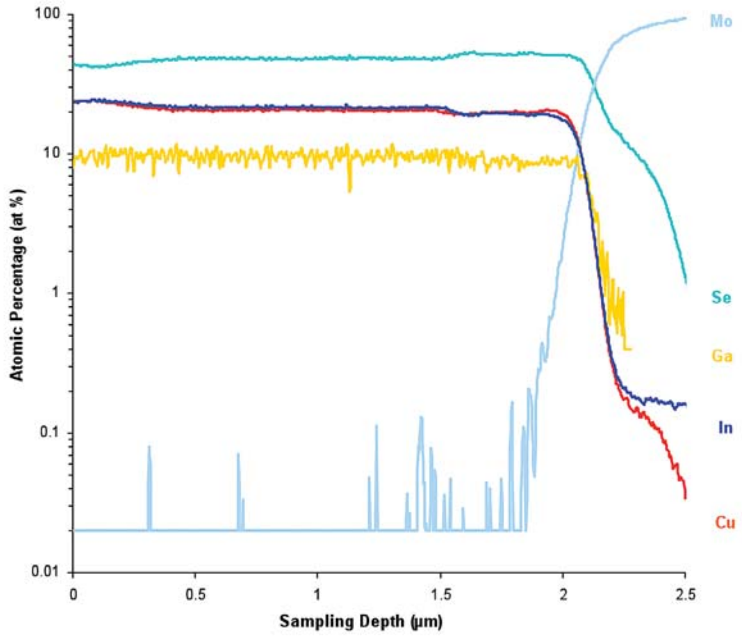

Figure 2. GD-OES depth profile obtained from a CIGS film on Mo-coated glass.

CIS Film	Cu	In	Se	In/Cu	Se/Cu
	at%	at%	at%	Mol Ratio	Mol Ratio
CIS-1	25.3	24.7	50.0	0.98	1.98
CIS-2	24.5	24.8	50.7	1.01	2.07
CIS-3	24.8	24.6	50.6	0.99	2.04
CIS-4	24.8	24.8	50.4	1.00	2.03
CIS-5	25.1	24.9	50.0	0.99	1.99
AV.	24.9	24.8	50.3	0.99	2.02
S.D.	0.29	0.12	0.34	0.01	0.04
RSD	1.2%	0.5%	0.7%	1.1%	1.8%

Table 2. ICP-OES measurements from five different film depositions indicate excellent reproducibility. Mole ratios for In/Cu and Se/Cu are another indicator of film quality.

Composition and stoichiometry verification

The composition of PV thin film and materials can be accurately verified using ICP-OES with both high accuracy and precision. Compared to atomic absorption spectroscopy (AAS), ICP has a large dynamic concentration range of up to 10^7 for many elements and permits simultaneous multielement determination without the need of a series dilution for high-concentration analyses. The sample preparation process consists of dissolving a thin film (or any applicable solid sample) into solution using mineral acids. This process generates a matrix solution congruent with commercially available calibration standards, such as those available from by the U.S. National Institute of Standards and Technology (NIST) and the national metrology institutes in Europe. As a result, the analytical results obtained by ICP-OES are generally independent of physical properties of the samples such as density, surface texture, film thickness, and crystal structure. This same ICP-OES technique is derived from applications used in the semiconductor industry where boron and phosphorus dopants are quantified in boron-phosphorus silicate glass films (BPSG), and these OES results are then used to calibrate XRF, FTIR, EDX, and SIMS [11].

It is certainly important to provide data and illustrate the quantitative nature of ICP-OES. Table 1 displays a comparison of ICP-OES experimental results with NIST-certified values and their uncertainties. With this type of agreement between experimental and theoretical data, actual samples can be analyzed with confidence. Results for a glass powder and soda-lime glass sample, a starting material, and final backing material for PV thin film, respectively, are also shown in the table. Different levels of impurities can easily be measured in this manner to ensure quality of the final glass substrate as well as prevent unwanted contamination in the final material.

Beyond the backing materials, PV thin films can be analyzed in exactly the same manner [12], and this analysis process has been utilized for CIGS, CdTe, CdS, CIS, and a host of III-V films. Table 2 shows that separate film depositions of a $CuInSe_2$ precursor film can be measured against one another with ICP-OES to show consistency between different processes. The results obtained are presented here in both atomic percentage and mol ratio from which the film stoichiometry can be calculated. It should be noted that Ga used in the CIGS to boost the film's light-absorbing bandgap can also be analyzed by ICP-OES with the same accuracy and precision.

A further application with ICP-OES has been used for determinations of major, minor, and trace elements in various electrochemical plating solutions. To lower the fabrication costs, thin-film PV manufacturers have investigated non-vacuum deposition approaches such as electrochemical deposition (ECD).

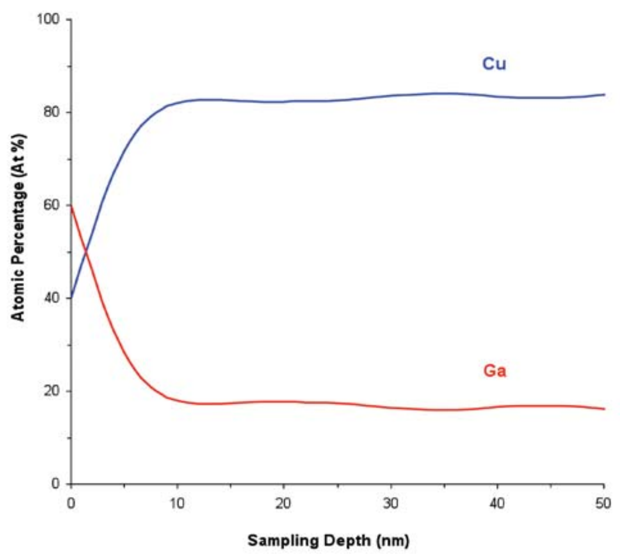

Figure 3. GD-OES depth profile obtained from a precursor CuGa film following chemical surface treatment.

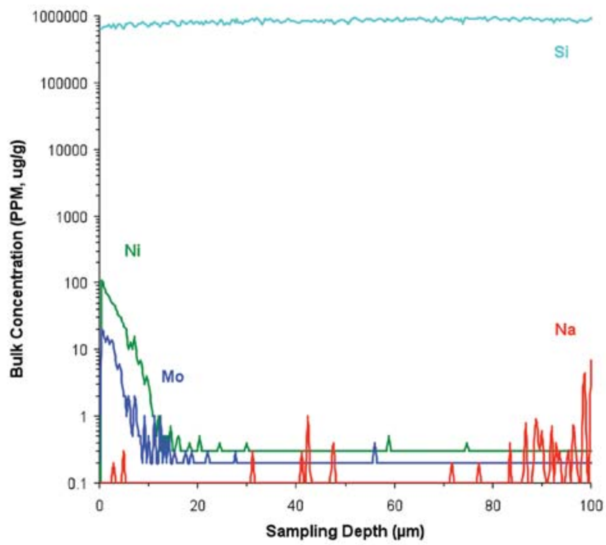

Figure 4. Deep depth profiling of an amorphous silicon thin film by LA ICP-MS.

Analyte	a-Si Film-1	a-Si Film-2	CuGa Film	CuGa Target
	ppm (µg/g)	ppm (µg/g)	ppm (µg/g)	ppm (µg/g)
Li	<0.05	0.06	<0.05	<0.05
Na	<0.01	12	2.4	2.2
Mg	<0.05	0.64	<0.05	<0.05
Al	<0.07	1.8	3.1	3.4
V	<0.01	0.05	<0.01	<0.01
Ti	<0.05	0.33	<0.05	<0.05
Cr	<0.05	4.2	<0.05	<0.05
Mn	< 0.5	1.3	< 0.5	< 0.5
Fe	<0.1	39	<0.1	<0.1
Co	<0.01	0.07	<0.01	<0.01
Ni	<0.05	2.7	<0.05	<0.05
Cu	<0.05	1.6	Major	Major
Zn	<0.1	0.9	1.7	1.6
Ga	<0.1	<0.1	Major	Major
Ge	<0.05	0.06	<0.05	<0.05
As	<0.05	0.08	<0.05	<0.05
Sr	<0.002	0.009	<0.002	<0.002
Y	<0.05	0.07	<0.05	<0.05
Zr	0.006	0.21	<0.005	<0.005
Mo	< 0.05	1.1	< 0.05	< 0.05
Ag	<0.01	<0.01	0.70	0.73
Cd	<0.05	0.08	0.34	0.38
In	<0.01	<0.01	0.04	0.04
Sn	<0.05	0.08	0.31	0.33
Sb	<0.005	0.01	<0.005	<0.005
Ba	<0.005	0.28	<0.005	<0.005
La	<0.01	0.05	<0.01	<0.01
Ce	<0.01	0.02	<0.01	<0.01
Hf	<0.01	0.02	<0.01	<0.01
Ta	<0.01	0.05	<0.01	<0.01
Tl	0.03	<0.01	<0.01	<0.01
Au	<0.02	0.07	<0.02	<0.02
Pb	<0.01	0.03	0.27	0.25
Bi	<0.005	<0.005	0.009	0.010
Th	0.12	<0.005	<0.005	<0.005

Table 3. LA ICP-MS results of a-Si solar thin films and CuGa film and corresponding sputtering target.

Many absorber layers (e.g., CdTe and CIGS) and window buffer layers (e.g., ZnO) can be electrochemically plated at reduced cost. The key to successful electrochemical plating is the quality of the plating bath chemistry; the concentration ratios of the film elements must be accurate and the unwanted impurities must be low. Because the ICP-OES results are consistent and reflect accurately any changes to the plating process, the use of this analytical technique for the quality control of plating bath solutions has been increasingly active for this type of thin-film PV manufacturing.

Elemental spatial distribution

An extension of compositional analysis is the need for depth profiling and elemental spatial distribution within the thin film. These types of data are important for both bulk elements, trace elements, and within both the thin film and solar cell. For traditional semiconductor thin films, SIMS is a workhorse for dopant profiling and its applications extend to other trace elements because of its high sensitivity. However, concerns exist with the ability of SIMS to profile solar thin films on a nonconductive glass substrate and the feasibility for quantitative analysis, especially of those major film elements because of its limited dynamic calibration range. In our laboratory, the elemental spatial distribution in PV thin films is typically studied using atomic spectroscopy and mass spectrometry, namely GD-OES and LA ICP-MS.

Glow discharge is an excitation source and owes its name to the luminous glow of the argon plasma. This plasma is generated by RF energy between an anode and a cathode sample surface and is followed by analyte atoms being knocked off the sample surface layer by layer. The sputtered atoms enter the GD plasma and collide with more energetic electrons or excited 'metastable' argon atoms to emit characteristic wavelengths of light [13]. Detection analyzers for a glow discharge source can vary as analyte ions can also theoretically be generated; however, the advantage of a polychromatic optical spectrometer is the available simultaneous multielement detection that in combination with the single-nanometer resolution in sputtering facilitates excellent depth-profiling capabilities.

Figs. 1 and 2 show GD-OES profiles obtained from a CdTe and a CIGS thin film, respectively. CdTe is deposited on a soda lime glass and CIGS on a molybdenum-coated glass substrate with a sampling depth in each case of more than 2.5µm. No surface charging was present. The profiles shown in each figure were simultaneously obtained under a single sputtering condition. This is an advantage since real-time profiling ultimately eliminates the need for overlaying different profiles obtained under different conditions. As a result, the association of those elements in the films and their corresponding concentrations can be directly investigated. Depth profiles obtained conveniently in this manner can be used to examine the film uniformity and possible interfacial diffusions, and to optimize CVD, PECVD, PVD, ECD, coevaporation, and other advanced deposition processes.

RF GD-OES can also be used to investigate the elemental concentrations on the top surface and in the near-surface region (e.g., < 20nm). The verification of surface composition of a thin-film postdeposition or after any surface treatment is extremely important for many reasons. One main reason is to ensure the interface integrity. For example, the band structure at the absorber-buffer interface or the p-n junction interface plays a crucial role in charge transport processes. Incorrect surface stoichiometry of one film alone can produce a poor band structure leading to low energy conversion efficiency and undesirable cell performance. In addition, the thin-film engineer needs evidence of minimal surface oxidation of the metal contact layer prior to deposition. Without this information, high contact resistance at the absorber-metal contact interface could lead to low photovoltaic efficiency.

Traditionally, Auger, SIMS, and XPS are used to study surface composition. However, the surface charging caused by the glass substrate, the surface equilibrium phenomena, and the thick information depth have prevented these techniques from revealing the true surface stoichiometry in such a challenging thin section. Fig. 3 provides a GD-OES depth profile for a CuGa precursor layer deposited using PVD (sputtering) after surface treatment. The sampling area used in the profiling was 4mm in diameter and the GD penetration depth was only 50nm. The CuGa target used for the deposition contains Cu (at 82%) and Ga (at 18%). As shown in the figure, the film and target compositions are fairly consistent in the 10-50nm region. However, the postdeposition surface treatment used in the process has dramatically altered the surface stoichiometry of the film by removing Cu and enriching Ga. As a result, the film composition on the top surface became undesirable, with Cu (at 40%) and Ga (at 60 %).

Previous GD-OES depth profiles have looked at bulk elements in the thin films. A higher sensitivity depth profile for trace elements is performed by LA ICP-MS. Laser ablation involves the conversion of a solid material into a plume of atomic vapour and microparticles by focusing a pulsed laser beam onto the sample surface. The plume is transported in an argon carrier gas to the inductively coupled plasma for atomization and ionization. The ions produced by the ICP are then analyzed by either a quadrupole- or a magnetic sector-based high-resolution mass spectrometer [14,15].

Unlike analysis of secondary ions, LA ICP-MS does not use a primary ion beam, and spatially and temporally distinguishes its ionization from the sampling process. This separation enables independent optimization of the two fundamentally different processes, and generates much more efficient ionization and more quantitative measurements [15]. Because the impending laser beam does not carry any charge, PV thin films deposited on an insulating substrate or on conductive metal oxide films can be readily profiled without experiencing any 'surface charging' encountered with traditional electron and ion beam technologies. Finally, LA ICP-MS utilizes a fast scanning mass spectrometer and simultaneous detection is readily available for elements across the periodic table.

An example of a depth profile with LA ICP-MS is depicted in Fig. 4. In this case, a relatively large sampling area of 110µm and equally 'large' vertical sampling depth over 100µm was sampled. Trace element depth profiles of Mo and Ni near the surface and Na at ~100µm depth can be obtained from this very thick amorphous silicon film. LA ICP-MS has an ability to 'sputter' deep into the silicon bulk (e.g., > 50µm) to study the spatial distributions of trace impurities in the bulk of a film or a material. Such an analysis appears to be neither feasible nor practical for other traditional depth-profile techniques, such as Auger, XPS, and SIMS.

Thin Film

"With a spot-size analysis of ~ 4mm, the glow discharge sampling technique provides excellent sampling statistics for thin-film characterization."

The OES and MS techniques have different advantages. A full rundown of each instrument is beyond the scope of this discussion; however, similar to ICP-OES, each technique allows simultaneous detection of elements across the periodic table. RF GD-OES provides improved depth resolution (single-nanometer resolution) along with analysis of metals and elements carbon, hydrogen, nitrogen, and oxygen. With a spot-size analysis of ~ 4mm, the glow discharge sampling technique provides excellent sampling statistics for thin-film characterization. Meanwhile, LA ICP-MS can analyze only metal and semimetals; however, the sensitivity of the ICP-MS surpasses that of OES (low parts per billion versus low parts per million), and the spot size with the laser ranges from 4 to 110µm. When needed, a sampling area of 1cm x 1cm is possible by rastering the laser beam across a thin-film surface. Both techniques can be applied to conductive and nonconductive surface materials, without surface equilibrium or charging issues at the sample or in the resulting data.

Trace elemental analysis

In order to maximize a solar cell's energy conversion efficiency and its viability, the quality of the films within the cell, such as absorber, buffer, antireflective coating, and front and back contact layers as well as the substrate, must be ensured. The verification of major film composition and its spatial distribution is described above; however, unintended impurities present in these films and coating materials must also be routinely monitored and controlled. Those impurities can adversely affect the cell's performance and can be detrimental to the lifetime of a PV module. All those films, coatings, and substrates can be analyzed for more than 80 elements by LA ICP-MS in a one-step elemental survey approach. The elements present in a material, including major (>1% w/w), minor (0.01 – 1% w/w), and trace elements (< 0.01% w/w) can be positively identified and quantified. Because the power density of the laser spot on a material surface is so high (~ $10GW/cm^2$), any material, including inorganic and organic, conductive and non-conductive, refractory and fragile, can be analyzed by LA ICP-MS.

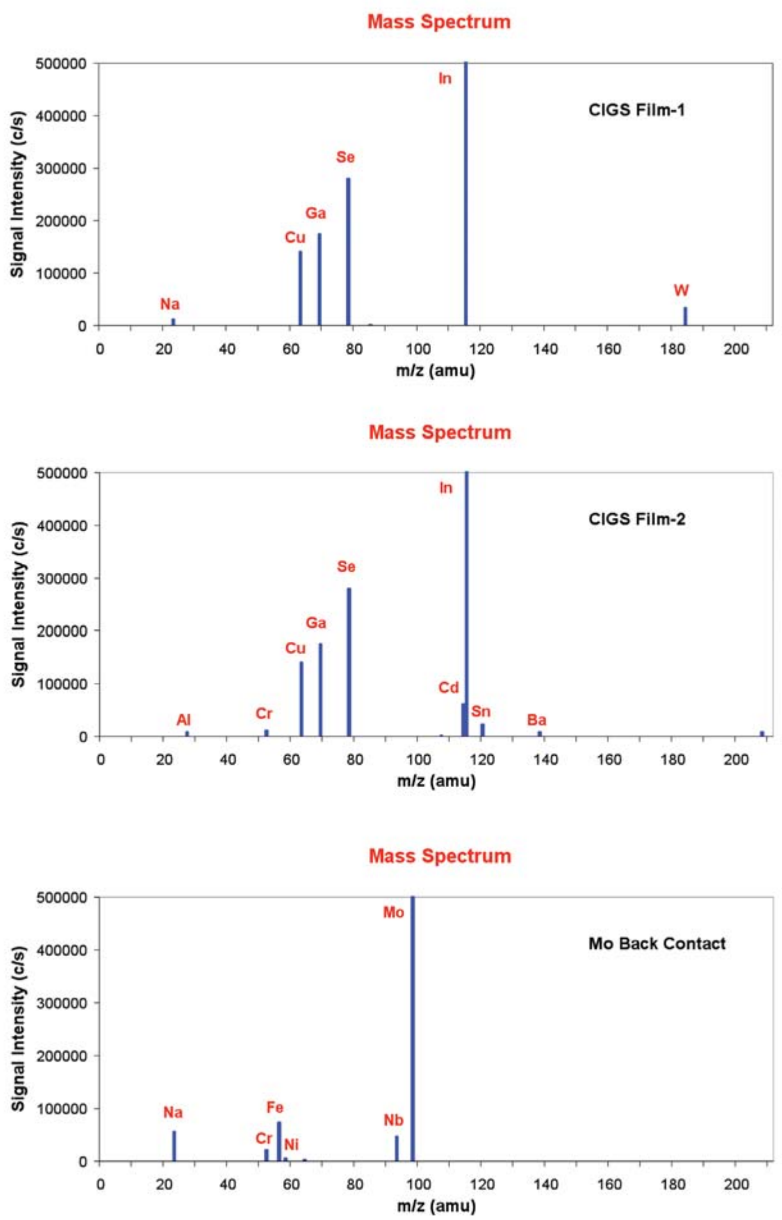

Figure 5. LA ICP-MS spectra obtained from two CIGS films and one Mo back contact.

Fig. 5 shows three LA ICP-MS spectra obtained from three films deposited on a soda-lime glass substrate: two CIGS films grown under two different deposition processes and a commercially available molybdenum back contact film. It should be pointed out that these mass spectra were collected for more than 80 elements with either single or multiple isotopes. For simplicity in interpretation, only the major isotope for each element that was positively identified in the films is shown here. As can be seen in the figure, different deposition approaches can introduce different contaminants. These contaminants could come from the deposition tools, target materials, or the handling process.

This LA ICP-MS elemental survey analysis has also been used to examine the components outside the cell but within a module for quality control purposes. These components include, but are not limited to: transparent top glass windows, encapsulation layers (usually thin sheets of ethyl vinyl acetate), and thin polymer rear layers (typically Tedlar) that prevent the ingress of water and gases, as well as the aluminium frame around the outer edge of the module.

In addition to the qualitative elemental survey, LA ICP-MS can also been used to perform quantitative analysis of various materials and films against NIST-traceable standards. This technique has been used

previously in the semiconductor industry for quantitative analysis of dopants in ultralow energy implants [16]. Table 3 shows the analytical data obtained from two amorphous silicon films, a CuGa precursor film and the sputtering target used to grow the CuGa film. A total of 68 elements were studied for these films and the concentrations of 35 important elements are provided in the Table. The other 33 elements were not detected at or above their corresponding detection limits (10 ppb for most of those elements). These consistent quantitative data, verified by NIST traceable standards, can help engineers select incoming raw materials, optimize film deposition processes, and track down the source of the contamination.

Conclusion

This article has presented surface analysis techniques and quantitative data generated for photovoltaic thin films, starting materials, and components within the solar module. Although not typically used for semiconductor or disk drive surface analyses, specific problem-solving for thin-film PV manufacturers has been achieved with the techniques presented here. Both LA ICP-MS and GD-OES are not new, as the laser technique has been used for close to 30 years with geology applications, and steel manufacturing and coating analysis has been the province of GD-OES. Despite such 'low-tech' beginnings, the techniques described here provide real data for PV thin films in R&D and manufacturing. No one technique is completely comprehensive for all analyses, but instead analytical tools must be used where a 'best fit' is realized and complementary in order to provide researchers and manufacturers the means to solve problems and improve PV efficiencies.

Other techniques will of course continue to serve for their specific advantages, for example SIMS for high-sensitivity depth profiling and Raman and FTIR for organic speciation, along with a host of other techniques and applications. Clearly, a phalanx of analytical, surface, and characterization techniques will be required as thin-film technologies continue to evolve.

Acknowledgments

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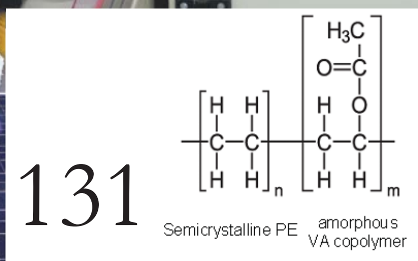
PV Modules



Kyocera claims new multicrystalline solar PV module conversion efficiency record of 17.3%

Just over two months after ECN and REC claimed the highest conversion efficiency for multicrystalline-silicon solar modules, Kyocera has topped their mark and set a new world record. The Japanese company says it has achieved 16.6% total-area module efficiency, with an aperture-area efficiency of 17.3%, besting the Europeans' previous aperture-area record of 17%.

Kyocera says it has improved its proprietary back-contact technology and module design to enhance the performance of each cell, thus increasing overall energy conversion efficiency. The scheme moves electrode wiring that is typically arranged on the surface of the cell to the back side, thus optimizing the light-capturing surface area to maximize energy conversion efficiency.

The record-breaking back-contact modules, which have a total area of 13,379cm^2, use 54 150 × 155mm multicrystalline cells in the development-stage configuration. Kyocera says it has achieved conversion efficiencies of 18.5% for individual cells in the development stage.

The results are based on research conducted in December by the National Institute of Advanced Industrial Science and Technology in Japan, according to the company.

Kyocera modules.

Module Production News Focus

Turkey primed for module production, says Schmid

With an expected Energy Feed-In Act for renewable energies due soon in Turkey, PV equipment supplier Schmid noted at a workshop it hosted with its Turkish sales partner, PV Teknik, that the country was poised to soon start producing PV modules for the domestic market. Turkey was claimed to have the best potential for solar energy after Spain, due to its geographical location and climate conditions.

Schmid and PV Teknik hope to become a key equipment and turnkey solutions provider to the nascent Turkish PV manufacturing industry.

HelioSphera to build $500 million, 160MW solar PV module plant

Greek solar manufacturer HelioSphera will build a new photovoltaics module factory in Philadelphia's historic Navy Yard mixed-use complex. Work on the 160-MW production plant is scheduled to begin in 2010.

"The plan is for the construction start to be summer or fall of 2010, with the construction period to last about a year to 18 months," Luke Webber, spokesman for the Pennsylvania Department of Community and Economic Development, told PV-Tech's Tom Cheyney in December 2009. "They will probably be open in some capacity in 2011 and be up to full production in 2012."

The new several hundred thousand square-foot factory will not be built by "retrofitting an existing building" at the yard, according to Webber. "They will be building it from the ground up," adding that "the only place in Philadelphia that you can build a project of this magnitude is the Navy Yard."

The project is expected to create at least 400 jobs within three years. Heliosphera began operating its first module production plant in September 2009, a 60MW line located in Tripolis, Greece. Oerlikon provided the turnkey micromorph-silicon thin-film PV equipment set for the initial site, but the tool company's participation in the Navy Yard factory had not been verified at this time.

Although he did confirm the construction timeline and green-field aspect of the development, HelioSphera's Charles Dumont would not tell PV-Tech whether Oerlikon would be involved. "The company does not want to comment further at this time. We will provide more details as the project progresses."

The total cost will be approximately $500 million, according to the participants. Some $49 million in various grants and loans will come from the state of Pennsylvania, the largest of which is a $20 million grant from the Redevelopment Assistance Capital Program, said Webber. He also noted that the Navy Yard site is part of one of the state's tax-free Keystone Opportunity Zones.

Drawing of the Philadelphia Navy Yard.

Siliken Group plans to build 50MW solar PV module line in Ontario

The Siliken Group plans to build a crystalline-silicon photovoltaics module production plant in Ontario, Canada. Set for an initial capacity of 50MW, the factory could start operations in the last quarter of this year and create as many as 150 jobs, according to the Spanish firm. Siliken says it is finalizing its site selection process and completing the necessary legal paperwork.

The new plant will join the company's existing module assembly facilities in Valencia, Spain, and San Diego, CA. Siliken says it plans to increase it production capacity to 250MW.

BP Solar, Jabil expand contract manufacturing agreement; 45MW module line to start in Mexico

In an expansion of its outsourcing strategy, BP Solar has signed a new deal with Jabil Circuit. The contract manufacturer will assemble BP's photovoltaic modules for the North American market in Jabil's plant in Chihuahua, Mexico. Production will begin on the manufacturing line in the second quarter of this year; initial capacity will be 45MW, with the possibility for expansion as demand increases.

News

The latest agreement builds on a relationship that began with the October 2009 announcement of a 45MW deal for Jabil to manufacture BP's PV panels in Poland for the European market. Since that time, the solar cell company has ordered a second 45MW module assembly line at the Poland facility to feed continued strong market growth.

Testing and Certification News Focus

Siliken extends PV module warranty to 10 years

Siliken's photovoltaic modules will now have double the warranty life, effective February 15th. The Spain-based producer has extended the warranty from 5 to 10 years. The product warranty completes the existing production warranties, which include a 10-year power coverage of 90% and 80% power performance over 25 years.

Siliken's photovoltaic modules all have the UL and TÜV certifications for application worldwide and a power tolerance of +3/0%. Siliken's photovoltaic modules are made of monocrystalline and polycrystalline silicon and are manufactured in the production plants at Valencia and Albacete, Spain, and San Diego, USA.

Scheuten achieves UL, CEC listing, FSEC certification for its Multisol P6-54 series

Scheuten Solar has achieved UL listing, FSEC certification and CEC listing for its Multisol P6-54 series of PV modules. The PV USA test conditions (PTC) rating for the Multisol P6-54 series now published by the Californian Energy Commission (CEC) is 90% of its standard test conditions (STC) nameplate rating.

Scheuten Solar's Multisol module array.

P6-54 recorded a low normal operating cell temperature (NOCT) of 45°C with a black frame and black back foil combination. The thermal characteristics of the P6-54 result from the design approach for all components.

1 SolTech receives UL/ETL certification for its latest module line

1 SolTech has received full UL/ETL certification for its line of PV panels as well as passing the compliance and testing audit procedures for its factory. 1 SolTech modules feature three bus-bar monocrystalline silicon cells with high-absorbency and enhanced low-light performance, produced by Suniva.

The cells are produced using low-reflective tempered glass 25% thicker than industry standards for superior durability; and lightweight, heavy-duty anodized aluminium alloy frames. Cell efficiency is rated at 18%, producing overall module efficiency of over 15%.

SolarWorld's 'Sunmodule' product line.

SolarWorld switches to linear performance guarantee on solar modules

In a move that many other PV module manufacturers are expected to adopt, SolarWorld is the first manufacturer to switch to a linear performance guarantee on its entire range of solar modules. SolarWorld claims that as a result of the change, it has extended the performance warranty for its modules from two to five years. Traditionally, the industry has used a stepped performance guarantee system, such as 90% of the lower nominal output for the first 10 years and then 80% for year 11 onwards.

The linear guarantee from SolarWorld includes a first year of operation guarantee of at least 97% of the nominal output, with the second year of operation declining by no more than 0.7% of the nominal output. In the 25th year of operation, the module would have an actual performance of at least 80.2% of the nominal output.

"We have deliberately invested for years in our research and development capacities so as to be able to consistently optimize our products," said Frank H. Asbeck, chairman/CEO of SolarWorld AG, in characterizing the strategy of the company. "We know what our products can do and pass on this security to our customers by way of our linear performance guarantee."

SBM Solar's nonglass, rigid, crystalline-silicon photovoltaic module.

SBM Solar earns UL certification for its nonglass, rigid c-Si photovoltaic modules

SBM Solar says it has become the first company to earn UL certification on its nonglass, rigid, crystalline-silicon photovoltaic modules. The panels are encapsulated with a non-EVA-based thermoplastic material developed by Dow Chemical.

The company says that its durable, customizable nonglass PV modules are 40% lighter and thus easier and cheaper to ship and handle (and have the highest power vs. weight ratio in the world). They are said to be suitable for applications with weight restrictions.

"Our 140W solar panel endured four years of rigorous UL1703 testing," says Osbert Cheung, SBM's founder and president. "UL approval, as well as our IEC61215 certification for hail impact resistance, demonstrates SBM Solar's strong commitment to quality and safety."

Other News Focus

LDK Solar joins PV Cycle on its recycling mission

LDK Solar is the latest company to become a member of PV Cycle, the organization that promotes the take-back and recycling of end-of-life PV modules, based in Brussels.

"LDK Solar is dedicated to sustainable practices that take into consideration the environmental impact of all stages of product life cycle, including end-of-life collection and recycling," stated Xiaofeng Peng, chairman and CEO of LDK Solar. "We look forward

The power of our PET.

dyMat® PYE backsheet
High grade polyester based
Over 3.000h DHT*

The lifetime of your PV module depends on the performance of the backsheet that protect it. This is why Coveme, leader in engineering polyester film, has developed an innovative backsheet based on a special PET for outstanding durability under extreme conditions. Choose the reliability of Coveme dyMat® PYE and you will find a partner that believes in quality beyond the surface.

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CNPV receives multiple module orders worth 145MW

PV systems developer, Photovoltaic Experts GmbH has signed a new contract with CNPV Solar Power to take 30MW of PV modules from 2010 to 2012. Photovoltaic Experts will receive 5MW of scheduled deliveries during 2010, with 10MW and 15MW scheduled for delivery in 2011 and 2012, respectively. The company will use the modules for projects in Germany, France, and Spain.

CNPV has also signed a long-term strategic partnership sales agreement with Delta Sud, a French project development and distribution company. The deal calls for the supply of 20MW of crystalline-silicon PV modules over the next three years. Under the terms of the agreement, CNPV will provide Delta Sud with 2.5MW of modules this year, with the remaining 7.5MW and 10MW scheduled for delivery in 2011 and 2012, respectively. Financial terms of the deal were not disclosed.

Edisun Power Europe has also secured a total of 60MW of PV modules from 2010 to 2012 from CNPV for projects across Europe. The new supply deal will see CNPV deliver 10MW during 2010, with 20MW delivered in 2011 and a final 30MW in 2012.

CNPV also signed a further long-term strategic partnership sales agreement with Volthaus to supply 35MW of crystalline-silicon photovoltaic modules over the next three years. The terms of the deal call for CNPV to deliver 10MW of modules to the south German project developer/installer during 2010, with the remaining 10MW and 15MW delivered in 2011 and 2012, respectively. Financial terms of the agreement were not disclosed.

LDK to deliver 30MW of solar modules to COU Solar

LDK Solar has signed a contract to supply solar modules to Canada-based COU Solar, a subsidiary of Oneworld Energy. Under the terms of the agreement, LDK Solar will deliver approximately 30MW of solar modules to COU throughout 2010.

Day4 Energy to supply 10MW of solar modules to German integrator Solera sunpower

Day4 Energy has signed a 10MW solar module supply frame agreement with southern German integrator Solera sunpower. The deal marks the latest expansion in the two companies' business relationship, which began in 2009. Solera recently installed 150KW of Day4's crystalline-silicon photovoltaic panels on two complete streets of housing developments in Immendingen, Germany. Financial terms of the agreement were not disclosed.

2BG installs 15MW turnkey module line for AV Project

Solar cell and module equipment supplier 2BG has ramped up a 15MW turnkey module line for the AV Project company in Avellino, Italy. The update of the line, which was installed in January, is the second 2BG line installed with the company and will allow the upgrade of AV's production capacity with the latest automation solutions. The original line was designed to process 48 cells per module, while the new line handles 60 cells per module.

AV Project purchased the first system in 2008. The two systems were configured in such a way as to minimize the disruption to production at the site. The companies further revealed that AV Project is in discussions with 2BG to construct a new project using 2BG's equipment.

ReneSola lands 600MW module OEM supply deal

Having announced plans last November to expand solar wafer capacity to 1GW in 2010, ReneSola has backed this up with a new supply agreement to provide 600MW of solar modules to an unidentified but described as a 'major global solar company.' The new contract calls for ReneSola to provide 200MW of solar modules annually for three years with shipments starting in 2010. This is ReneSola's first major OEM contract.

USE secures 31MW supply deal from ET Solar

German-based systems integrator Umwelt Sonne Energie GmbH (USE) has secured a 31MW PV module sales agreement with ET Solar Group for 2010. USE said it would apply the modules to various projects in Germany and other central European countries.

Trina Solar to supply 80MW of PV modules to two German companies

Trina Solar has signed an agreement with German systems integrator AE Photonics to supply 40MW of crystalline-silicon photovoltaic modules in 2010. The terms of the deal call for 20MW to be shipped during the first half of the year by the vertically integrated Chinese solar manufacturer, with agreed prices for the first quarter. First shipments began in January. Financial terms of the contract were not disclosed.

The company has also signed an agreement with ITEC of Germany to supply 40MW of PV modules during 2010. The deal calls for 18MW to be shipped in the first half of the year, with agreed prices for the first quarter. Initial shipments of the crystalline-silicon modules began in January 2010.

Canadian Solar to supply 60MW of modules to Fire Energy

Canadian Solar has entered into a sales contract with Fire Energy Group, the system integrator providing project management and distribution services on a global scale. Under terms of the contract, shipments started in January, with Canadian Solar expected to supply 60MW of PV modules to Fire Energy in 2010. Fire Energy Group will use its global reach to promote Canadian Solar's PV products in Spain, Germany, Italy, the U.S., the Czech Republic, Morocco and China.

Worldwide Energy reports module contract order total

Worldwide Energy and Manufacturing USA has announced that the contract orders for its solar division, AmeriSolar, have reached an estimated US$58 million, as of January 11.

The majority of these solar module contracts are new orders received during the fourth quarter of 2009 while some of the orders were received earlier in 2009 and have been re-signed as new orders with their shipments pushed out to 2010. Shipments of all these orders are expected to be completed in 2010.

Solarfun wins bidding on three PV module contracts in China

Government-funded projects in Anhui and Jiangsu provinces in China that have scheduled completion dates in 2010 are now being awarded to PV module manufacturers. Solarfun has said that its subsidiary, Jiangsu Linyang Solarfun, has been contracted to supply Xuzhou Xie Xin PV Power 10MW of solar modules for a project based in Xuzhou City, Jiangsu, as well as two contracts totalling 2.65MW for a government-funded project in Anhui.

Solarfun is one of four companies that won the bid to participate in the 15MW project funded by Anhui Province. However, the project is subject to further government approval and financing.

to contributing to the development of new standards of sustainability with fellow members of PV Cycle."

Solar module sales at Centrosolar almost double in 2009

Preliminary financial results from Centrosolar highlight the challenging environment for German-based PV producers and installers experienced in 2009. The sales volume in the second half of 2009 was almost double the figure for the prior-year period, with module sales reaching 87MW in 2009, compared to 58MW in 2008. However, group sales were down 7% from 2008, at €309 million. Sales in 2008 reached €333 million. Fourth quarter sales topped €105 million.

The company noted that the poor demand in the first half of the year, coupled to falling module prices, impacted results. It was also capacity constrained in the second half of the year, which contributed to limiting revenue growth.

However, Centrosolar believes its focus on rooftop installations and its international footprint and sales overseas will limit the expected sales impact that feed-in tariff cuts in Germany will have on the company. It declined to give a sales forecast for 2010, due to the impending FiT cuts.

Centrosolar's c-Si modules.

Ready Solar to equip its preassembled AC photovoltaic power systems with Enphase microinverters

AC solar systems provider Ready Solar and microinverter company Enphase Energy have expanded their relationship, with the purveyor of the 'Solar in a Box' self-contained power unit agreeing to use the microinverters in all of its preassembled systems in 2010. The companies first starting cooperating in 2008, when in August of that year Ready Solar began shipping its products equipped with the Enphase modular devices.

Contractors can buy complete, easy-to-install solar electric systems from their local electrical product distributors, according to Ready Solar, which services this market with more than 120 manufacturers' sales representatives across 40 states and Canada.

Canadian Solar, West Holding JV in 18MW distribution deal

Canadian Solar has announced a joint venture and an 18MW distribution deal with West Holding, Japan. The agreement specifies a transfer of 14% of the shares in Canadian Solar Japan to West Holding.

Canadian Solar will retain the remaining 86% of the shares, while West Holding will distribute and sell solar residential rooftop systems designed by Canadian Solar Japan. The sales target for 2010 is set at approximately 18MW; the deliveries began back in December 2009.

Shawn Qu, chairman and CEO, said, "West Holding is a leading independent distributor of residential solar systems in Japan and is very experienced in distributing, marketing and selling imported PV modules. This was a key criterion in our selection of this company as one of our partners in Japan. Our high-powered, cost effective modules coupled with their strength as a distributor and local understanding of marketing and sales will help make both companies successful in Japan."

Spire signs Napson as solar capital equipment rep in Japan

Spire has signed Tokyo-based metrology systems firm Napson to be its exclusive solar capital equipment representative in Japan. The Bedford, MA-based equipment and turnkey-line company said that its solar simulator for testing photovoltaic modules will be its lead product offering for the Japanese market. Financial terms or other aspects of the deal were not disclosed.

Location of Spire's Solar Simulator on the Spi-Line module production line.

"This agreement further demonstrates Spire's commitment to our Japanese customers," said Roger G. Little, Spire's chairman & CEO. "Napson has successfully served Japan for 25 years with products similar to Spire's manufacturing and test equipment. Our solar simulator for testing photovoltaic modules is the industry standard; we want to lead with this machine in Japan."

CPV start-up Morgan Solar boosts first-round investment funding to US$8.2M

Toronto-based CPV start-up Morgan Solar said that it has increased its first-round investment funding to US$8.2 million from the US$4.7 million announced in October 2009. Strategic investors in the initial round include Iberdrola, Nypro, venture capital firm Turnstone Capital Management (which led the round), and two unnamed Canadian VC groups.

The funds will be used to finance activities leading up to the commercial release of Morgan Solar's concentrated photovoltaic solar panel, the Sun Simba HCPV, which is designed for utility-scale solar farms and distributed generation.

"The most important goal for solar energy is to become competitive with other electrical generation technologies," said Nicolas Morgan, the company's VP of business development and marketing. "Our view is that this can only be achieved with low-cost, scalable, high-efficiency solar panels. The Sun Simba HCPV is our answer to this challenge."

Early manufacturing for testing and certification has begun at Morgan Solar's facility in Toronto, with initial commercial deliveries expected by the end of the year. Global sales, manufacturing, and delivery capabilities will ramp up in 2011.

SunSimba HCPV system from Morgan Solar (artist's impression).

Special News Feature

Point-of-use PV: New Mexico start-up Solar Distinction to build modules with specialty applications in mind

By Tom Cheyney

New Mexico Governor Bill Richardson likes to say that his state is "becoming the centre of North America's solar industry," but California, Ontario, and others might take issue with his understandable boosterism. Still, you'll get no argument that the so-called "Land of Enchantment" can lay claim to being among the leaders in the solar revolution taking hold across the country.

In both manufacturing and power plant development, the state has made significant strides in recent months, adding hundreds of megawatts to its pipeline. Start-up Solar Distinction has announced plans to build a module factory and R&D centre in the Albuquerque area – yet another company looking to produce solar products locally.

The organization behind the new firm with the distinctive name is the Noribachi Group. The New Mexican cleantech private equity fund and venture 'accelerator' (they avoid the term 'incubator') was founded in 2007 by 'Silicon Valley expats,' Farzad and Rhonda Dibachi, according to one of the group's directors, Bruce Wiggins.

He told me during a phone interview that the solar start-up was created last October, with the goal of manufacturing standard and specialty PV panels in the state. The custom modules will go into the solar lighting and consumer products made by three other Noribachi ventures already in operational mode – Visible Light Solar Technologies (which has a just-commissioned 32,000-sq-ft factory in Albuquerque), Qnuru, and Regen.

Down the line, Solar Distinction looks to develop "new-generation AC solar panels" and more modules "that combine cell with materials that disguise the cells," he said. An example of this chameleon-like design strategy include a Visible Light system already retrofitted on gaslamps in Albuquerque's old town area. The LED lighting devices feature triangular-shaped polycrystalline-silicon panels laminated with micah that power the illusion of an antique flickering street lamp created by the light-emitting diode arrays.

"You can't tell there's a solar cell on the light," Wiggins explained.

The Noribachi team behind the freshly minted PV company is in the process of deciding on a module factory site in the greater Albuquerque area, according to the director. They will either renovate an existing structure or start from scratch with a greenfield project, as long as whatever plot is chosen includes enough land to install a 1 or 2MW solar field adjacent to the facility, which will supply power to the operations and double as a testbed for their products.

The timeline for equipping and ramping panel production for the first 25MW line is pretty aggressive, with Wiggins pointing to the end of 2010 for first shipments if they can find a site with a decent building or mid-2011 if they start with "raw land."

Once the initial production is up and running, plans call for another 25MW to be added in a year or two.

When I asked him whether Solar Distinction might choose a turnkey solution for starting up its part-standard, part-specialty module manufacturing, he said that is "a distinct possibility. We will probably purchase new equipment and have them help us put the line in." The company has begun discussions with equipment and cell suppliers, with a decision likely to occur by June.

While not ruling out the possibility of researching thin-film or third-gen PV, Wiggins and his colleagues plan to stick with tried-and-true poly- and monocrystalline cell technology for the time being. (The trio of sister companies currently use either Chinese-made panels or elements bought in the States and integrated in its factory, in Visible Light's case.)

"There's lots of room for improving the manner in which those cells are used," he explained. "We believe that the existing technology has not been exploited even to a tenth of a percent of what it could be. There's a huge amount of room there before you have to go to the more exotic kinds of materials."

There's a myriad of commercial and industrial uses that aren't being made now. Our view of the world is to put solar at the point of use and to develop storage systems that permit you to not only produce the power but to store the power and then to use the power within a short radius of where the production occurs, so you don't have all those transmission issues."

Building-integrated and building-applied PV, consumer electronics, outdoor solar lighting, remote power appliances for construction crews, solar electric boosters for water heaters, micro power plants on unused commercial or government land – all are part of Solar Distinction's possible portfolio of product apps, according to Wiggins.

One slick piece of enabling technology to make the Noribachian distributed-generation vision a reality is what he called "a smart circuit board that regulates the input power from either the solar or the grid as it's needed, it regulates the charge on the battery that's included in the product, and the discharge of that power to the use. It can regulate it into an infinite variety of applications."

Having already received a US$500,000 job creation grant from the state's Economic Development Department to go toward staffing the panel production facility, Solar Distinction's chief believes they will get fast-tracked permits from the city of Albuquerque and stand to benefit from a variety of state and federal incentives and tax breaks. The company may opt for industrial revenue bonds to help finance construction and equipment purchases, he said.

Although he wouldn't divulge any dollar figures, Wiggins did say "we know what we absolutely need and know the amount we want," claiming that the Noribachi approach to doing business is "highly capital efficient…we use dollars far better and more efficiently than most people do."

The group has no plans to go into the integration side of the solar business, although it may partner with integrators and installers, he said. But there's a rub.

"Part of what we're trying to do is develop products that eliminate integration to the greatest extent possible," Wiggins pointed out. "We are, if anything, the anti-utility. When you go to the distributed model of solar at the point of use, and if you can solve the integration issue and the storage issue, then basically you don't need the utility, assuming you have enough solar power to do what you need to do."

Photos by Kip Malone, courtesy of Visible Light Solar.

Special News Feature

2009 PV module market– Installations and shipments up, revenues down

By Ash Sharma, Renewable Energy Director and Sam Wilkinson, Renewable Energy Research Analyst, IMS Research.

IMS Research estimates that in 2009, the PV market – in terms of both new installations and shipments of PV modules and inverters – grew substantially. Latest results from the recently published report 'The World Market for PV Cells and Modules' reveals that PV module shipments grew considerably once again in 2009 – by over 25%, to more than 8GW.

However, IMS Research's ongoing surveying of integrators and installers and analysis of grid-connection statistics also revealed that new installations grew by a much more modest 5-10%, but exceeded 6GW for the first time.

Like many others, following Q1 and Q2's disastrous results, IMS Research had in fact expected 2009's shipments to decline. However, following unprecedented growth in Q3 and Q4 and having collected and analysed data from all areas of the supply chain, results show that module shipments grew by over 25%.

While many may understandably be excited and encouraged by the news that shipments did in fact grow, market revenue growth tells a very different story. The collapse of the Spanish market, combined with a difficult economic climate, caused a significant drop in demand and prices plummeted by 40% as a result. Average prices were also driven down further by thin-film modules continuing to account for an increasing proportion of shipments. Consequentially, PV module revenues declined by over 20% in 2009.

The number of PV systems that were actually completed and connected to the grid in 2009 tells yet another story. Official statistics and government numbers are still being finalised and it will be some months before a final figure is arrived at.

However, IMS Research estimates that annual PV installations grew by 5% to 10%. Installations in Europe were realised particularly quickly in the second half of the year. Germany led the way, installing around 3GW of new PV capacity. Italy did not disappoint either, although it will be some time before the GSE discloses a final figure for the year. We understand that some 100MW of systems were completed before the end of the year in Italy, but not connected to the grid due to administration issues and the total for Italy will be closer to 480MW.

With 2009 PV module shipments growing far beyond expectation and installations growing less spectacularly, the natural question to ask is where all of these modules have gone?

We are seeing delays of two quarters between a module being shipped and it finally being connected to the grid and therefore being counted as an 'installation' in official figures – perhaps longer in very large installations.

In addition, we've seen that a significant proportion of PV modules were shipped in Q4 in anticipation of an unseasonably strong German market in the first half of 2010. This is likely to have been caused by intense speculation of a cut to the German tariff in July, reversing the country's normal seasonality.

Early results show that the big winner in 2009 was First Solar, with shipments of its cadmium telluride modules more than doubling over 2008. As a result, thin film modules are estimated to have increased their share of the market further and accounted for 20% of shipments in 2009.

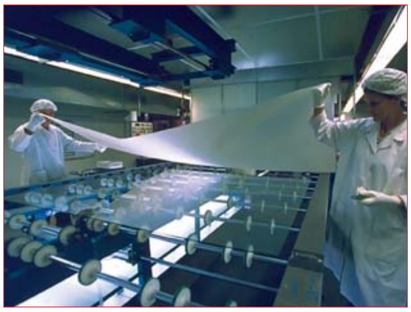
Another unlikely winner is Q-Cells International which IMS Research expects to shortly reveal as the largest PV system integrator in 2009 once it finalizes its research this month.

As for the PV market in 2010 as a whole, IMS Research forecasts that shipments will once again grow, not as fast as installations though as they continue to catch up with the surge in module shipments in 2009. With many expecting a drop in demand in the second half of the year, further falls in module prices are predicted.

Which begs the more important question, can the market grow in revenue terms this year too?

Product Briefings

Saflex



Saflex claims 33% less material usage with new thinner PVB-based encapsulant

Product Briefing Outline: Saflex, a unit of Solutia, has launched a new thin-gauge polyvinyl butyral-based (PVB) encapsulant designed specifically for photovoltaic applications. The new product, Saflex PA41, is claimed to significantly reduce encapsulant usage by 33% while maintaining module durability and processing performance. The global launch of Saflex PA41 comes shortly after successful completion of IEC 61646, certification, with testing on thin-film modules. Saflex also partnered with module manufacturers to confirm that handling, processing and throughput of Saflex PA41 met or exceeded expectations compared to thicker-gauge PVB encapsulations.

Problem: PV module encapsulation materials are regarded as a high-cost item in the total manufacturing cost of modules. The reduction in material usage while retaining the required lifetime protection criteria as well as reducing manufacturing time is critical to the overall cost reduction programs required for commercial PV module production.

Solution: Saflex PA41 is a second-generation product designed specifically for photovoltaic applications and reduces encapsulant thickness by 33% (from 1.14mm to 0.76mm). The formulation of the PVB was modified to incorporate 'high flow' characteristics that enable encapsulant thickness to be decreased while ensuring the finished module package continues to meet critical durability and performance requirements. The new formulation is also less viscous compared to traditional PVB products, which improves the encapsulant flow around bus bars and other critical components.

Applications: PV module encapsulation, including c-Si and thin-film types.

Platform: Saflex PA41 also recently passed IEC 61646 certification testing and is UL recognized.

Availability: Currently available.

Atlas

Full-spectrum monitoring device from Atlas enables compliance with test specifications during ISO 17025 audits

Product Briefing Outline: In order to help customers show objective evidence that they are in compliance with test specifications during ISO 17025 quality audits, Atlas now offers the 'Atlas LS-200' Full-Spectrum Monitoring device. The LS-200 has been specifically designed for use in Ci Series 'Weather-Ometers' to precisely measure the SPD output of the xenon lamp.

Problem: The output of the calibrated lamp is dependent on the power it is supplied with; therefore great care must be taken to perform initial and all subsequent wattmeter calibrations as accurately as possible. Any alteration of the environment (geometry) will impact the calibration. With the advent of performance-based standards that identify the spectral power distribution and not specific filter combinations, users have until now had no way to verify that they are actually meeting the test method they are running.

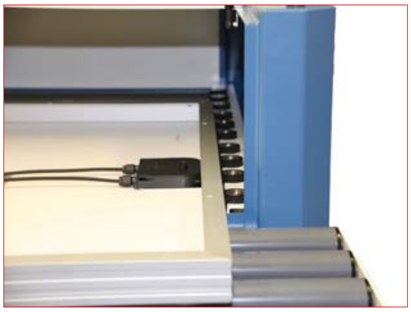
Solution: The device is easily mounted on the specimen rack, and the output is measured over a short amount of time (30 minutes is sufficient). The data can be downloaded and exported into a common spreadsheet program and analyzed to quickly and easily determine compliance to the performance-based standard that is running. There is no need to retrofit the device for older Ci Series instruments. The LS-200 works with any generation of Weather-Ometer. For labs that may not have the resources to purchase the device, Atlas' Technical Service group offers measurement of customer instruments, in addition to normal preventive maintenance and calibration services.

Applications: The LS-200 has been specifically designed for use in Ci Series Weather-Ometers to precisely measure the SPD output of a xenon lamp.

Platform: Atlas is planning to adapt the LS-200 device to be used in any Atlas xenon weathering instrument, including the 'Xenotest' and 'Suntest' lines.

Availability: Currently available.

mbj-Solutions



mbj-Solutions applies electro-luminescence inspection to modules

Product Briefing Outline: mbj-Solutions has introduced an offline solar module inspection system designed for use in the factory and laboratory. The 'SolarModule EL-basic' is an advanced offline electroluminescence inspection system. Different module sizes, both laminated and not laminated, can be inspected without any extensive adjustment work. The design of the system combines usability, high resolution, short tact time and fast return on investment in one machine.

Problem: Micro-cracks on solar modules are mostly invisible to the human eye but present a significant risk of decreasing the module's performance. Micro-cracks can happen anywhere and anytime, during production, transportation or installation.

Solution: Once a module is placed on the roller tables, sensors detect its leading edge and the module is moved into the system automatically. Guide rollers assure the module's precise positioning. The operator then connects the power supply to the solar module. After the electrical connection is confirmed, the module will be conveyed to the inspection position and the operator may close the front cover. Image acquisition starts automatically. A high-resolution image is captured of each solar cell. Three cooled near infrared (NIR) CCD cameras are moved to acquire images of each particular solar cell within the module under test. This inspection concept allows for shortest inspection cycles and highest resolution.

Applications: The system is designed for both mono- and multicrystalline silicon solar modules. Its software-controlled test module power supply allows it to run all available module power classes, e.g. 6 x 10 module with 200Wp, 210Wp, etc.

Platform: The Solar Module EL-basic has a unique mechanical design that makes it flexible and very easy to operate. Roller tables provide effortless loading and unloading of the modules, which face down during the entire procedure.

Availability: Currently available.

Product Briefings

Mitsubishi Plastics

Mitsubishi Plastics' high gas barrier back-sheet designed for thinner PV modules

Product Briefing Outline: Mitsubishi Plastics has launched the high gas barrier PV back-sheet 'Back-Barrier' to the global market. The new back-sheet material is Mitsubishi Plastics' latest development of high gas barrier films with the world's highest level of water vapour barrier, according to the company and customer evaluation tests.

Problem: The continued strategy of moving to thinner solar wafer thicknesses to reduce cell and module production costs has a knock-on effect of making module frames thinner and less bulky. However, there is a growing need to enable correct long-life protection of the cells with back-sheet materials designed specifically for thinner modules as traditional materials and thicknesses can cause issues with the longevity of the modules.

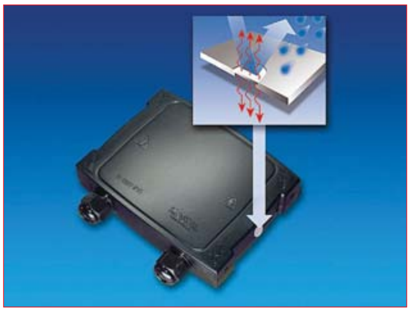
Solution: The new Back-Barrier material is based on four key concepts: 1) high humidity barrier to ensure both consistent generating efficiency and mechanical strength; 2) halogen-free; 3) metal-free; and 4) easy bonding to encapsulation material like EVA. As a result, the product avoids the lowering of electric generation efficiency and strength of the back-sheet, thereby contributing to improved durability of solar cells with consideration to the environment.

Applications: MPI offers two types of back-sheets: one for crystalline silicon solar modules, requiring a 0.2g/m^2/day humidity barrier, and one for thin PV cells, requiring 0.02g/m^2/day.

Platform: Back-Barrier is being developed for use in dye-sensitized and organic thin-film solar cells with a much higher humidity barrier.

Availability: Currently available.

Schreiner ProTech



Pressure compensation seal from Schreiner ProTech protects junction box from harsh environments

Product Briefing Outline: Schreiner ProTech has designed a rugged, self-adhesive Pressure Compensation Seal (PCS) to provide solar module junction boxes with long-lasting protection against severe environmental conditions, preventing damage to sensitive electrical components.

Problem: Condensation, specifically when formed in the photovoltaic module and transferred into the junction box, can decrease power output and corrode electrical contacts, resulting in safety issues. While the value of alternative energy sources like solar power is increasing, production costs of solar energy systems need to be reduced and reliability improved to ensure long-term viability.

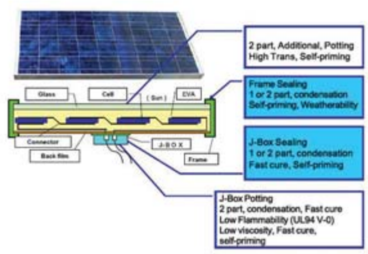
Solution: The new splash-proof (PCS) membrane vent material delivers permanent weather resistance and prevents the intrusion of water, oil and dust within the junction box housing, even after the component has been submerged in water for 30 minutes. Ideally suited for use with solar power systems, Schreiner ProTech's new water-repellent membrane ventilates solar module junction boxes, thus reducing the harmful effects of condensation within the housing while offering reliable protection to PV modules.

Applications: PV module junction boxes.

Platform: Schreiner ProTech's PCS meets the high standards of IP 67. Additionally, the PCS can be customized and installed off the roll in a semi- or fully-automated process, enabling leaner manufacturing processes and lower production costs.

Availability: Currently available.

Shin-Etsu Silicones of America



Shin-Etsu Silicones' potting and sealing materials offer superior module protection

Product Briefing Outline: Shin-Etsu Silicones of America has recently introduced a diverse line of advanced performance, silicone-based products specifically designed for applications that benefit the protection and performance of PV modules in the field. These are comprised of two key product categories that cover potting and sealing applications.

Problem: Potting materials are designed to weatherproof solar panel junction boxes, thus protecting the valuable electronics encapsulated within. Sealing materials for solar panel frames and junction boxes are engineered to seal the junction box (J-Box) to the back sheet and also provide a waterproof seal between the PV panel and the frame. Correct and long-lasting protection is required for the module to function properly and safely during its expected lifetime.

Solution: Shin-Etsu's potting materials (KE-200, KE-200F, KE-210, KE-210F) quickly cure at room temperature, making the junction box both corrosion- and moisture-proof. Major benefits include: superior adhesion strength to various substrates, excellent heat stability (no reversion under airtight conditions), high dielectric breakdown strength, and easy reparability. Their performance properties include strong adhesion to back sheet materials such as PVF and PET, super-fast room-temperature cure, and excellent weatherability and electrical insulation.

Applications: Potting materials are designed to weatherproof solar panel junction boxes. Sealing materials for solar panel frames and junction boxes are engineered for sealing the junction box to the back sheet.

Platform: Potting materials have a reduced low-molecular-weight siloxane Σ (D3 to D10) <300ppm. KE-210 and KE-210F materials are UL94 V-0 compliant. Sealing material KE-220 has fast room temperature cure. KE-45, KE-4828, KE-220 materials maintain good elasticity over a wide temperature range (-40°C to 180°C) and have superior weatherability and electrical insulation properties.

Availability: Currently available.

Investigation of the curing reaction of EVA by DSC and DMA

Markus Schubnell, University of Applied Sciences Northwestern Switzerland, Windisch, Switzerland

ABSTRACT

In today's PV modules, the solar cells are commonly encapsulated in EVA. During lamination EVA undergoes a crosslinking reaction. From a practical point of view, two major interests arise. For quality control purposes, one needs to know the degree of curing of the EVA encapsulant after lamination. The focus in process optimization is on understanding the kinetics of the crosslinking as a chemical reaction. If this is known (and proven), one can predict appropriate crosslinking conditions (i.e. lamination temperature and time) that have to be matched to reach a certain degree of crosslinking. This contribution mostly deals with this latter aspect. DSC as well as DMA data and model-free kinetics were used in this study to establish the kinetics of the EVA crosslinking process. It was found that both techniques adequately predict the degree of crosslinking for any temperature as a function of the curing time.

Introduction

Solar cells are most commonly encapsulated in EVA (ethylvinylacetate), which serves as a sealant and adhesive to the front (most commonly glass) and the back layer (usually glass or tedlar – a polyvinylfluoride).

EVA is widely used because of its excellent long-term behaviour regarding strength, mechanical behaviour, encapsulation properties, high transmittance in the VIS, UV stability, electric insulation capabilities and its low cost. EVA is a block copolymer consisting of typically 65% polyethylene and 35% VA (see Fig. 1). Uncured EVA is a thermoplastic that exhibits a glass transition and melting. To become usable as an encapsulant for PV applications it has to be crosslinked, a task that is usually achieved by peroxides. Upon heating, peroxides decompose into two oxy radicals that may both withdraw a hydrogen atom from a single EVA molecule and thus initiate the crosslinking process. Only at this stage does EVA become a mechanically durable material as is needed in PV modules. For process and quality control purposes, it is important to have a tool providing information regarding the degree of curing reached after or during processing.

The usual way to determine the crosslink density of EVA is by solvent extraction [1]. DSC measurements can be used for this purpose, as recently demonstrated [2]. In this contribution, the aim is not only to determine the degree of curing but also to investigate the crosslinking process as a kinetic phenomenon and to describe the degree of curing as a function of temperature (dynamic experiments) or time (isothermal experiments). We show how this can be achieved by using DSC and DMA data and model-free kinetics.

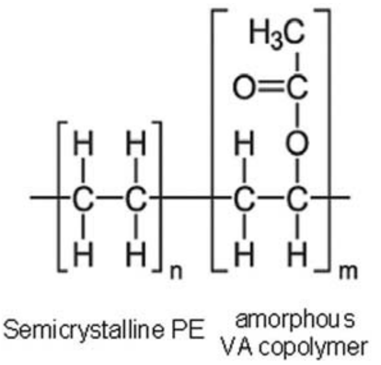


Figure 1. Chemical structure of EVA block copolymer.

Experimental

Samples

The EVA sample was available as a film with a thickness of 0.43mm. From this film, disk-like test specimens were cut out. To prepare the samples for the postcuring experiments (DMA and DSC), fresh EVA test specimens were kept isothermally in the DSC for the specified times.

DSC experiments

DSC experiments were performed using a Mettler Toledo DSC 1 equipped with an intracooler and FRS5 sensor. Samples were encapsulated in 40µl aluminium pans, the typical sample mass being between 5 and 6mg. The heating and cooling rates are indicated in the respective figures.

DMA experiments

DMA experiments were performed with Mettler Toledo's DMA/SDTA861^e. In a DMA the test specimen is subjected to a sinusoidally varying force. As a consequence the test specimen is deformed. However, it generally does not immediately react to the periodically changing force, i.e. there is a phase shift between the applied force and the deformation. This phase shift characterizes the viscoelastic properties of the sample. Based on the force and deformation amplitudes, the phase shift and the geometry of the test specimen, the storage and loss components of the complex modulus can be calculated. Its real part (i.e. the storage modulus) is a measure of the mechanically stored energy in the test specimen. The imaginary part (i.e. the loss modulus) describes that part of the mechanical energy that is dissipated into heat and therefore irreversibly lost.

"Based on the force and deformation amplitudes, the phase shift and the geometry of the test specimen, the storage and loss components of the complex modulus can be calculated."

The tangent of the phase shift, tan δ, is also known as the loss factor and is a measure of the damping behaviour of the material. The modulus and tan δ depend on the temperature and the measuring frequency. At room temperature, rubbery materials (such as EVA) show typical storage modulus values between 0.1MPa and 10MPa. In dynamic mechanical analysis, the modulus is determined as a function of temperature, frequency and amplitude. Depending on how the force is applied to the test specimen, either the shear modulus (in shear mode), G, or the Young's modulus, E, (in tension or bending mode) is measured.

All measurements were carried out in shear mode for this particular study. Disks with a diameter of 4mm and a thickness of 0.43mm were used as samples. The maximum applied force was 5N; the maximum displacement was 5μm; and all measurements were performed at 1Hz. The used heating rate is indicated in the respective figures.

Model-free kinetics

Chemical reactions are usually described by the general rate equation which relates the reaction rate, $\frac{d\alpha}{dt}$ to a function describing the temperature dependency of the reaction, $k(T)$, and a conversion-dependent model function that describes the course of the reaction, $f(\alpha)$, i.e.

$$\frac{d\alpha}{dt} = k(T)\, f(\alpha)$$

The temperature dependence of the reaction rate is described by the well-known Arrhenius equation:

$$k(T) = k_0\ e^{-E_a/RT}$$

Here k_0 is the pre-exponential factor, E_a is the activation energy of the reaction, R the gas constant, and T the temperature. The model function is generally unknown and needs to be specified for each reaction separately. For complex reactions this is generally not possible, especially because it is not only chemistry that determines the course of a reaction but also transport processes among the reactants. Furthermore, the concept of a constant activation energy throughout the reaction is doubtful if several reactions are running in parallel. Therefore, a holistic model-free approach to describe the kinetics of complex reactions has been proposed. In model-free kinetics (MFK), the activation energy depends on the degree of conversion. Apart from the ongoing

PV Modules

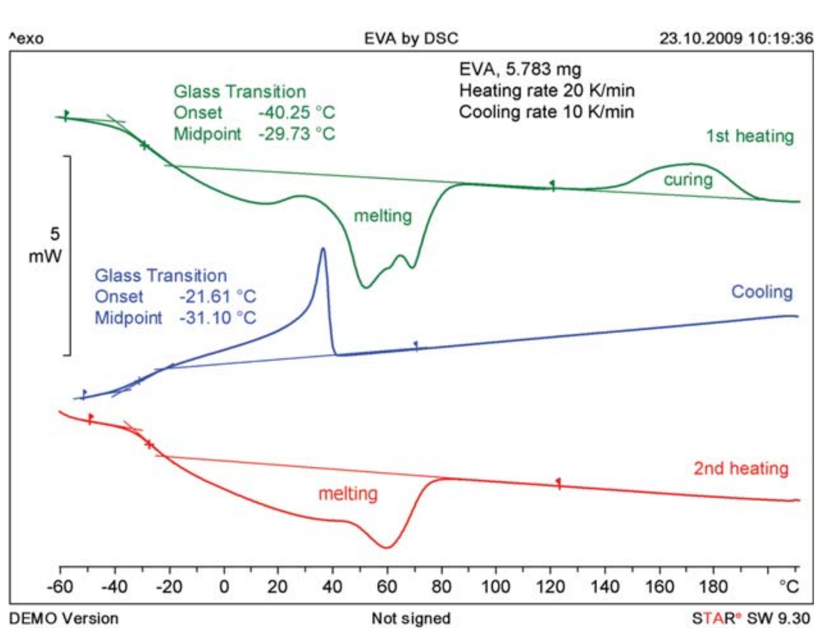


Figure 2. Graph showing 1st and 2nd heating and the intermediate cooling experiment on a fresh EVA sample. Basic effects are the glass transition (around -30°C), melting (between -30 and 80°C) and the curing reaction (around 170°C), the latter showing up only during the first heating. The exothermal peak during cooling is due to crystallization.

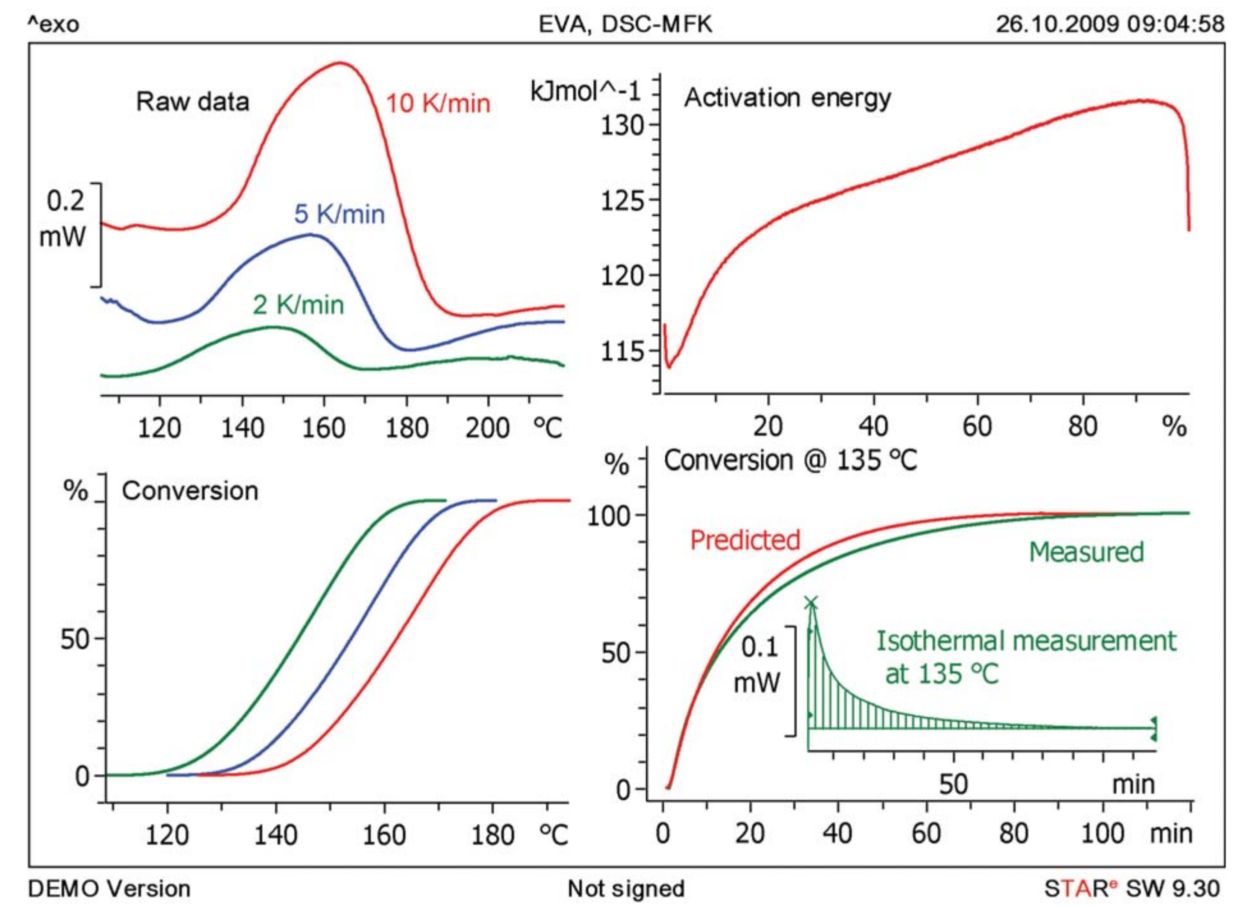


Figure 3. Model-free kinetics of the curing reaction of EVA based on three DSC experiments with different heating rates.

chemical reactions, it also describes other processes such as diffusion among the reactants. Therefore, it is understood as an apparent activation energy, thus lacking the strict interpretation of the activation energy.

> "In model-free kinetics (MFK), the activation energy depends on the degree of conversion."

MFK is based on the isoconversion principle, which states that at any particular conversion, the reaction rate depends only on the temperature, and is independent of the heating rate. A practical implication of the isoconversion principle is that in order to calculate the apparent activation energy, at least three experiments have to be performed under different thermal conditions, each also requiring calculation of each experiment's respective conversion curves. Based on the conversion curves the apparent activation energy is determined as a function of the conversion. Several different procedures have been proposed to calculate the apparent activation energy. This study uses the procedure developed by Vyazovkin (see [3] and references therein). In principle, the MFK approach can be used for any kind of experimental data that describe the reaction and that can be converted into a conversion curve.

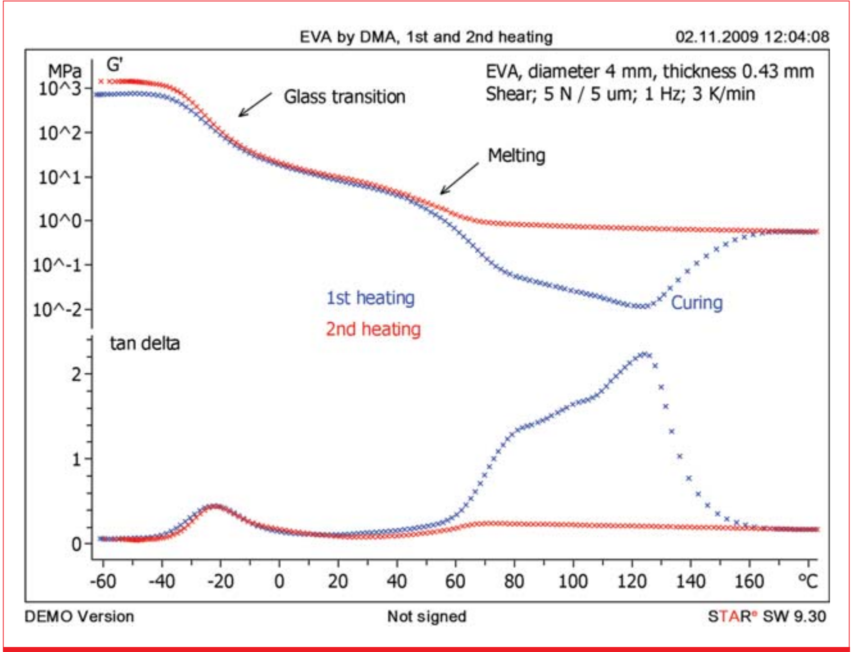


Figure 4. DMA experiments of uncured and cured EVA.

Results and discussion

DSC experiments

In Fig. 2 the DSC curves of the 1st heating, the subsequent cooling and the 2nd heating experiment on a fresh EVA sample are shown. During the 1st heating one can first see the glass transition followed by melting. The exothermic peak at around 170°C is due to the curing reaction of EVA. The cooling and 2nd heating curve of the sample support this interpretation: the glass transition shows up on both experiments; during cooling we

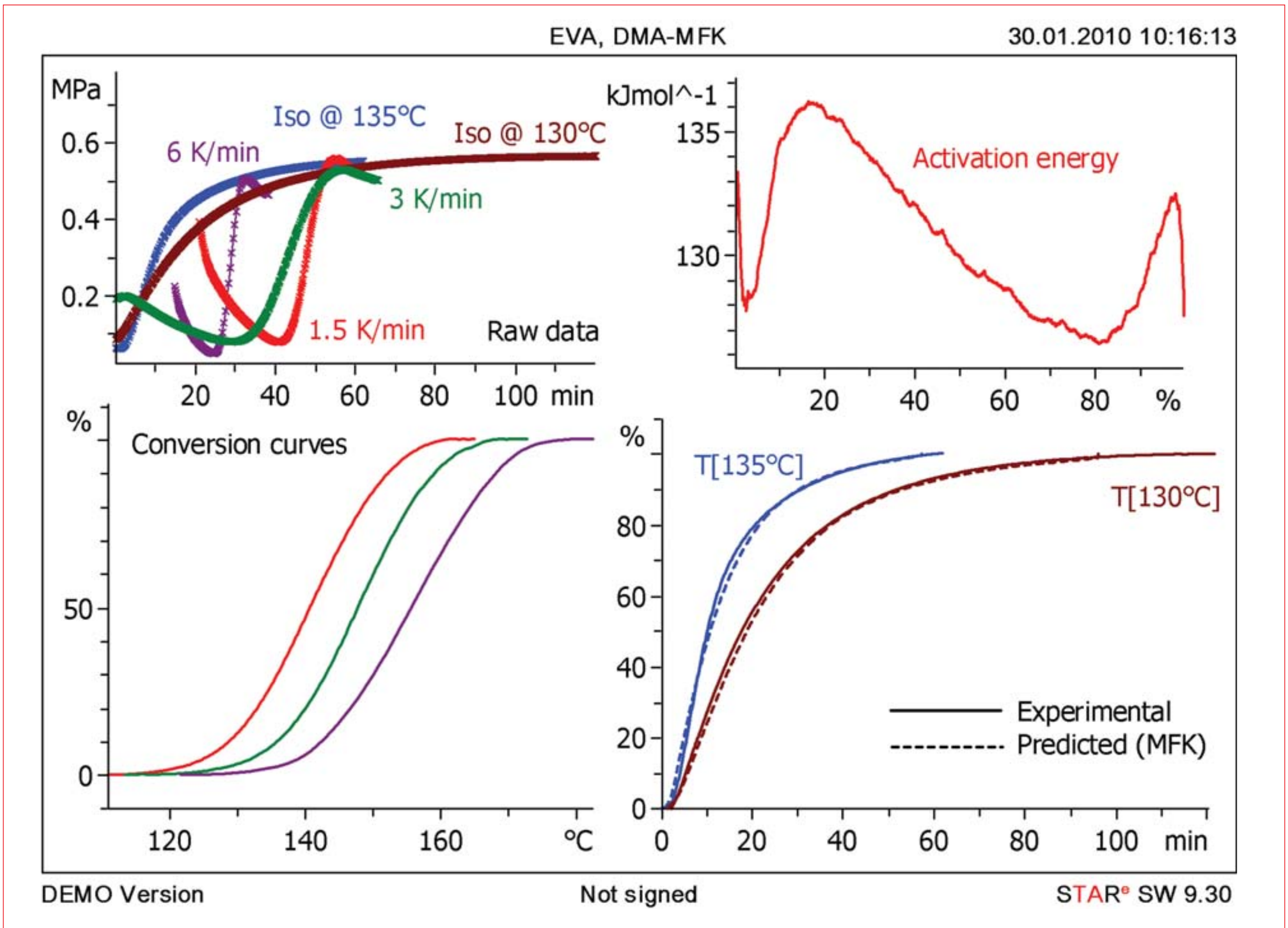


Figure 5. Model-free kinetic analysis of DMA data.

additionally find crystallization and upon the 2nd heating, another melting takes place. The different shape of the melting peaks of the 1st and the 2nd heating is due to the changing thermal history of the sample.

To study the kinetics of the reaction, model-free kinetics were applied using three different heating rates (2, 5 and 10K/min; see top left diagram in Fig. 3). In order to get the degree of conversion at a certain temperature, the partial area of the reaction peak up to this temperature, $\Delta H_p(T)$, is normalized to the overall reaction enthalpy, ΔH_{tot}, as follows:

$$\alpha(T) = \frac{\Delta H_p(T)}{\Delta H_{tot}}.$$

Based on the conversion curves of the reaction peaks (bottom left diagram in Fig. 3), the activation energy is calculated as a function of the conversion (top right diagram in Fig. 3). The conversion-dependent activation energy can now be used to make isothermal predictions, as illustrated in the bottom right diagram in Fig. 3 for 135°C. The diagram also shows the result of the corresponding isothermal experiment. In conclusion, a reasonable agreement is found between what is predicted by model-free kinetics and actual experimental data.

Using DSC data for this particular reaction is questionable in that as apart of the curing reaction the peroxide decomposes during the reaction. This of course also affects the measured DSC signal; i.e. the measured signal in the curing temperature range arises as the sum of the curing reaction and the degradation of the peroxide. Therefore, to exclusively follow the curing reaction and thus to validate the DSC results, an alternative experimental technique is needed.

> “Based on the activation energy, the isothermal course of the curing reaction can be predicted at any temperature.”

DMA experiments

Network density increases during a curing reaction. For low network densities, as is the case for the EVA sample investigated here, the modulus is proportional to the network density. Thus, the curing process can also be monitored by measuring the modulus, and can be carried out experimentally using DMA. Fig. 4 shows the shear storage modulus, G´, and tan δ during the 1st and 2nd heating as measured by DMA. One can clearly distinguish the glass transition at around -20°C followed by the melting and the curing reaction, which begins at around 125°C. The variation of the modulus during the curing reaction depends on the applied frequency, which decreases as the frequency is increased. The selected frequency of 1Hz compromises a short measurement time (resolution) and high sensitivity towards the cross linking.

In order to apply model-free kinetics, the curing effect on the modulus has to be transformed into a conversion curve describing the progress of the curing reaction. This can be done by normalizing the difference of the modulus during curing, $G'(T)$, and the modulus before curing, G'_{bc}, to the difference of the plateau modulus, G'_p, and the modulus before curing, as illustrated in the following equation:

$$\alpha(T) = \frac{G'(T) - G'_{bc}}{G'_p - G'_{bc}} \qquad (1)$$

Using this equation, the three curves for G´ shown in the top left diagram of Fig. 5 result in the respective DMA conversion curves (bottom left diagram, Fig. 5). The conversion-dependent apparent activation energy can be calculated from these curves (top right diagram, Fig. 5). Based on the activation energy, the isothermal course of the curing reaction can be predicted at any temperature (bottom right diagram,

Fig. 5; predictions are shown for 130°C and 135°C). Again the predicted and actually measured isothermal conversions agree reasonably well with each other.

In Fig. 6 the conversion-dependent activation energy as well as the predictions on the curing reaction and its corresponding experimental isothermals at 135°C are compared for the DSC- and DMA-based data. It can be seen that the gross value of the activation energy is the same for both techniques, and while the predicted conversion curves agree reasonably well, DMA predicts slightly higher degrees of conversion. The reason for this is due to the fact that the DMA degree of conversion depends on the plateau modulus (see Equation 1). The plateau modulus, however, changes during the experiment (see Fig. 4, 2nd heating). This analysis assumed the modulus value at the end of the curing reaction as the plateau modulus, leading to an overestimation of the DMA conversion of – in a worst-case scenario – about 8%.

> "For large degrees of curing, the postcuring effect may become difficult to quantify."

Postcuring experiments

For quality control purposes, one has to rely on postcuring experiments, i.e. comparing the postcuring effect of a processed sample to a previously measured overall curing effect. In a similar way, isothermal process conditions can be experimentally verified and optimized. Postcuring studies can be performed both with DMA and DSC. Several samples have been precured for different times at 135°C and then dynamically postcured. Respective results are shown in Fig. 7.

The bottom diagram in Fig. 7 displays DSC postcuring. It illustrates that the postcuring peak is relatively broad and the related enthalpies are rather small. Consecutive experiments on samples that have been precured the same way indicate that the reproducibility regarding the degree of curing is around 5%. The top diagram in Fig. 7 shows the data for DMA postcuring experiments. For large degrees of curing, the postcuring effect may become difficult to quantify. Based on the data shown in Fig. 7 one can plot the degree of curing as a function of the curing time, as shown in Fig. 8.It is clear from Fig. 8 that the DMA experiments deliver slightly lower degrees of curing. This can be explained by the fact that due to degradation of the peroxide in the EVA,

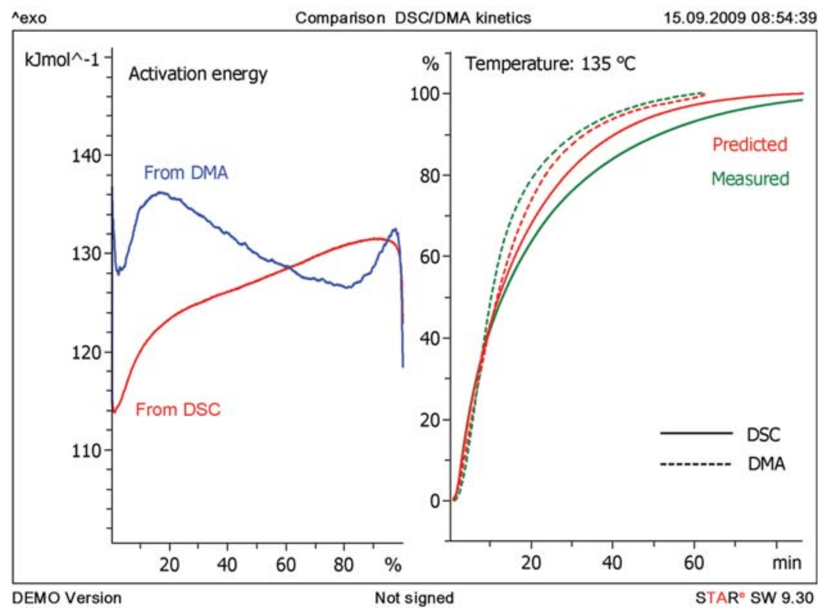


Figure 6. Comparison of DSC and DMA results on the curing of EVA.

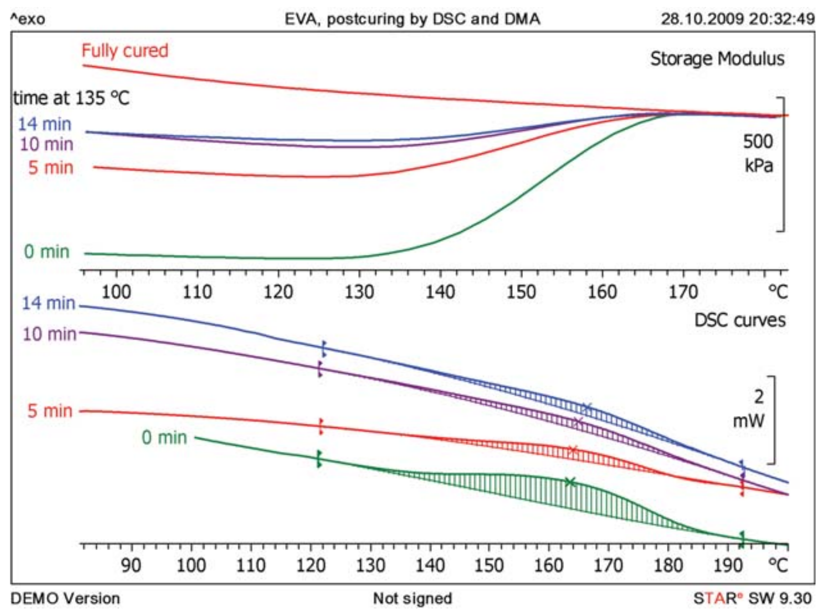


Figure 7. Postcuring by DSC (bottom) and DMA (top).

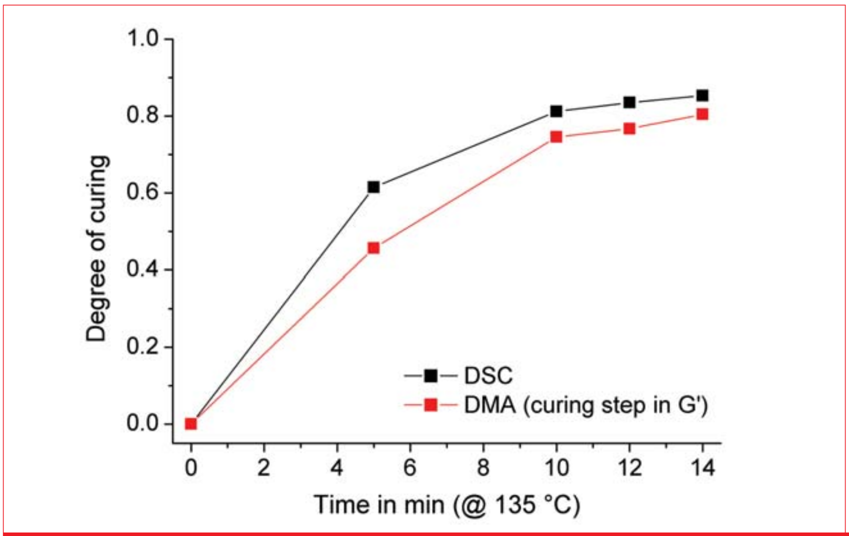


Figure 8. Degree of curing at 135°C as a function of curing time.

the 100% curing enthalpy as measured by DSC is too low. Consequently, the measured postcuring enthalpies are slightly too high.

> "The comparison of DSC and DMA results shows that both techniques deliver consistent results."

The degree of curing of processed samples was also analyzed. From DSC a degree of curing of about 68% was seen, the uncertainty being in the region of 5%. This value again agrees well with respective DMA measurements, which delivered a degree of curing of 71%, the uncertainty being also around 5%. It can therefore be concluded that within an uncertainty range of about 5%, DSC and DMA results deliver equivalent results regarding the degree of curing.

Conclusions

Both DSC and DMA experiments can be used to investigate the kinetics as well as the postcuring, and thus the degree of curing of EVA. DMA delivers the more reliable results because it is sensitive only to the curing process. DSC on the other hand is affected by the degradation of peroxide acting as a curing agent for EVA. However, the comparison of DSC and DMA results shows that both techniques deliver consistent results. Thus, optimization of lamination process conditions can be achieved by applying model-free kinetics to either DSC or DMA data. The benefit of using DMA lies in the fact that this approach also delivers information about the temperature and frequency-dependent viscoelastic properties of EVA.

Acknowledgment

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About the Author

Dr. Markus Schubnell graduated from Bern University, Switzerland with a Ph.D. in physics. He has been working at Paul Scherrer Institute in Switzerland in the field of solar energy (high temperature solar chemistry, thermophotovoltaics) for about 10 years. He is now working at the University of Applied Sciences Northwestern Switzerland as well as with Mettler Toledo GmbH. His interests are focused on the use of thermal analysis (DSC, DMA) of polymers, among other materials.

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Achievements and challenges in crystalline silicon back-contact module technology

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ABSTRACT

The main goal of the solar industry is to reach grid parity as soon as possible. This can be achieved by reducing the manufacturing costs, by increasing conversion efficiencies and/or by improving the lifetime of solar modules. Driving down the cost of modules is not straightforward. Commercially available PV modules are typically sold with 20-year warranties, and changing these materials for economic reasons requires extensive material testing and recertification of the new module design. In the following sections, we will focus on the cost drivers of module manufacturing processes and how that could evolve into new module designs.

Introduction

Potential problems that may ensue from attempts at lowering costs in module manufacturing include yield problems, for example when thinning wafers down to below 160μm. During cell manufacture, handling of thin wafers and the impact of the various process steps such as wet chemistry, printing of metallization and high-temperature firing processes have to be reconsidered. During module manufacture, the standard soldering techniques applied to large and thin silicon solar cells can lead to cell breakage due to mechanical stresses. Therefore, innovative module design strategies have to be developed that can cope with the material properties of thin silicon wafers. Meanwhile, novel designs of the solar cells are needed to further boost the module output power. On top of that, there is little science available to assess the performance and reliability of solar modules for field operation over 20 years.

Costs

Technology advances and upscaling were the main contributors to an average module price reduction of about 10% per year in the past three decades. In the past, a main component in the module cost structure was attributed to the making of solar cells owing to large equipment costs and the considerable manpower needed to make high quality solar cells. This approach is undergoing changes now as throughputs in advanced process tools increase rapidly. This is clearly visible from Fig. 1, which shows the cost structure of crystalline silicon modules broken down for the different aspects of the value chain. The costs of solar cells were responsible for 35-40% of the total module costs in 2005, but that fraction will decrease to an estimated 25% in 2015. Material costs will become the determining cost factor throughout the value chain in the near future. In a crystalline silicon module, the main material contributions are silicon, metals and encapsulation materials.

Following the targets for cost reduction implies that crystalline silicon modules that are sold in the range of 1.7-2€/Wp today need to be in the range of 1-1.2€/Wp in five years' time. This means that a cost reduction of roughly 40-50% must be realised, but how can we achieve that? Increasing the cell efficiency from 15-16.5% today to 18%-20% five years from now will account for 50% of the targeted 'cost reduction.' These efficiencies apply to crystalline wafer-based cells that are mass-produced. The question, and the ultimate challenge for module technology, is how to achieve the other 50%.

Thinner and larger solar cells

Mechanical considerations

It is clear that wafers need to get thinner. The efficiency of solar cells is only slightly affected when the wafer thickness is reduced from 200μm to 120μm [1], which proves that there is still a lot to be gained in the cost-performance ratio of wafers and cells. The wafer manufacturer's aim is to produce as many wafers as possible per kilogramme of silicon. Reducing wafer thickness and reducing kerf losses are two ways in which this can be achieved. In the past five years, wafer thicknesses have dropped from 300μm to 160μm in production, with wafers of a thickness of below 100μm being studied in R&D demonstrations [2-4]. Such extremely thin solar cells have to be fabricated in alternative ways. For instance, a full-size

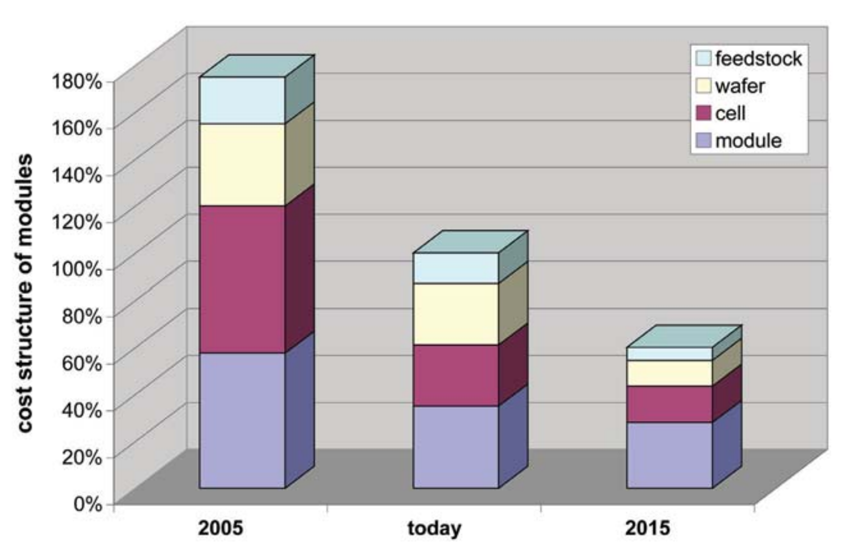

Figure 1. Past, present and prediction of the cost structure of crystalline silicon modules broken down according to the different parts of the value chain. The module manufacturing costs have been calculated relative to today's module manufacturing costs.

aluminium rear-side is no longer possible as it leads to excessive bowing of cells. Also, aluminium no longer provides adequate passivation for high-efficiency solar cell concepts, which has resulted in several research routes towards open-rear side cell concepts [5]. Improved passivation will lead to a higher current, but will be somewhat compensated by additional resistive losses from the rear side. The net result is a higher cell efficiency and a cell with low-bow properties.

The combination of thin and highly efficient cells poses problems for the interconnection process. More efficient cells produce higher currents, which means that wider and/or thicker interconnects, better known as tabs, are necessary to keep electrical losses at an acceptably low level. However, when exposed to high temperatures (>250°C) during the solder process, thin cells tend to break much more easily. This is caused by differences in the thermal expansion coefficient between silicon and the copper tabs. In addition, substituting lead in solder pastes will lead to an additional increase in process temperature of 40-50°C. This will obviously lead to further yield problems during module manufacturing. During field operation, the temperature cycles seen by the interconnection will result in damage to the silicon. The interconnection will result in (micro-)

Figure 2. Picture of a open rear-side solar cell. The rear-side is shown on the left and the front side on the right.

cracking of silicon and eventually pull-out of silicon from the cell, leading to a decrease in module efficiency and ultimately failure. Alternatively, cracks can develop in the solder itself resulting in an increase in electrical resistance through the interconnection [6].

Low-stress interconnection technologies have been developed based on conductive adhesives in order to facilitate the manufacture of modules using thin cells with a large surface area [4]. The lower processing temperature of these adhesives, as compared to soldering, results in a lower residual stress after cooling to room temperature. Adhesives can be formulated to be snap-cured which results in a processing speed that is comparable to the time necessary for making soldered interconnections. The greater elasticity of interconnections made with conductive adhesive and a lower processing temperature as compared with soldering has proven to be functional on cells with a thickness of 100μm. The durability of the interconnection was tested in full-size modules according to IEC61215 standards and has been found to be as suitable as for soldered modules using similar cells. Conductive adhesives also have the advantage over traditional solders of being lead-free.

Electrical considerations

With the exception of a few high-efficiency concepts that are based on monocrystalline silicon Cz wafers, most solar cells are designed and manufactured as vertical devices. This means that the emitter is located on one side of the cell and the base on the opposite side. Metal structures are applied to both sides of the cell to form base and emitter terminals and to drain the current off in a lateral way to facilitate interconnection of neighbouring cells. The front-side metal structure of a cell is designed as a set of fingers and busbars. The fingers are needed to collect the current, but also cause shading. Therefore, the front-grid design is the result of optimization between shading losses and resistive losses.

"Applying metallization to a solar cell is roughly two orders of magnitude more expensive than using metal foils in a module."

Electrical losses caused by series resistance of the front-grid metallization are typically in the range of several percent. Electrical losses due to rear-side metallization are generally very low for cells with a full-size aluminium rear side. In a module, resistive losses due to interconnection of cells, known as tabbing and bussing, can add up to several percent. As a net result, industrial cells with full aluminium rear side typically leave the cell manufacturing company with 77-79% fill factor, while the module fill factor is typically in the range of 72-74%. Hence, it is worthwhile looking into combined cell-module concepts for lowering these resistive losses. Lowering ohmic losses in solar cells is not straightforward, and will lead to additional costs [7].

Electrical conductors can be applied to the solar cell via printing or plating technologies, or can be applied in the module by metal tabs or foils. Applying metallization to a solar cell is roughly two orders of magnitude more expensive than using metal foils. Therefore it is our strategy to reduce the resistive losses at the module level, not at the cell level.

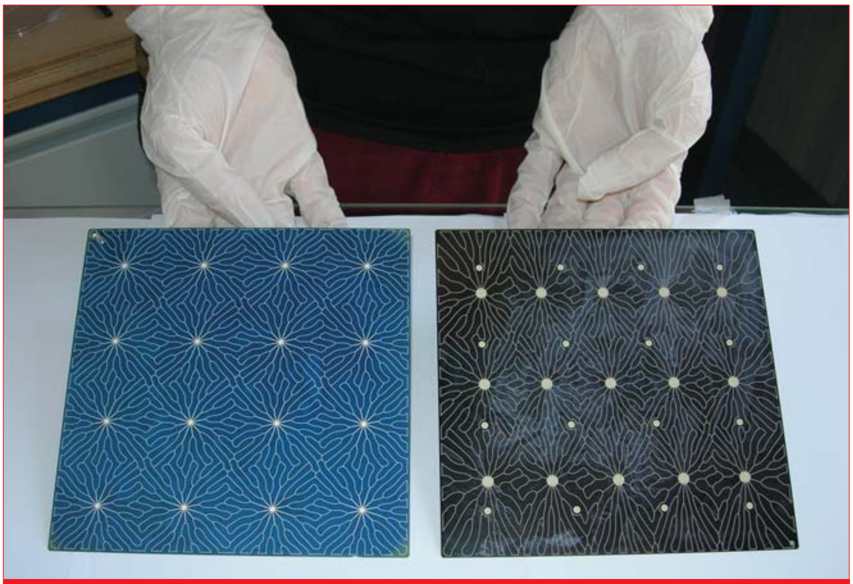

Figure 3. Picture of the front-side (left) and rear-side (right) of an ASPIRE MWT solar cell. The front-side design is registered as the industrial design Sunweb and owned by Solland Solar Energy Holding BV. The open rear-side design follows from an optimization between passivation requirements and resistive losses.

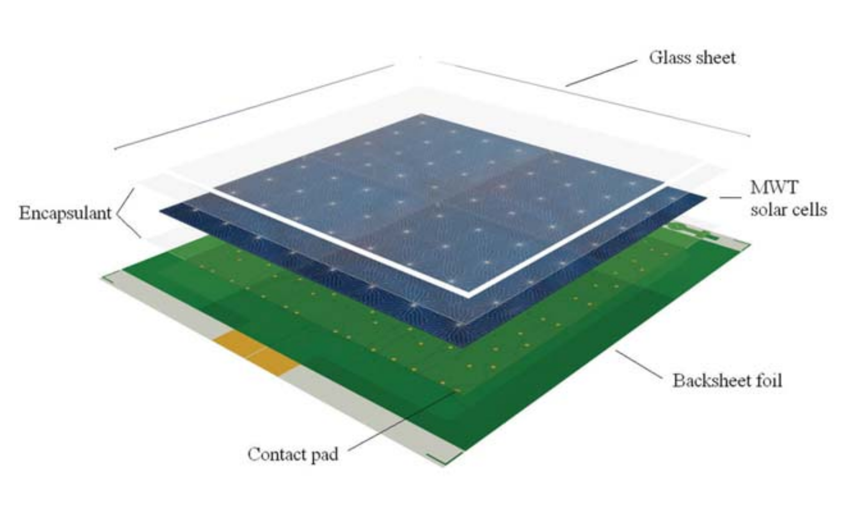

Figure 4. Back-contact module assembly using MWT solar cells.

The module concept is based on draining the current underneath the cell at multiple locations, for example as shown in Fig. 3. The solar cell design is a metal-wrap through (MWT) cell with open rear side. The front-side metallization pattern has been optimized to minimize shading and resistance losses. The front-side metal coverage is typically 2% less in comparison with conventional cells, leading to 2% higher currents. Busbars are no longer necessary because the current is drained through 16 holes in the wafer and appear as 16 contact points on the rear side of the solar cell. Resistive losses due to front-side metallization are also smaller in comparison with conventional solar cells because the effective finger length is smaller. The rear-side design is the result of a trade-off between passivation and resistive losses, i.e., metal coverage. The net result is a premium cell efficiency and a cell concept that has the mechanical properties to survive the subsequent module processing steps.

Back-contact module concept

In order to fully benefit from the advantages of back-contact cells such as MWT cells, an alternative module manufacturing technology is required. At ECN, a method using a patterned conductive back-sheet foil as the module substrate was developed. The foil is similar to a standard Tedlar-PET-Tedlar back-sheet foil with an additional layer consisting of a metal sheet. The conductive sheet is patterned to match the contact points on the rear of the back-contact cell, resulting in a series interconnection of the cells on the foil. Cells are placed on the foil using a method analogous with pick-and-place technology used for surface-mount devices in the electronics industry. This reduces cell handling to just one pick-and-place step and therefore reduces the likelihood of damaging the cells. Since the front contacts and tabs are no longer required, the cells can be placed closer together in the module, which leads to an improved packing density. There is also no need for string interconnections at the top and bottom of the module, which also increases the effective area of the module. The cell-to-cell interconnection takes place during lamination, resulting in a single-shot interconnection and lamination technology.

The temperatures at which the connections are established are identical to the lamination temperature of approximately 150°C. An electrically conductive adhesive that is cured during lamination establishes the electrical connections between the MWT cells and the conductive back-sheet foil, as shown in Fig. 5.

Since shadowing losses no longer play a role, the metal layer in the back-sheet foil can be designed to be much wider than the width of a busbar in conventional cells. The cell design and module layout can be optimized simultaneously with respect to module output and total costs. For example, the number of contacts between the rear of the cell and the conductive components of the module can be optimized for both cell and module efficiency. An important parameter that affects module performance is thickness of the conductive layer. The costs of the metal sheet, e.g., copper and the processes used to create the specific design pattern, will increase with increasing layer thickness. Likewise, the resistive losses in the module will reduce with increasing layer thickness. This will lead to an economic optimum. An example of module fill factor calculations based on an MWT cell with a fill factor of 77.0% is shown in Fig. 6. When the thickness of the copper layer increases, the fill factor of the module starts approaching the fill factor of the MWT cell, for which several data points were verified by measurements. In comparison with conventional modules, module fill factors will be significantly higher. Several side-by-side comparisons on neighbouring wafers, cells and modules have been performed [9], showing consistently that MWT modules produce 2% more output current and module fill factors are 3% higher than modules fabricated with H-pattern cells.

Pilot line for manufacturing back-contact modules

Fig. 7 shows the pilot line for assembling back-contact modules [10], which was developed together with Eurotron [11]. This assembly line consists of five stations performing the following steps. **Station 1**: Patterned conductive foil is placed on a carrier plate that transports the foil through the module build process. The foil is held in place by vacuum support. **Station 2**: The conductive adhesive is printed on the foil. The complete foil is printed in less than 60 seconds. A 60-cell module requires about 2000 dots of conductive adhesive to be printed. **Station 3**: The first sheet of encapsulant needs to be perforated at the positions where the conductive adhesive has been printed to allow contact with the cells. This station can perforate and place a complete encapsulant sheet in less than one minute. The foil is then automatically placed over the conductive foil without damaging or smearing the conductive adhesive dots. **Station 4**: Cells are individually picked from a stack by a robot and placed at pre-programmed positions on foil with the contacts on the cell making contact with the conductive adhesive (Fig. 8). A vision system checks the integrity of the cell and its orientation. The module assembly is then returned to Station 3 for a second sheet of encapsulant (without holes) and a sheet of glass. In a production line, additional in-line stations would be included for these operations. **Station 5**: For the lamination process, the glass sheet needs to be at the bottom of the module stack. A conveyer belt attached to a pneumatic arm is used to invert the carrier with the module stack in place. The module is then fed out of the pilot line to be placed into the laminator. Lamination is subsequently performed to create the monolithic module, during which process both the encapsulant and the conductive adhesive are cured.

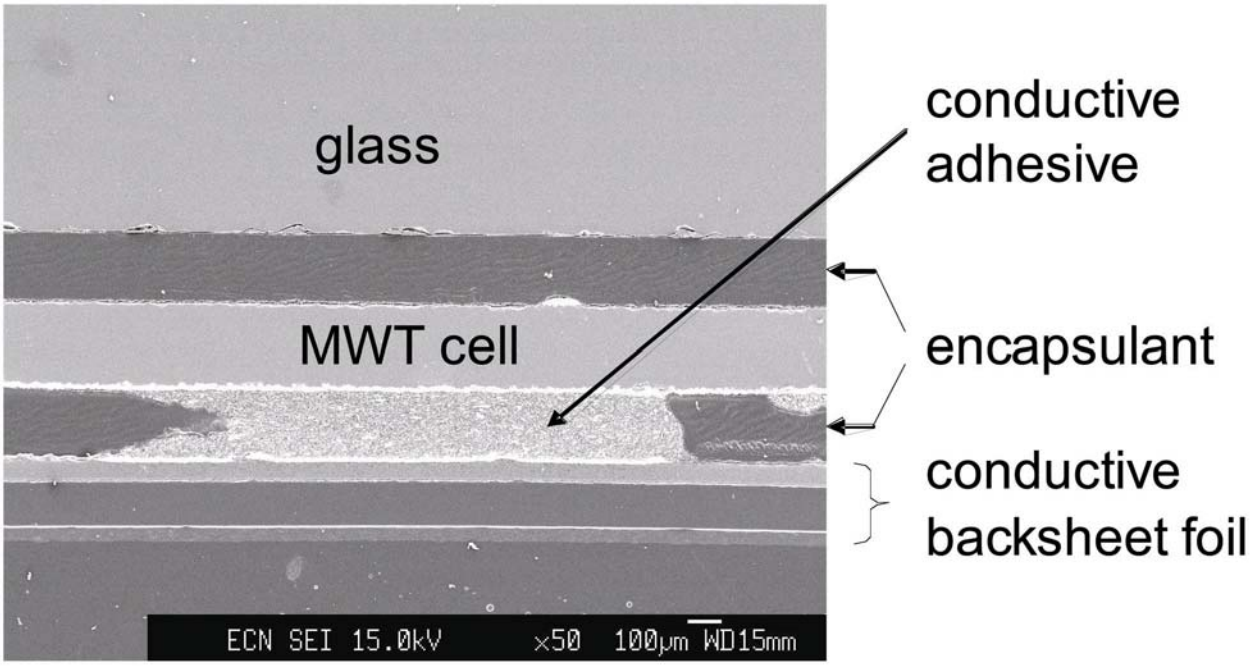

Figure 5. Cross-sectional view of the module.

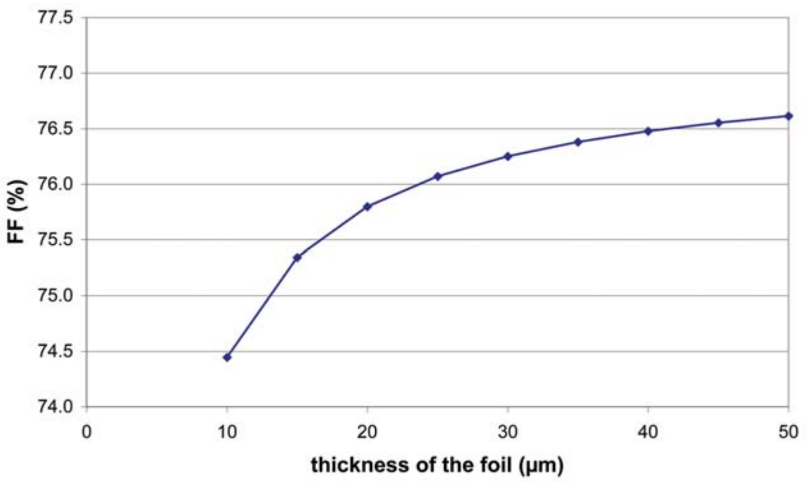

Figure 6. Results of fill factor calculations of the MWT module as a function of copper layer thickness in the back-sheet foil.

Figure 7. Picture of the pilot line at ECN for manufacturing back-contact modules.

Further automation can be implemented in production, such as automatic feed-in of materials. A production line will also be fitted with a number of carriers with a return system taking a carrier back to the start of the line after module build-up is complete. A production line has a potential throughput rate of one module well within a minute for 60 cell modules, which is equivalent to 150MWp using 16% solar cells.

Premium efficiency MWT modules

As a demonstration of the capabilities of MWT cells and modules, we recently manufactured high-efficiency MWT cells and modules in 2009. High-quality multicrystalline wafers with a thickness of 160μm were obtained from REC. Several improvements in texturization, emitter formation and metallization were implemented. A batch of 80 wafers was used to result in an average cell efficiency of 17.6%, of which the best 36 cells had an average efficiency of 17.8% with a highest efficiency of 17.9%.

The 36 best cells were used to manufacture a module with the pilot line at ECN. Improvements in processing of the module were made to ensure improved deposition of conductive adhesive and better settings for combined lamination and curing. The performance of the finished module was measured at ECN and this measurement was confirmed by measurement at JRC-ESTI. Aperture area efficiency was 17.0%. The processes used for manufacture of the cells and ultimately the module are industrially applicable and not restricted to the laboratory.

Figure 8. Close-up view of the pick-and-place robots.

	I_{SC} (A)	V_{OC} (V)	FF (-)	Efficiency (%)
Premium cell	8.86	0.632	77.8	17.9
Average 36 cells before encapsulation	8.85	0.631	77.4	17.8
Module (aperture area = 8885cm²)	8.86	22.67	75.0	**17.0**

Table 1. Overview of premium cell and module efficiencies achieved in 2009. Cell efficiencies were measured with a class A solar simulator at ECN; module efficiency was independently verified by JRC-ESTI.

Outlook and conclusions

The single-shot interconnection and encapsulation process proves an effective route towards reduction of the cost-performance ratio of crystalline silicon modules. Two main questions remain, however. The potential for module performance increase is definitely there, but how about the manufacturing costs of this module technology? The second is whether this technology will survive the required 20-25 years' operation in the field. Clearly, the back-contact module assembly method is ideal for working with very thin silicon wafers. This means that the costs targets for 2015 for feedstock and wafers (Fig. 1) seem to be very well within range. Furthermore, the cell cost and efficiency targets seem to be in range. Material costs in the cell will be reduced when transforming existing cell production lines from conventional H-pattern cells to MWT cells, while efficiencies increase. Applying MWT cell strategies to monocrystalline wafers will further reduce the gap towards the 20% target. But at the module level, there are still some items to be resolved. Conductive back-sheet foils will be more expensive than standard TPT foils, and conductive adhesive is also an additional cost item. At present there is no commercial party producing conductive back-sheet foils in high volume. However,

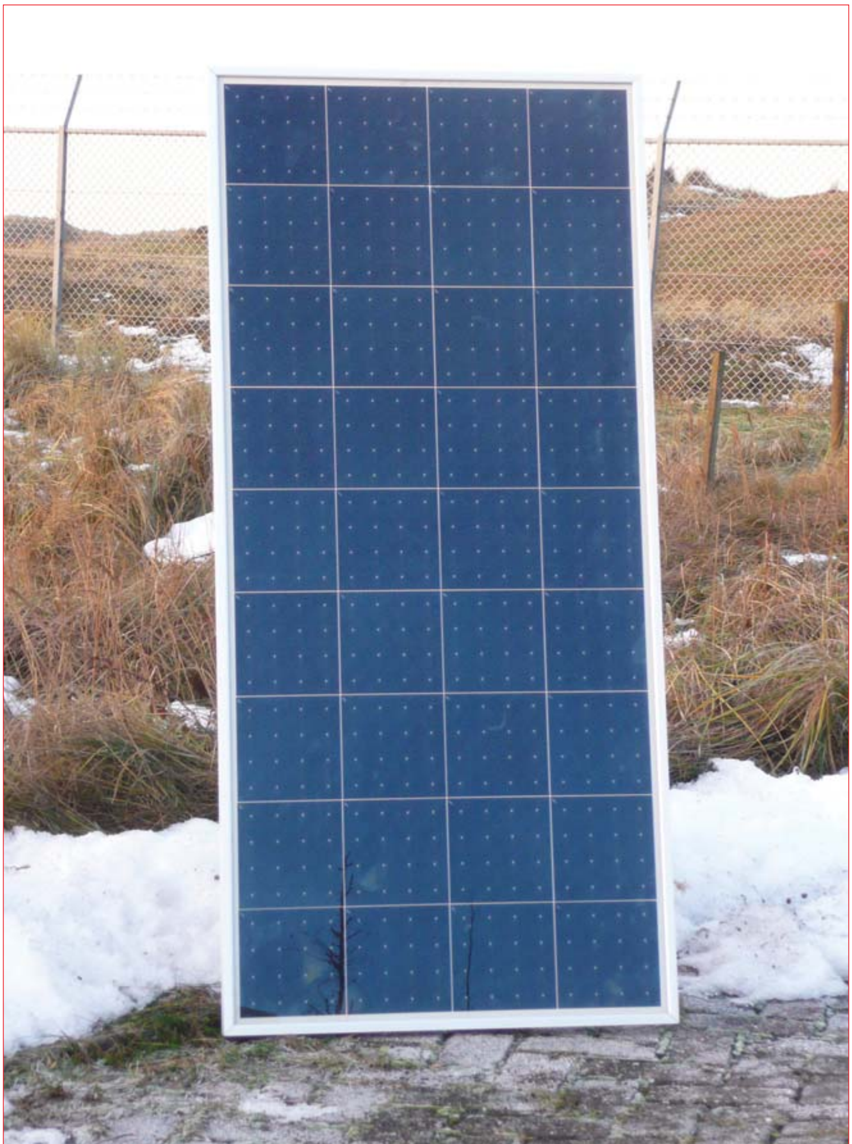

Figure 9. Picture of the finished MWT module. All of the conductive back-sheet is within the active area of the cells. There is no need for bussing at the top and bottom of the module resulting in optimum packing density.

following the line of reasoning that the ultimate limit of what can be achieved by upscaling will be determined by the material costs, the conductive back-sheet foil will eventually be not much more costly than a TPT foil. Therefore, we believe that it is more important to show that the lifetime expectancy of the back-contact module concept is at least as good as conventional module technology. This is where our present focus is, and laboratory tests have so far shown to give very promising results.

Acknowledgements

The author would like to acknowledge all of the scientists and operators at the ECN Solar department for contributing to this work. Special thanks also applies to co-workers at Eurotron, JRC-ESTI, REC and Solland Solar Energy for providing materials, equipment and/or service in various projects. Finally, ECN wants to thank SenterNovem and the European Commission for their financial support.

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Dr. Paul C. de Jong is the head of the Module Technology group within the Solar Energy department at ECN. He received his Ph.D. in electrical engineering from the Delft University of Technology in 1998 on the topic of smart sensor systems. His research focuses on the design, fabrication, characterization and analysis of solar modules. In December 2009, his group reached the 17.0% efficiency target for modules made with multicrystalline silicon solar cells, which was a combined effort with the solar cell architects and solar cell processing groups at ECN.

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Snapshot of spot market for PV modules – quarterly report Q4 2009

pvXchange, Berlin, Germany

ABSTRACT

Solar enterprises will each be faced with the occasional surplus or lack of solar modules in their lifetimes. In these instances, it is useful to adjust these stock levels at short notice, thus creating a spot market. Spot markets serve the short-term trade of different products, where the seller is able to permanently or temporarily offset surplus, while buyers are able to access attractive offers on surplus stocks and supplement existing supply arrangements as a last resort.

Introduction

As expected, a slight reduction in prices has characterized the last months of 2009. In comparison, early 2009 saw prices for photovoltaic modules in the spot market fall by 20-40%. As seen in Fig. 1, Chinese manufacturers of crystalline panels lowered their prices by an average of 45% during 2009. European and Chinese producers have had to cope with a sales price reduction of 35%. Although CdTe module prices fell by only 20%, the top sellers for 2009 on the pvXchange spot market were First Solar panels. Second in demand were high-performance polycrystalline products; Yingli, Suntech and Canadian Solar came out on top as the absolute favourites, followed by a wide range of very reasonably priced products from other manufacturers. Also performing well sales-wise were the microcrystalline modules from Sharp, Mitsubishi and Schott Solar. SunPower's high-performance monocrystalline modules could enjoy as many new customers in Europe. In contrast, European manufacturers were only minimally involved – with the exception of German market products and Norwegian manufacturer REC – despite very good conditions. This year has responded well to what was requested by the market with popular modules from well-known suppliers.

Module Type	Average price, December 2009 EUR/W	Change since January 2009
Crystalline silicon from European suppliers	2.05	-35,7%
Crystalline silicon from Chinese suppliers	1.62	-45,1%
Crystalline silicon from Japanese suppliers	2.05	-35,1%
Thin-film CdS/CdTe	1.68	-20,0%
Thin-film silicon (a-Si or microcrystalline)	1.46	-33,9%

Note: all prices net 1) This only shows the price for PV modules. 2) The prices are not end-consumer prices. 3) Prices represent the average offer prices on the international spot market.

Source: www.pvXchange.com

Figure 1. pvXchange module price barometer for December 2009 showing % change since January 2009.

Crazy autumn

In September, module prices almost stabilized. Then, in October, they began rising for the first time in 2009. But the most tangible change was the first ever hike in inverter prices caused by a severe bottleneck. Since the beginning of autumn, the demand for all PV components surpassed the expectations of many manufacturers and wholesalers, many of whom were no longer able to keep up with the spate of new orders. A number of products are completely sold out for the rest of 2009. In particular, there is a shortage of high-performance modules from well-known manufacturers and products based on microcrystalline silicon and cadmium telluride, a sector that saw the most drastic price increases. It is likely that a number of projects have not been completed on schedule by the end of the year due to a lack of inverters.

Pressure on solar contractors and project developers increased everywhere as compensation rates dropped not only in Germany, but also in other European countries in January 2010. Some manufacturers are attempting in vain to counteract this trend by offering a 10% price reduction on current list prices for deliveries ordered in 2010.

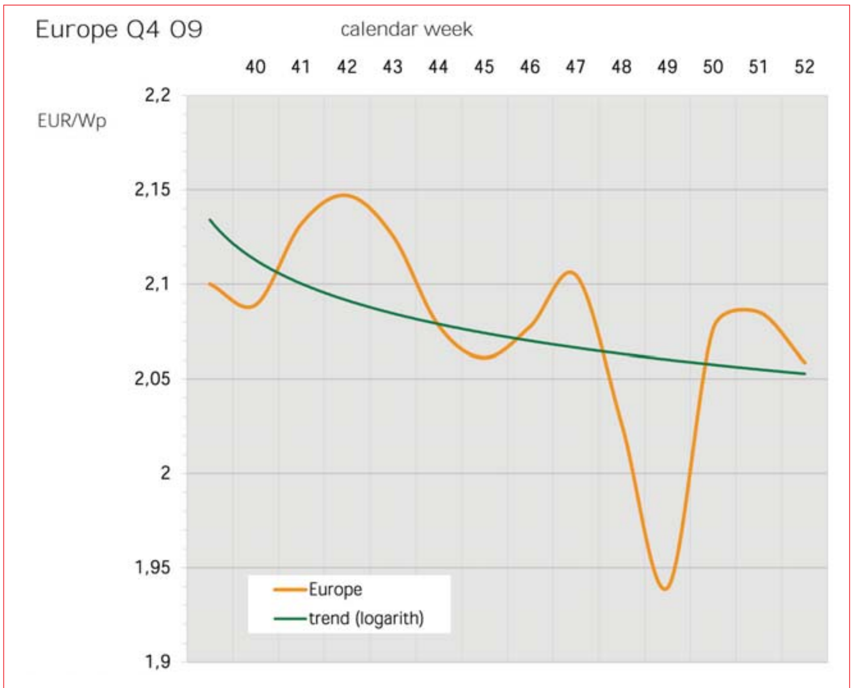

Figure 2. Development of module prices for modules produced by European manufacturers from October to (end of) December 2009.

PV Modules

All's well that ends well?

2009 ended with a newly installed total capacity of between 5.5 and 6.5GW, of which about 3GW was installed in Germany. Overall, it was a difficult year that saw a massive fall in prices of solar modules due to the growing production capacities, the financial crisis and the collapse of the Spanish market.

Last year's winners (from a stock performance perspective) were the large solar suppliers. The stock prices of Roth & Rau, centrotherm photovoltaics and Solar SMA were very impressive, clocking a high export share of up to 90%. These companies' expertise and technology leadership has helped in achieving such a strong growth rate.

The start of the 2010 spot market is showing a small price reduction compared to December 2009. Price development in the short term will mainly depend on decisions of the German government and developments in the new markets of China, India and the U.S.

However, the opinions of solar module manufacturers on the industry's outlook for 2010 are different. Ambitious heavyweights like Samsung and LG Electronics will begin the year with mass solar cell production. Hyundai is focused precisely on the completion of the photovoltaic value chain. Sharp is in the process of jointly building a thin-film solar module factory with the electricity producer Enel Green Power (EGP) and the semiconductor manufacturer ST Microelectronics. Companies with a good market position and strong sales capabilities will be the winners in 2010.

"2010 will bring huge overcapacity throughout the whole value chain, while the mass production will bring further price reductions of solar systems during the year."

In any case, 2010 will bring huge overcapacity throughout the whole value chain, while the mass production will bring further price reductions of solar systems during the year. Only quick movers and heavyweights will survive the strong competition. Newcomers will have to quickly prove that their products can be competitive on the market or face the consequences.

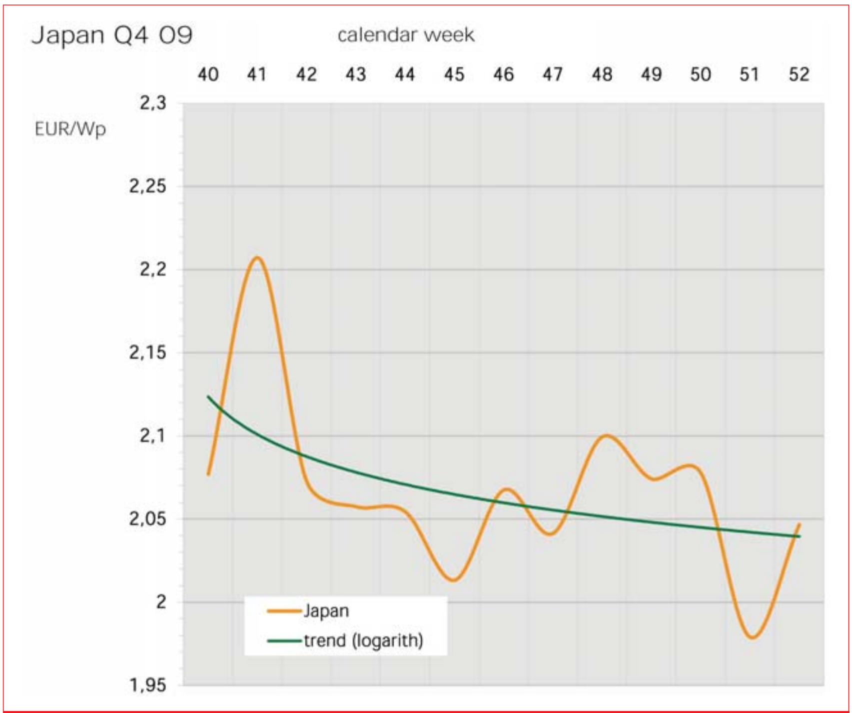

Figure 3. Development of module prices for modules produced by Japanese manufacturers from October to (end of) December 2009.

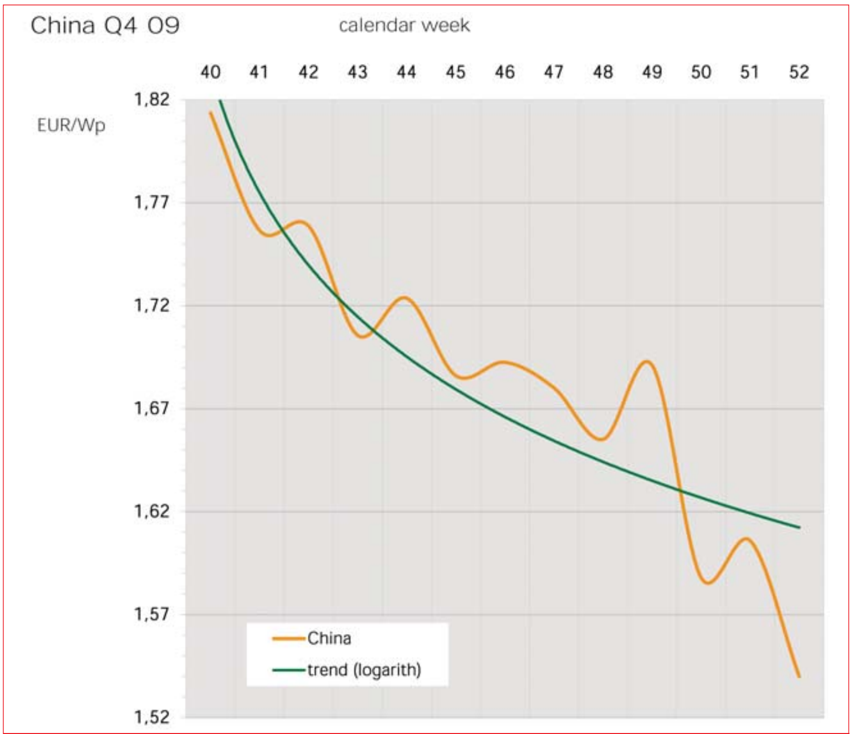

Figure 4. Development of module prices for modules produced by Chinese manufacturers from October to (end of) December 2009.

About the Authors

Founded in Berlin in 2004, **pvXchange GmbH** has established itself as the global market leader in the procurement of photovoltaic products for business customers. In 2009, the company procured solar modules with an output of around 75MW. With its international network and complementary services, pvXchange is constantly developing its position in the renewable energy market, a market which continues to grow on a global scale. Based in Europe, pvXchange also has a presence in Asia and the USA.

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Power Generation

T-Solar uses SunFab for 120MW power plant pipeline

A joint venture called T-SEP has been formed on a 50-50 basis by Global EcoPower and T-Solar to develop solar projects in France, equalling 120MW over the next three years. T-Solar began production of its Applied Materials supplied a-Si thin-film 'SunFab' line nearly a year ago and has an annual capacity of 45MW or 700,000m^2 of modules per year. The move is in response to what the companies claimed were attractive feed-in-tariffs in the country. The power plants to be planned and built will be insured by the German Allianz company. The T-Solar Group operates 28 photovoltaic parks in Spain.

These could be some of the first major projects planned by a SunFab line user, which would potentially see the line reach sustainable full capacity and deliver on the low cost-per-watt goals the technology is expected to deliver. Applied Materials had previously claimed that the large area (5.7m^2) modules offered the lowest installed cost opportunity for utility-scale projects.

T-Solar power plant at La Seca, Spain.

Global EcoPower is developing 36 projects representing a potential installed capacity of 270MW. Most of these projects are in the south of France. The company has a strategy of keeping ownership of half of the projects while selling the other half.

Asia Region News Focus

UL and China's grid authority to partner on renewable energy standards and solar R&D centre

The State Grid Electric Power Research Institute of China (SGEPRI) is to work with Underwriters Laboratories (UL) to advance standards and development practices for renewable energy. Authorized by National Energy Administration, SGEPRI will also establish a National Solar Energy R&D Center, and undertake standards development, testing capabilities as well as technical evaluation, certification and training.

"The application of renewable energy in China is coming to a critical point, so determining how to safely connect photovoltaic (PV) systems to the grid is critical for China," noted Mr. Yi Hu, Vice President, SGEPRI. "By leveraging UL's expertise in product testing and standards development, SGEPRI can further solidify our role as China's primary scientific research and development organization for power grid connections. The alliance gives us the tools we need to develop and achieve a set of world-class standards, testing capabilities and technical evaluation for power grid connections of renewable energy, and paves the way for the application of new and clean energy in China."

The partners expect to roll-out new advanced standards and development practices throughout China while providing training to industry on safety certification, components testing, and equipment calibration and measurement.

Satcon delivers 23MW of its PowerGate Plus inverters to GCL Solar

Satcon Technology has delivered 23MW of its PowerGate Plus 500kW solar PV inverters to GCL Solar for its 20MW Jiming Hill Xunzhou solar plant and its 3MW Yancheng Guoneng rooftop installation.

The Xunzhou solar plant, located on 400,000m^2 of hillside in the Xuzhou City Jiangsu province, is expected to have a power generation of approximately 26,000,000kWh per year and operate for approximately 1300 hours annually, making it reportedly the largest installed solar power plant in China, the companies said.

Esar Solar Power and Fidelis Energy team on 5MW India solar power plant

Esar Solar Power (ESP) and Fidelis Energy will develop a US$25 million, 5MW solar power plant in the Thar Desert near Jaisalmer, India. Fidelis will design and construct a multi-megawatt solar power system. ESP has signed a 10-year power purchase and sale agreement with the state's government-owned power distribution company. The project is scheduled for completion in October 2010.

European Region News Focus

Edison Power Europe exceeds previous year's output by 36%

Edison Power Europe has announced that it produced 36% more power output than the previous year. The accumulated output of all the group's facilities in Switzerland, Germany, Spain and France in 2009 was 5.5GWh, or almost 5% more than expected. The increase in output of 36.4% over the previous year was due to the construction of additional facilities.

Satcon to supply 2.5MW of solar PV inverters to project on island of Rhodes

Satcon has signed a deal with EasyPower to supply 2.5MW of its PowerGate Plus 100KW solar PV inverter solutions across 25 installations on the island of Rhodes, Greece. The solar power plants, which will be developed and constructed by EasyPower, are expected to generate enough solar energy to supply 1.2% of the island's electricity demand. The installations will be owned by EasySolar, RNA Power, and Diachrisi Iliakis Energeias as part of a 2.5MW project, which will be used to provide peak power demand in the summer as well as baseload support to the island's network of diesel generators.

TerniEnergia to construct 10 PV plants in Italy

TerniEnergia has begun constructing 10 solar PV plants in Umbria, Marche, Sicily and Apulia regions for a total capacity of approximately 10MWp. Around 4.5MWp of these installations are for joint venture companies, while the remaining 5MWp are to be set up on account of third parties, of which 3.5MWp are without solar panels supply. The completion of construction works is scheduled for March 2010.

TerniEnergia installation using SolarWorld modules.

GDF Suez signs contract for largest PV power facility in France

GDF Suez has signed an agreement to build the largest PV power facility in France. The energy provider, its joint venture partners and the Mayor of Curbans, Daniel Rolland, signed the Curbans-based project contract together. This project goes towards GDF Suez's 2013 goal of achieving a diversified electricity production base with an installed capacity of 10,000MW.

The project will have an expected output of 33MWp, the system consisting of around 145,000 PV panels producing over 43 million kWh of energy annually. The facility will cover 150 acres at 3,280 feet altitude.

SunPower to buy European project developer SunRay for US$277M, add 1.2GW-plus pipeline

SunPower has signed a definitive agreement to buy European solar power plant developer SunRay Renewable Energy. SunPower will acquire SunRay from its shareholders (which includes management and Denham Capital) for a total of US$277 million – US$235 million in cash, and US$42 million in the form of letter of credit and promissory notes, the companies said.

When the transaction closes, SunPower will add to its portfolio a photovoltaic project pipeline of more than 1.2GW, consisting of sites in various stages of development, in Italy, France, Israel, Spain, the United Kingdom, and Greece.

Amplio completes 6MW of plants with 30MW in the pipeline

The Amplio Group has completed and connected two plants of 1MW each and expects to connect four additional 1MW plants by the end of February 2010. At the conclusion of these installations, Amplio's investment will be approximately €13 million for a total of 6MW of solar plants in the provinces of Foggia and Lecce in the region of Puglia in southern Italy.

These latest projects bring Amplio's total investment in solar in the last 12 months to approximately €33 million, financed in part with equity and vendor finance in order to accelerate construction of the solar plants. Amplio is currently expanding its solar team and is seeking finance for an additional 20-30MW in 2010.

Fluor wins engineering services contract for a new 50MW CSP power plant

Fluor Corp. has won the engineering services contract for a new 50MW concentrating solar power (CSP) plant in Badajoz, Spain. Spanish energy firm Elecnor is owner of the project, which will use parabolic trough technology. Financial terms of the contract were not disclosed. Fluor will provide detailed engineering and other associated services for the project.

The Badajoz project is currently underway with engineering expected to be complete by the second quarter of 2011. Fluor's Asturias and Madrid, Spain, operations will lead the engineering effort with support from its Southern California operations centre. Fluor has been providing front-end support work to Elecnor for this project since early in 2009.

SPI signs sales agreement with Annerher to establish 'Yes! Solar Power' in Spain

Solar Power, Inc. (SPI) has signed a sales representation agreement with Annerher S.L. of Barcelona, Spain to establish 'Yes! Solar Power' dealers based in Spain and Portugal. Annerher will represent the dealer program and sales of the company's 'Yes! Energy Series' residential PV solar products, integrated solutions and SPI's commercial solar solutions. Annerher will solicit dealerships throughout Spain and Portugal in order to distribute SPI's PV solar product lines.

U.S. Region News Focus

PowerVault selected for largest NW utility-scale solar project

PV Powered's PowerVault DC-to-medium voltage turnkey inverter platform has been selected for use in the Northwest's largest utility-scale project to date. The ground-mounted project will begin installation in April 2010 with an additional 5MW of projects to follow later in year. The project is being developed in Lake County, Oregon, near Christmas Valley by the Obsidian Finance Group of Portland, Oregon.

Obsidian Finance will manage the project under a 20-year PPA with a large Pacific Northwest utility. Engineering procurement and construction are being handled by Swinerton management and consulting office, San Diego.

NextLight to start construction of 50MW Silver State PV power plant

Solar power plants located on U.S. Bureau of Land Management land in Nevada are starting to gain approval with the news that NextLight Renewable Power will start construction of a 50MW PV power plant called Silver State, near Primm, Nevada, in early December 2010. NV Energy and NextLight announced a 25-year contract for the purchase and sale of energy from the plant that should see deliveries start in May 2011.

Con Edison proposes development of 25MW of solar installations in New York City

Con Edison has filed a proposal with the New York State Public Service Commission to support the development of 25MW of solar energy resources in New York City by 2015. The company has suggested that the state set aside US$24.8 million of its renewable energy funds for these programs for residential and commercial customers in the city.

The proposed incentives would target smaller solar projects: one provides customers with rebates based on the production of their PV panels, another encourages solar generation in areas where it could provide the greatest benefit to the electric system, while yet another program is designed to facilitate the deployment of solar in the low-income residential market, according to the utility.

SunEdison completes phase one of its 16MW North Carolina solar farm

SunEdison has activated the first phase of its 16MW solar farm in Davidson County, N.C. The first phase of the project represents 4MW of generation capacity and is comprised of more than 14,000 solar panels that will generate over 6 million kWh of electricity in the first year of operation. Duke Energy is buying the farm's entire output under a 20-year PPA.

The farm will generate 115 million kWh of electricity over 20 years and is one of several North American utility-scale power plants that SunEdison has financed and developed, and now operates.

SunEdison's 16MW solar farm in Davidson County, N.C.

Sanyo, InSpec partner for total energy solutions

Sanyo North America and InSpec have formed a partnership agreement aimed at providing total energy solutions for customers seeking to reduce energy consumption and improve the overall efficiency of their facility operations.

As part of this agreement, InSpec has created InSpec Energy Solutions to encourage the adoption of energy efficiency and resource conservation projects, including commercial and utility-scale solar integration, high efficiency HVAC systems and other environmental friendly products. InSpec will evaluate the efficiency of a customer's facility operations and provide solutions that reduce waste and improve cost performance.

Other Region News Focus

esolar PV installation.

eSolar, Ferrostaal join forces to develop CST power plants in Spain, UAE, other countries

eSolar and Ferrostaal have formed a partnership to deploy turnkey concentrating solar thermal power plants in Spain, the United Arab Emirates, South Africa, and other unnamed countries. Under the terms of the deal, eSolar will provide solar field and receiver technology, while Ferrostaal will provide the power block as well as manage the overall realization as general contractor, including financing activities. Financial terms of the agreement and specifics about the individual projects have yet to be disclosed.

The companies cite a range of mutual benefits resulting from the partnership. Ferrostaal adds solar power tower technology to its CST portfolio, which already includes parabolic trough and Fresnel lens components, while eSolar will have a significant global reach through a partner with the experience and financial strength to execute projects rapidly.

Israeli developer Arava Power signs deals to build 100MW of PV plants

Israeli solar energy developer Arava Power has signed long-term deals with 15 agricultural cooperatives to build midsize photovoltaic installations at an investment of 2 billion shekels ($533 million). The power plants will total 100MW and will average 6.5MW per field. Total investment is said to be 2 billion shekels ($544 million).

Arava will install the systems on cowshed and factory rooftops in the signatory cooperatives. The types of modules to be deployed or other balance of system details have not been disclosed. Yosef Abramowitz, president of Arava, told the source that for each of the 15 midsize field locations, the company also plans to install a large-size field, adding another 500MW to its pipeline.

Siemens has invested heavily in Israeli companies recently, putting $15 million into Arava Power late last year to build ten 5MW solar fields and buying Solel Solar Systems in October for $418 million.

ECD, Enfinity join forces to develop, build 10MW of rooftop solar systems in Ontario

Energy Conversion Devices and Enfinity plan to collaborate on the development and construction of a 10MW portfolio of rooftop solar installations throughout Ontario this year, taking advantage of the Canadian province's new feed-in tariff program. ECD said its United Solar Ovonic subsidiary will provide both the Uni-Solar amorphous-silicon thin-film photovoltaic laminates and its new PowerTilt product for the projects.

The rooftop installations will be placed on a number of different roofing materials. ECD claims that PowerTilt is particularly well-suited for the Ontario market, given its easy installation on any roof type, light weight, and higher energy production. ECD will also provide development equity during the construction phase of the projects.

Enfinity will lead the rooftop acquisition from its Ottawa office and will arrange construction debt and take-out equity financing for the projects. Upon commercial operation, the projects portfolio will be sold to the permanent equity owners.

ECD President/CEO Mark Morelli said his company is pleased with the "expanding partnership with Enfinity with the collaboration on this Ontario portfolio. Since announcing the framework agreement with Enfinity last year, thus far we have partnered on nearly 6MW of projects in Belgium and France that are being supplied by our roofing materials channel partners."

"This codevelopment approach in Ontario is a further example of our demand-creation strategy where we will partner on solar projects that have attractive rates of return for project investors. The Ontario Power Authority has demonstrated an impressive commitment to the promotion of renewable energy development and ECD intends to be a major player in the province in the years to come," stated Morelli.

Product Briefings

GE

GE's 600kW solar inverter takes lead from wind turbine capabilities

Product Briefing Outline: Building on a platform of power electronics, monitoring and controls that enhance wind energy grid integration, GE has developed a 600kW solar inverter, which includes grid-friendly features to deliver performance in large-scale solar installations similar to conventional power plants.

Problem: Because the energy output of a solar power plant is directly related to the availability of the sun, anticipating the load that the solar power plant will provide can present a challenge for the utility grid, causing the plant to trip off-line. In order to ensure that solar power plants stay online, providing cleaner, more reliable energy, the variability needs to be managed so that it is more predictable – even during disturbances such as intermittent cloud cover.

Solution: The GE inverter utilizes a two-stage power conversion approach, which provides the output of the inverter at a standardized grid voltage of $480V_{ac}$. This voltage minimizes AC side current, eliminating the need for an intermediate transformer, resulting in higher conversion efficiency compared to a single-stage power conversion system. If multiple converters are connected to a medium voltage grid, a standard medium voltage transformer can be used. Fitted with a robust outdoor-rated enclosure, the GE 600kW Solar Inverter has been designed to perform even in extreme environmental conditions. The GE inverter is certified to applicable UL and CSA standards.

Applications: Large utility-scale power plants.

Platform: GE's SolarRIDE-THRU technology allows inverters to stay on-line during grid disturbances. SolarRIDE-THRU includes Low Voltage Ride Through (LVRT), Zero Voltage Ride Through (ZVRT), and High Voltage Ride Through (HVRT) capabilities. GE's SolarFREE Reactive Power feature provides controlled reactive power through all operating conditions.

Availability: Currently available.

SunLink

SunLink's 'Ground Mount Solution' offers fast-track utility-scale module installations

Product Briefing Outline: SunLink has introduced a new ground-mount system to its family of commercial and utility-scale module mounting products. The new technology joins the company's flagship roof-mount system and the recently released thin-film solution for Nanosolar. Designed as a total system to save on procurement, management, and deployment time, the patent-pending system is available as a ballasted or post-mount solution, making it ideal for a wide variety of installations and situations.

Problem: Utility-scale PV projects require fast installation times to meet fast-track construction schedules. Non-penetrating ground-mounted ballasted systems are an alternative to post-mount systems, which are more costly, especially in installation engineering time.

Solution: SunLink's cost-effective ground-mount product is designed for a wide variety of brown- or greenfield installations, the ground mount is available as either non-penetrating ballasted systems that require no digging or trenching, or as post-mount systems. The low-profile comprehensive design employs tilt angle options ranging from 20 to 40 degrees and advanced system engineering, optimized to minimize environmental impact. By delivering the system on-site with pre-cut, pre-drilled, and pre-welded components, installation time and cost-per-watt are dramatically reduced.

Applications: The ballasted system is ideal for agricultural land, leased land, brownfields, landfills, and even retired airfields that may require system relocation at a later date. There are no footings to dig up if the system or land needs to be reused.

Platform: Low-profile, single-row design reduces ballast required and assembly time. All components are galvanized steel, aluminium or stainless steel, and all edges are coated. Optional locking system reduces theft.

Availability: Currently available.

Sputnik Engineering

Sputnik's MaxWeb xp data logger meets new EEG operational guidelines

Product Briefing Outline: Sputnik Engineering has launched the web-based data logger MaxWeb xp, which records power measurement values, yield data and events in photovoltaic plants and transmits them automatically to the SolarMax web portal. In addition, the data logger also monitors the plant's operation for faults and sends fault signals to as many as three recipients by e-mail or SMS.

Problem: Regulations and requirements in Germany demand that grid operators be enabled to reduce the effective output of large-scale PV plants. On the grid in Germany, access to the relevant PV plants is usually provided by wireless control signals. Since January 2009, the new requirements apply to all PV plants with a connected capacity greater than 100kW or with a grid contact point to the medium-voltage grid.

Solution: Usually the grid operator signals four different output levels. In relation to the rated capacity of the solar plant, this refers to values of 100%, 60%, 30% and 0%. While 100% means no change in output, when output is set to 0%, the plant shuts down. In response to the 30 or 60% command, MaxRemote reduces plant output correspondingly. Unlike the inverters of many other makers, SolarMax inverters do not need an additional interface converter, thus reducing costs. The addition of the MaxRemote option to the expansion port integrated into the MaxWeb xp makes additional external interface converters unnecessary. An easily navigable menu permits the plant operator to give the signal from the wireless remote control receiver unrestricted access to the necessary inverter control commands.

Applications: PV power plants.

Platform: The data logger MaxWeb xp signals the feed-output back to the grid operator via the SolarMax web portal or by e-mail. All the steps are stored and recorded so that the plant operator can trace the relevant events. MaxRemote also makes it possible to meet the grid operator's future requirements such as transmitting commands for the input of reactive power to the connected inverters.

Availability: Currently available.

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Market Watch

Utility solar business models

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ABSTRACT

U.S. electric utilities are beginning to explore participating in the U.S. solar markets in new and unique ways, including utility ownership of solar projects, innovative program designs that purchase solar energy from customers or third-party providers, and providing financing for customer or third-party projects. Known as *Utility Solar Business Models*, these utility innovations are expanding and diversifying the market in new and unique ways, driving hundreds of megawatts of new business, but how these new projects and programs impact the solar value chain and what is driving the change varies from utility to utility. This article lays out the evolving nature of utility engagement with solar markets, defines utility solar business models generally, and explores some of the specific program that utilities are proposing.

To date, the United States' photovoltaic markets have largely been driven by net-metered residential and commercial customer projects, in large part due to federal, state, and utility incentives (see Fig. 1). The rapid growth of the commercial market in particular can almost entirely be attributed to the development of the well-known 'solar-services' business model, also known as the solar performance or the third-party solar model, which began in the early 2000s. In short, the commercial solar market surpassed the residential sector, and in 2008 represented only 10% of the number of installations but well over two-thirds of the annual grid-connected megawatts in the U.S. PV market [1]. This article will provide background information on the U.S. solar markets, and define what a utility solar business model is and the drivers of different model types.

Under the new business model, third-party solar companies own and operate rooftop photovoltaic systems on commercial rooftops and sell the output to the building owners at a long-term, fixed price that is lower than the local electric utility's rates. The customer now pays a portion of their bill to the utility and a portion to the solar company, and over the long-term, hedges the presumed rise in utility electricity rates for the portion that is offset by solar. The solar company uses economies of scale in financing, purchasing, and incentives to drive down costs and provide a packaged solar product at very low risk and up-front cost to the customer.

The traditional customer-ownership model was turned on its head by the new third-party business model, and in the process, the market expanded significantly. In a similar fashion, utility solar business models (USBMs), where utilities become drivers of significant PV developments, are poised to add an additional layer of maturity to the evolving and expanding solar markets. Utility ownership of PV assets is one of the clearest examples of a USBM, with hundreds of new megawatts of PV project deployment having been announced by utilities, but there are a number of other types of models in this emerging market area.

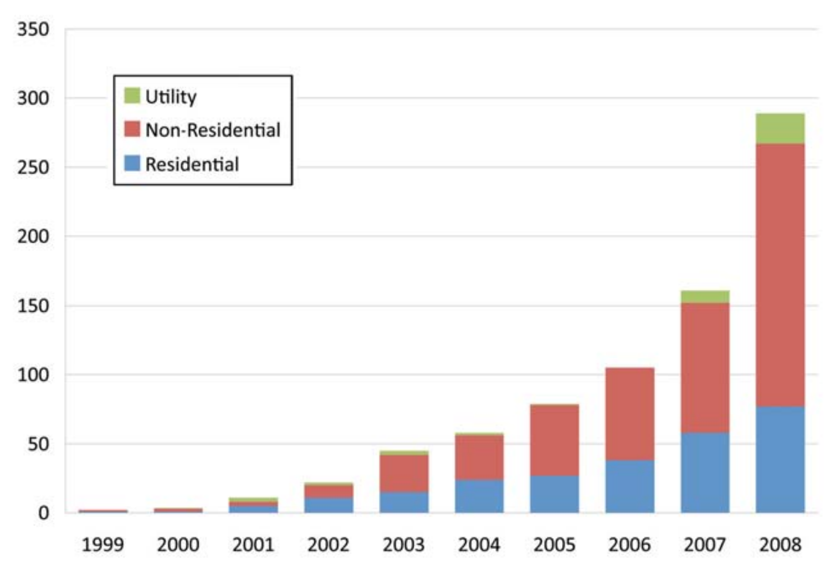

Figure 1. Annual installed grid-connected PV capacity by sector in the United States (1999-2008) [1].

The Solar Electric Power Association (SEPA), a non-profit educational association in the U.S., has been researching and tracking USBMs since 2007 and disseminating the information in a series of reports, webinars, articles, and conference sessions. By educating the solar industry, utilities, policy makers, and stakeholders about these developments, ultimately the industry as a whole can benefit from a better, more proactive relationship with utilities.

Evolving utility engagement in solar markets

It is important to understand the evolving nature of utilities' engagement with solar technologies and markets. SEPA has developed a five-stage framework for categorizing utility solar engagement, which ranges from no engagement to managing customers to utility solar business models (Table 1).

Most utilities have little to no experience with solar, which flows from the heavy concentration of solar market activity in a small number of states (Stage 1). These utilities are located in less active solar states that include some combination of no incentives, no formal solar or renewable policies, and/or low electricity costs. However, as these three disincentive factors change over time more utilities will begin to see inquiries and interest from customers, beginning with residential, small business, educational, or non-profit organizations that are seeking to install a PV system. The utility, sometimes in isolation and at other times in concert with regulators or other stakeholders, develops a basic process for managing these customers (Stage 2). Many utilities spend and lose an inordinate amount of political capital in dealing with individual consumer requests and/or the development of these basic procedures. The stereotype of 'solar versus the utility' often surfaces here as these proceedings are fleshed out.

Stage	Description	Comments
1 None	No solar market activity exists.	Majority of utilities; generally states with no incentives, solar or renewable policies, low electricity costs, and/or smaller utilities.
2 Managing customers	Managing residential and commercial interconnection requests.	Net metering and interconnection procedures and contracts.
3 Facilitating customers	Developing programs or procedures that reduce customer costs, stream line processes, educate consumers, or other methods.	Examples include developing incentives programs or adopting procedural or contractual interconnection best practices.
4 Meeting solar goals or requirements	Internal or external goal or policy requirement, such as renewable portfolio standard.	Utility develops and implements strategic plan for meeting target, often with new focus on utility-scale projects.
5 Developing utility solar business models	Utility adds value to solar markets by reducing costs, minimizing customer burdens, expanding solar access, and/or improving efficiency and integration, through activities that create sustainable, long-term returns for IOU investors and POU communities.	Utility adds value to solar markets by reducing costs, minimizing customer burdens, expanding solar access, and/or improving efficiency and integration, through activities that create sustainable, long-term returns for IOU investors and POU communities.

Table 1. Five stages of U.S. utility solar engagement.

A certain number of utilities will continue to the next stage, where through the leadership of utility management, the dedication of committed employees, or pressure from outside stakeholders or new state policies, the relationship moves from managing customer needs to facilitating customer interests (Stage 3). This could involve the development of a utility incentive program, or the improvement of net metering or interconnection procedures toward industry best practices. At this point, utilities often begin to recognize that solar markets entail long-term impacts that need to be managed more effectively, through a wide variety of possible mechanisms, if for no other reason than to manage utility resources and customer relations.

The next stage – meeting solar goals or requirements, Stage 4 – is triggered by a change in policy, either internally at the utility or externally through state policy or regulations, that moves the utility toward more formalized solar strategies. This occurs most often because of a legislatively mandated renewable portfolio standard (RPS) or similar requirement, sometimes including a specific percentage or quantity requirement for solar resources. A utility will develop a comprehensive portfolio strategy to reach the target, which can include expanding the customer facilitation stage, but also includes the addition of utility-directed solar procurement.

Procurement can take various forms but is most commonly done through traditional requests for proposals (RFPs) and bilateral project negotiations. However, a handful of utilities are also beginning to utilize standard purchase contracts or feed-in tariffs. The formalization of utility activities on both the customer and utility side of the meter to achieve the renewable- or solar-specific goal is a first step in a long-term process that can directly and significantly expand the regional solar market.

The last stage of utility engagement is the development of utility solar business models (Stage 5), which involve innovations that reduce costs, minimize customer burdens, expand solar access, and/or improve efficiency and integration, often within the framework of a solar goal or requirement. To the extent that such innovations add distinctive value in the solar supply chain, utilities should be able to capture some share of that value for their customers and, in the case of investor-owned utilities, for their investors. However, utilities operate in different regulatory environments, under different cost structures, at different sizes and with different resources, and they have diverse internal cultures. Individual utilities therefore approach new technology – the change it represents, and the new opportunities it offers – very differently.

It is worth noting a few things about the progression of utilities through these stages. **First**, each new stage generally expands the market, much like the new opportunities created when the third-party ownership business model emerged. These changes add layers, but do not replace the local solar market. As markets begin to expand, utility staff interacting with solar in some way expands across and up the utility employment structure.

Second, it must be noted that not all utilities will move at the same pace. The diversity of utilities and their business environments ensures a wide continuum of approaches and timeframes for solar engagement. **Third**, while the progression stages reflect past patterns, utilities will not necessarily move from one stage to the next in precisely this order. Florida utilities are an interesting example of this distinction. The customer-based PV market is relatively thin (Stage 2 and 3) and there is no state RPS requirement, but a number of large, centralized projects have been announced and are beginning to be implemented (Stage 4), some of which are utility-owned (Stage 5). The particulars of the political environment, utility decisions, and many other factors can circumvent what could be thought of as an orderly progression.

Fourth, the stages can occur in parallel, e.g., customer activities need not be abandoned in favour of policy-driven procurements or emerging business models. **Finally**, the stages can begin to develop and move quickly, often in response to policy changes that cause ripple effects up and down the progression. There is often, but not always, a lag between policy enactment, utility implementation strategies, and market impacts. A new RPS strategy may include customer, procurement, and business model activities simultaneously, developed in relatively short order, depending on the policy schedule and pre-existing market conditions.

Defining utility solar business models

There are almost 3,300 retail-serving electric utilities in the U.S., consisting of a wide mixture of regulated investor-owned and public power utilities, which include cooperatives, municipals, and utility districts. For example, there are 210 investor-owned utilities – a little over 6% of the total number – but they serve 71% of the retail consumers [2]. In the context of this article, a utility is a retail electric load-serving entity. Holding companies and unregulated subsidiaries of investor-owned utilities may have an associated name and arm's length relationship with the load-serving entity, but their market activities are similar to other competitive entrants into the solar business landscape. Their presence may not be welcomed by solar incumbents, but they are largely free to compete in the market (though usually subject to affiliate transaction rules, and sometimes with significantly greater resources).

A traditional utility, on the other hand, is subject to a significant amount of regulation within a defined service territory by a combination of federal law and regulation, state law, and for investor-owned utilities, by state regulatory commissions. Unlike other businesses, utilities need to balance the interests not only of shareholders or investors (for IOUs), but also those of multiple classes of customers, and of society as a whole. This ongoing process of balancing stakeholder interests puts utilities in a unique business environment, and it is this group of traditional utilities that are the subject of the 'utility' in USBMs under study.

A USBM is a utility's business plan for playing a more integral role in the solar value chain and benefitting its constituents as a result. More specifically it answers questions such as:

Power Generation

- How will the utility create meaningful value in the solar marketplace?
- How can the utility benefit by capturing a share of that value?
- How can the utility sustain its solar business over time?

The utility needs to define how it can reduce costs, minimize customer burdens, improve efficiency, expand access and/or generate profits within the solar value chain – in short, how it can create value. In the early stages of this exploration, this is often done within the context of fulfilling a policy requirement. Later on in the process as solar costs, technology risk, and other factors change, utilities will begin to explore the boundaries beyond what law and policy require, and will see entrepreneurial and profitable avenues for project or program development. The value also needs to be meaningful. High profitability over low gross revenues is not an attractive proposition. Ultimately, the value needs to be sustainable over time or the investment is not worth the effort.

> "High profitability over low gross revenues is not an attractive proposition."

These three business model questions are not necessarily profound. Remove 'utility' and 'solar' and they can be applied to any company looking to develop or expand their business. But while these are apparent to conventional businesses, regulated utilities are both unique due to their regulatory structures and historically less inclined toward entrepreneurial action as a result. However, pressures from industry restructuring, new technologies, and other changes in the modern economy are beginning to implement change in this regard. If distributed solar is wildly successful, it could have a significant impact on utility finances and grid operations. Seeking out cost savings, efficiencies and expanded services today, as well as new opportunities and profits tomorrow, will begin to position savvy utilities for the future, which will simultaneously boost segments of the solar industry with new programs and projects.

In order to be successful, a business model project needs to provide a win-win-win scenario for the utility's owners (i.e. shareholders or citizens), customers (ratepayers), and society (everyone). In the short term, the economic equations may not make sense. Solar's internalized costs may be higher than other generation options for some applications, but in the context of a renewable portfolio standard, legislation can neutralize some cost concerns while markets develop and costs decline. Even if solar costs are greater than other renewable technologies, diversifying the utility's RPS portfolio may have other benefits that lower the risk of non-compliance. Centralized solar projects may be along different transmissions paths, have different siting and permitting issues, or have different overall market delays. Distributed projects can be deployed faster more widely; can buy time and reach customers that larger renewables projects may not; and diversification away from wind-only renewables may have important benefits beyond cost alone.

Many utilities will take a traditional path for compliance by providing incentives to customers and/or issuing RFPs for projects. But these options offer little value for utilities. The costs are passed through to ratepayers and society benefits from the economic and/or environmental components of new technology deployment, but there are no clear paths for utilities to benefit. However, successful utility solar business models offer a 'carrot' or incentive for the utility, which can complement and introduce efficiencies beyond the conventional 'stick' approach. In this way, the models bring new and scaled-up opportunities to the solar industry, benefiting ratepayers and society in the process.

It is also important to point out that although business models often develop in response to policy requirements, other motivators can be at least as powerful. Customer satisfaction, long-term business development, competitive technology costs and other non-regulatory motivations can drive new future USBM opportunities.

Nevertheless, achieving a win-win-win for all key stakeholders is not easy. Developing 'outside-the-box' ideas by utilities, receiving approvals from decision-makers, and working through various issues with stakeholders can be complicated. Diverse utility types, market structures and regulatory environments can limit peer-to-peer transfer and applicability. Over the last two years, SEPA has been working to categorize and track a number of new utility initiatives in this emerging and nascent area.

Utility solar business models

SEPA categorizes and tracks utility solar business models in three areas:

Utility Ownership of solar assets

Utility Energy Purchases from customers or third parties

Utility Financing for customer or third-party projects.

Utility ownership

Utility ownership of solar assets is the most direct change in the engagement of utilities with solar markets in certain states. For investor-owned utilities, owning a physical asset, solar or otherwise, is how utilities make profits as they earn a regulated rate of return on the capital investment. In contrast, purchasing the solar energy from a third party involves only recovering the costs of the purchase from ratepayers.

> "Ownership is most prevalent among investor-owned utilities due to tax incentive structures."

However, some utilities are beginning to explore, have announced plans for, and are implementing owning and operating solar projects directly. Ownership is most prevalent among investor-owned utilities due to tax incentive structures. As municipal, cooperative and other public power utilities cannot utilize tax credits or depreciation directly and relative to third-party ownership, ratepayers would pay increased costs in this instance. There are a number of positive and negative drivers for this recent trend.

Positive drivers

- Earning a regulated rate of return on owning the capital asset
- Utility eligibility for the federal investment tax credit
- Interest in diversifying the risk of RPS non-compliance from delays or cancellations by non-utility project developers
- 'Imputed debt' from power purchase agreements, which may negatively impact a utility's financial balance sheets
- Decreases in solar costs making it a more reasonable investment option
- Different and available tax equity sources than are prevalent in third-party financing models
- Lower costs of capital for financing relative to some third-party options
- Potential to capture value from tax benefits that might otherwise be lost through 'flip' structures that transfer

Utility	Size	State	Status	Description
Arizona Public Service	1.5MW	AZ	Regulatory process	Distributed projects: customer and community sites as demonstration on same distribution feeder; integrating with Smart Grid initiative; participating customers offered 20-year fixed price solar tariff.
Consolidated Edison	1.8MW	NY	On-hold	
Duke Energy	10MW	NC	Implementing	Distributed projects: miscellaneous customer sites; originally proposed as 20MW.
Florida Power & Light	110MW	FL	Implementing	Centralized projects: 25MW PV, 10MW PV, 75MW CSP.
Pacific Gas & Electric	250MW	CA	Regulatory process	Distributed projects.
Public Service Electric & Gas	120MW	NJ	Implementing	Miscellaneous projects: 35MW centralized, 40MW distributed, 43MW community, 2MW low-income.
San Diego Gas & Electric	26MW	CA	Regulatory process	Distributed projects: miscellaneous utility and customer sites; originally proposed as 52MW; additional non-utility-owned project component.
Southern California Edison	250MW	CA	Implementing	Distributed projects: 50MW/yr for five years of 1-2MW PV systems on customer rooftops; additional 250MW non-utility owned projects to be bid out in similar increments.
Tucson Electric Power	10-15MW	AZ	Regulatory process	Distributed projects: 'several' 1-4MW utility or customer sited systems; coupled with fixed-price solar tariff.
Western Massachusetts Electric Company	6MW	MA	Implementing	Distributed projects: miscellaneous utility and non-utility sites; additional future expansions proposed.

Table 2. Sample of utility ownership programs and announcements.

ownership from non-utility investors to utilities after tax benefits have been utilized.

Negative drivers

- Requires approval from regulators; potential negative stakeholder reactions
- 'Normalization' of the federal investment tax credit over the life of the asset, rather than on an accelerated basis (available to competing non-utility developers)
- Regulatory changes to allow non-physical assets, such as energy purchases or financing, to be treated as equivalent to capital investments eligible to earn a return
- For certain utilities, lack of tax appetite to utilize tax credits
- Specific state laws or regulatory environments that prohibit utility ownership of generation
- Utility or regulator assessments that discourage ownership because of real or perceived technology, performance or other risks.

Source: Mike Taylor, SEPA.

Figure 2. Southern California Edison's first utility-owned rooftop project in Ontario, Canada.

Utility	Size	State	Status	Description
Gainesville Regional Utilities	4 MW/yr	FL	Implementing	Distributed projects: customer ownership through a 32 cents/kWh utility feed-in tariff as an alternative to the existing rebate program.
Hawaiian Electric Company and Utilities	16 MW	HI	Regulatory process	Distributed projects: third-party ownership; utility will affiliated lease rooftops for projects and purchase power.
Portland General Electric	TBD	OR	Implementing	Distributed projects: third-party ownership with utility ownership through a 'flip-model' at a later date after incentives are utilized.
Public Service Electric & Gas	30 MW	NJ	Implementing	Distributed projects: customer ownership with utility providing financing to qualified participants; utility earns a rate of return on investment as if a capital asset.
Sacramento Municipal Utility District	1 MW	CA	Completed	Community project: third-party ownership with utility energy purchase; customers can purchase 'shares' of output as 'virtual net metering'; similar programs with other smaller municipal utilities.

Table 3. Sample of energy purchases or financing programs and announcements.

Utilities in a number of states (Hawaii, California, Arizona, Florida, North Carolina, New Jersey, Maryland, Massachusetts, Michigan, Ohio and Illinois) have announced intentions to acquire or now own hundreds of megawatts of photovoltaic systems. These include aggregated distributed systems on the utility side of the meter, and medium-sized centralized systems less than 25MW in size. However, centralized project ownership is very likely as solar system costs decline and ownership risk (technology, performance, operations and maintenance, etc.) is better understood.

Utility ownership represents a significant change to the solar industry. Upstream companies likely view this as a new and expanding market opportunity and may welcome the change. However, downstream companies may perceive a threat to their existing ownership business models. Utilities need to anticipate and structure business model design to manage 'blowback' issues that could arise. The few utility commission proceedings on utility ownership that have been completed have brought up cost and rate impacts, as well as anti-competitive or monopoly concerns from various stakeholders. Commissions need to ensure that competition remains open and fair, but also that utility ownership serves the economic interests of ratepayers, where third-party ownership could be a lower-cost option. Ensuring competitive utility pricing relative to third-party projects can actually effect downward price pressure on both sectors, which is a win for ratepayers regardless of ownership.

Utility energy purchases & financing

Both energy purchases and financing business models have generally been met with less concern from stakeholders, perhaps because the models are more likely to involve direct partnerships with customers or solar companies, but also because they are less numerous. Although less numerous, the models are increasingly diverse, as outlined in the points below.

- Community net metering or tariff projects, where the utility develops a larger-sized system and essentially sells 'shares' in the project that allow customers to offset their consumption directly or pay a fixed-priced tariff based on the output of their share
- Feed-in tariffs that are based on time-of-use or market rates, or that offer more compelling business opportunities relative to a traditional rebate program
- A flip-model between the utility, an investment bank, and site owners; ownership is transferred to the utility after the tax benefits are fully utilized
- Project financing for residential and commercial net metering customers that uses renewable energy credits to repay the loan, and earns the utility a return on its loan investment
- Competitive bidding or auctions for third-party-owned projects that are sited in strategically valuable locations for grid support, smart grid testing, or peak generation benefits.

> "USBMs should be seen as an expanded market opportunity, not a replacement of existing market sectors."

Conclusions

Residential and commercial photovoltaic projects will continue to be important as market segments, but the solar industry is diversifying away from rooftop net-metered projects as its primary economic model. Utilities are beginning to play a part in this diversification. USBMs are very nascent and are being explored through the various social, political and regulatory processes under which utilities operate. In many cases, the projects need to be structured so as to provide involvement with and synergies within the existing solar industry. For many facets of the solar industry, USBMs should be seen as an expanded market opportunity, not a replacement of existing market sectors. While this change is complex, solar companies that see these developments as new opportunities for growth may be the ones that are best adapted to absorbing and profiting from the change.

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About the Author

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BIPV

BIPV News

Inovateus to install Scheuten panels in BIPV projects

Inovateus Solar has become the North American channel partner for Scheuten Solar products. Under the partnership, Inovateus will install Scheuten panels in both residential and utility scale BIPV projects.

Inovateus's first order, to be received in the U.S., is for a 150kW installation in Muskegon, Michigan. Once complete, this will be one of the largest installations in the state. Full Circle Solar will perform the installation for this particular project.

"They have extensive experience in Europe, a trusted name, and perhaps most importantly they have a proven record with European investors that are eager to finance US projects with Scheuten Panels," said Tim Polega, director of engineering at Inovateus Solar.

Scheuten Solar BIPV installation.

Mario Botta-designed building integrates flexible thin-film solar laminates into retractable roof

Italian architectural firm Mario Botta has used 80 UNI-SOLAR PVL-136 thin-film laminates from United Solar Ovonic (USO), a wholly-owned subsidiary of Energy Conversion Devices (ECD) as part of newly completed building design in Piazza San Lorenzo, Italy. The flexible lightweight laminates are part of an 'EnerCover' building integrated solution provided by Ondulit Italiana SpA. The building uses a retractable curved rooftop with an output 10,88kW and is being used for retail, offices and apartments.

"Mario Botta's Gallarate installation is another excellent example of how architects and designers are using the unique properties of UNI-SOLAR laminates within the design of cutting edge architectural designs where typical glass panel products would not work," noted Mark Morelli, ECD's president and CEO. "The end result is a beautiful building with a fully retractable UNI-SOLAR PV rooftop that produces clean energy."

Winsol Energy completes BIPV greenhouse

Winsol Energy Systems, based in Brindisi, Italy, has recently completed a 99kWp BIPV greenhouse. The roof-integrated system includes 450 Winsol monocrystalline silicon WXS220S modules of 220Wp connected to two Bonfiglioli RPS450-60 inverters of 60kW each.

Winsol's 99kWp BIPV greenhouse.

While this is the first BIPV greenhouse designed by the company, Winsol hopes to have 50 similar PV designs by the end of 2010. The majority of the greenhouses will be designed for use within agricultural properties.

Derbigum integrates 1.87MW of ECD thin-film PV laminates on Flanders Expo rooftop

Energy Conversion Devices said that 1.87MW of its Uni-Solar amorphous-silicon thin-film photovoltaic laminates have been installed on the roof of the Flanders Expo in Ghent, Belgium. The laminates were integrated by Derbigum into a lightweight, building-integrated PV Derbisolar product, a durable roofing membrane that forms a waterproof BIPV solar solution.

Derbigum said they chose ECD's laminates because they are light and flexible, there is no perforation of the roofing membrane, they have excellent performance in diffuse light, and are highly damage-resistant since the solar cells are concealed inside a polymer laminate and not glass.

Applied Photovoltaics receives $1.1 million in tax credits

BIPV module manufacturer, Applied Photovoltaics, will receive nearly US$1.1 million in tax credits from the federal government. In addition to designing and manufacturing BIPV modules for custom applications, Applied Photovoltaics specializes in the fabrication of photovoltaic module manufacturing equipment, as well as providing consulting services and PV module sales.

Suntech completes 3.12MW BIPV installation in Shanghai

Suntech has completed two BIPV solar systems on the China Pavilion and the Theme Pavilion of the 2010 Shanghai World Expo. These systems are also connected to the grid and have a combined power output of 3.12MW.

The Shenergy Group, Shanghai, engaged Suntech's system integration team to design, manufacture, and install the two solar systems. The Theme Pavilion involves a 2.8MW integrated solar system comprised of 96 custom-designed triangular sections and covers an area of 31,104m^2. The two systems are expected to generate 2.8 million kWh of electricity annually.

"The use of solar energy systems to power the China and Theme pavilions clearly reflects the spirit of this year's Shanghai World Expo, and its theme, Better City Better Life," said Dr. Zhengrong Shi, chairman and CEO of Suntech. "With the combination of advanced solar technologies and architecture, we can seamlessly integrate solar systems into a building's structure. These promising capabilities will help to reduce the urban carbon footprint and facilitate sustainable development."

Suntech's BIPV installation, China Pavilion, Shanghai.

New Energy Technologies develops 'spray on' solar solution for BIPV applications

New Energy Technologies has reached the next development stage of a process for spraying solar cells and their related components onto glass. This product, while still awaiting patent and in the early stages, is expected to make significant changes to the BIPV market if it proves successful.

"The ability to spray solar coatings directly onto glass follows on the heels of our recent breakthrough which replaced visibility-blocking metal with environmentally-friendly see-thru compounds, and marks an important advance in the development of our see-thru glass windows capable of generating


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electricity," commented Meetesh V. Patel, president and CEO of New Energy Technologies.

"In commercial terms, this new spray technology could translate into important manufacturing advantages for our SolarWindow, including significant cost-savings, high-speed production, and room-temperature deposition – common barriers to commercial success for innovative solar technologies."

Once scaled-up, fully developed, and in possession of a patent, this product will be produced for use in commercial production. The company's researchers anticipate that the ability to spray solar coatings directly onto its SolarWindow, also currently under development, could potentially provide significant commercial production advantages over thin films.

Ascent Solar develops new BIPV product range

Ascent Solar is developing a new range of BIPV products for the U.S. standing seam metal roof marketplace. The material used for this product is being tested and optimized through the existing agreement the company has with EnergyPeak.

Farhad Mogadam, CEO of Ascent Solar, commented, "We are excited to be working with the experienced photovoltaic metal roofing systems provider EnergyPeak. Metal roofing systems are an ideal end market solution of our unique, lightweight and flexible photovoltaic modules. With a short-term total addressable market of 10 million square feet of BIPV per year and long-term 100 million square feet of BIPV per year, EnergyPeak is an ideal business partner for this endeavour."

Both Ascent and EnergyPeak have said that they expect the BIPV CIGS-based products to be processed through the first half of 2010, with the intent to purchase modules for projects in the second half of 2010.

Frost & Sullivan '2009 BIPV niche player of the year award' goes to AES

The Frost & Sullivan '2009 world building-integrated photovoltaic niche player of the year award', has been presented to Atlantis Energy Systems (AES), for its range of BIPV products.

The award is in recognition of the company's initiatives in entering a niche market with innovative solutions, understanding customer needs and providing solutions, blending innovative developments, superior quality, and service.

AES's flagship product, Sunslates, launched in 1998, and is a complete solar electric roofing tile system. It is also currently the only product of its type that offers a roof warranty. AES continues to develop BIPV products through its R&D program.

Installation of Dow Chemical's Solar Shingles on a rooftop.

Dow Chemical reveals site for Powerhouse Solar Shingle production facility

Dow Chemical has announced that Midland, Michigan, will be the site for the first full-scale production facility for its Dow Powerhouse Solar Shingle, subject to finalizing local, state and federal funding.

The Michigan Economic Development Corporation (MEDC) is considering up to US$140 million in economic incentives for the plant. Local, state, and federal funding will also go toward accelerating production plans for the solar shingles already being manufactured in a small-scale market development plant at Dow's Michigan operations in Midland.

The MEDC economic package will add to the US$100 million in investments Dow has already made in the development of solar solutions since the program's foundation in 2007, when the company was awarded a US$20 million Solar America Initiative Pathways Program grant by the U.S. Department of Energy.

"Dow welcomes the opportunity to work with the City of Midland, the State of Michigan and Governor Granholm to secure support for renewable energy technologies, like the Dow Powerhouse Solar Shingle," said Andrew Liveris, Dow chairman and CEO. "Collaboration between government and business is essential to overcoming the challenges facing our society today, including energy, climate change and the creation of sustainable jobs. As the leader in applied chemistry, Dow is well positioned to address the technical challenges of bringing affordable, renewable energy solutions to the market and to be a leader in ushering America into the new clean-energy future."

If the plant goes ahead as planned, approximately 1200 jobs to support the increased solar shingle production will be available in the manufacturing, commercial, and technical areas, with staffing anticipated to begin in late 2010.

Dow's Solar Shingles, which features integrated copper-indium-gallium-(di) selenide thin-film cells, are expected to be available in limited amounts by mid-2010 and projected to be more widely available in 2011 as production scale-up begins.

AmpleSun, Broosha Solar Italia, R&TIA to supply 500kWp to Italy

AmpleSun and partner Broosha Solar Italia have reached an agreement with the Research and Technological Innovation Agency (R&TIA) for the supply of 500KWp of amorphous-silicon thin-film modules ASF Series. The companies will utilize these modules for three BIPV projects. The smallest of the three will be a 40KWp system in the city of Modica, Sicily. The other two plants, each for 230KWp, will be based in the industrial zone of Caltagirone, Sicily.

"We are confident that our decision to utilize the ASF modules for thin-film installations will contribute positively to our image of high-quality system integrator," said Fabrizio Nardo, CEO of R&TIA. "We are aware that thin-film will play a fundamental role reaching grid parity."

Custom BIPV skylight using AES's BIPV module products.

Solyndra teams with flat roofing specialist alwitra

Flat roofing materials specialist alwitra has entered into a long-term framework agreement with CIGS thin-film supplier, Solyndra. Although no details were given to the possible megawatt levels or time-span of the agreement, the partnership would seem obvious, considering alwitra's history and innovations in the reflective 'Evalon' roofing membrane market and its use of flexible thin-film substrates for flat roof applications.

"With alwitra's global presence and their award-winning line of highly reflective Evalon roofing membranes, this agreement builds on the benefits of Solyndra PV installations on reflective commercial rooftops and will expand our footprint in the important roofing channel," noted Chris Gronet, Solyndra CEO and founder.

alwitra's 'Evalon' roofing membrane.

Enel to use 25MW of flexible a-Si thin film substrates on major rooftop installation

Enel Green Power will use flexible amorphous silicon (a-Si) thin-film substrates totalling 25MW on rooftop installations of buildings owned by Interporto Campano and CIS, which both collaborate in the logistics industries. Upon completion in 2010, the projects will become some of the largest PV rooftop installations and the largest using flexible thin film.

The project will be owned by Enel Green Power and is to be built in the town of Nola, in the Province of Naples, Italy on commercial and logistics properties. It will be fully integrated with the existing architecture and benefit from the attractive BIPV FiT program.

"We are very pleased to have reached this agreement with such key organisations as Interporto Campano and Centro Ingrosso Sviluppo Campania. This agreement will enable Enel Green Power to build one of the largest roof-top photovoltaic plants in the world, at a logistics centre of enormous importance to Southern Italy and an example of excellence at the international level", said Francesco Starace, Chairman of Enel Green Power.

Proposed site – logistics centre in Southern Italy.

"With the signing of this agreement with Enel Green Power", remarked Carlo Calenda, General Manager of Interporto Campano, "we have reached the fundamental objective of a substantially neutral energy balance, since the Enel plant can generate about 90% of all the electricity consumed by CIS and Interporto Campano."

Calenda also noted that bids were submitted for the project and chose Enel and the flexible thin film technology because the companies shared a 'strategic vision that goes beyond the individual project.'

News

BIPV: A key element in achieving the PV industry vision

Daniel Fraile Montoro, EPIA, Brussels, Belgium

ABSTRACT

Photovoltaics will play a key role in achieving the European goals against climate change by contributing significantly to the renewable energy portfolio. This contribution will be made through centralized and decentralized PV power plants, in some cases as ground-mounted systems but mainly through Building Integrated Photovoltaic (BIPV) systems. This paper quantifies the European potential of PV in the building environment, gives an overview of the current market and policy situation and presents some of the activities carried out by the European Project SUNRISE. Furthermore, it aims to provide an overview of the possible system applications and offers a wide range of functions that BIPV may fulfil as a building component.

In September 2008, the PV industry unanimously agreed to revise its objective and define a more ambitious target of solar energy covering up to 12% of the European electricity demand by 2020. This requires a number of boundary conditions to be met, for which building-integrated photovoltaics has a key role to play.

The PV industry vision

In March 2007, the European Union adopted an integrated climate and energy policy, putting forth ambitious quantitative policy goals for implementation by 2020. These goals are the reduction of greenhouse-gas emissions unilaterally by 20% from 1990 levels; ensuring that renewable energy represents a 20% share of total energy use – this implies a share of as much as 35% of electricity consumption; and to reduce overall energy consumption by 20%.

The so-called '20/20/20' goals are underpinned by a broader EU policy rationale to promote environmental sustainability and combat climate change, increase the security of energy supply as well as to support the EU economic competitiveness and the availability of affordable energy.

The 'SET For 2020' study [1] was commissioned by EPIA in 2009 to the strategic management consultancy A.T. Kearney. It demonstrates how PV could help in meeting the EU goals and reach up to 12% of the European electricity demand by 2020 if boundary conditions are met. This would represent up to 389GW of cumulative installed capacity.

Among the boundary conditions identified in the study, available roof and façade space represent a key element of PV market deployment.

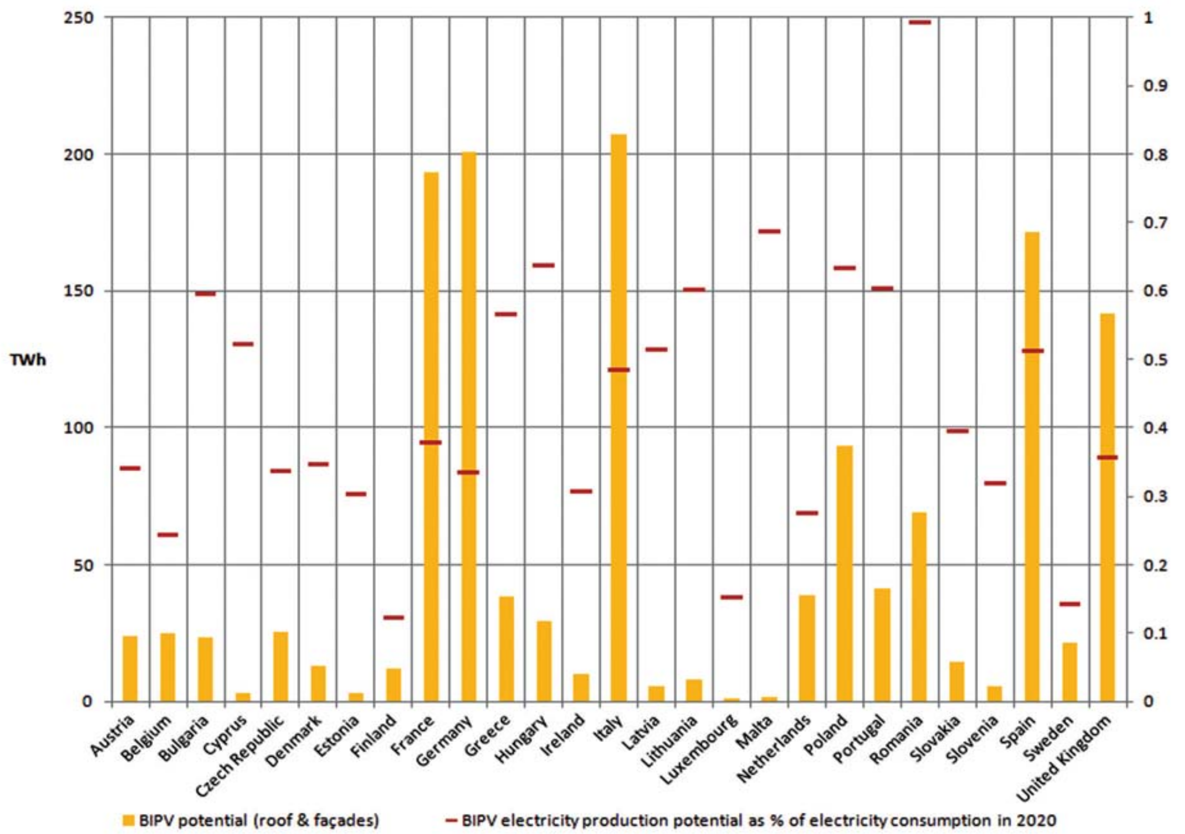


Figure 1. BIPV technical potential by country in the EU-27 [2].

European population	497,659,814
Total ground floor area	22,620.9km²
BIPV potential (roof & façades)	12,193km²
BIPV potential (roof & façades)	1,425 TWh/a
Expected electricity demand in 2020	3,525 TWh/a
Potential share of BIPV in 2020	40%

Table 1. BIPV potential in 2020 in the EU-27 [2].

A large PV potential in Europe

Based on a study from IEA PVPS (International Energy Agency – Photovoltaic Power System programme), EPIA has calculated the size of available spaces which are architecturally suitable for the integration of PV under three assumptions:

- Out of the total ground floor area, 40% for roof and 15% for façades are suited to use for PV applications, taking into account construction, historical and shading elements as well as sufficient solar yield conditions.
- Average ground floor area per capita of $45m^2$ (western/central Europe), which results in a BIPV potential per capita of $18m^2$ of roofs and $6.5m^2$ of façade.
- Average module efficiency of 12.5%.

Considering the current population in EU-27, over 1,500GW could technically be installed in Europe with an annual electricity production of about 1,400TWh. This would represent 40% of the total electricity demand by 2020 – a large potential which would also be true for other continents.

> "The technical potential for BIPV is huge and space availability does not represent any limitation for the growth of photovoltaics."

The methodology hereby used is just one of the many that have been developed in the last few years and the assumptions and results can therefore be discussed. However, regardless of the methodology, the conclusion remains the same: the technical potential for BIPV is huge and space availability does not represent any limitation for the growth of photovoltaics. Not only is this true for Europe, but it is also for very promising PV markets like USA, China and Japan.

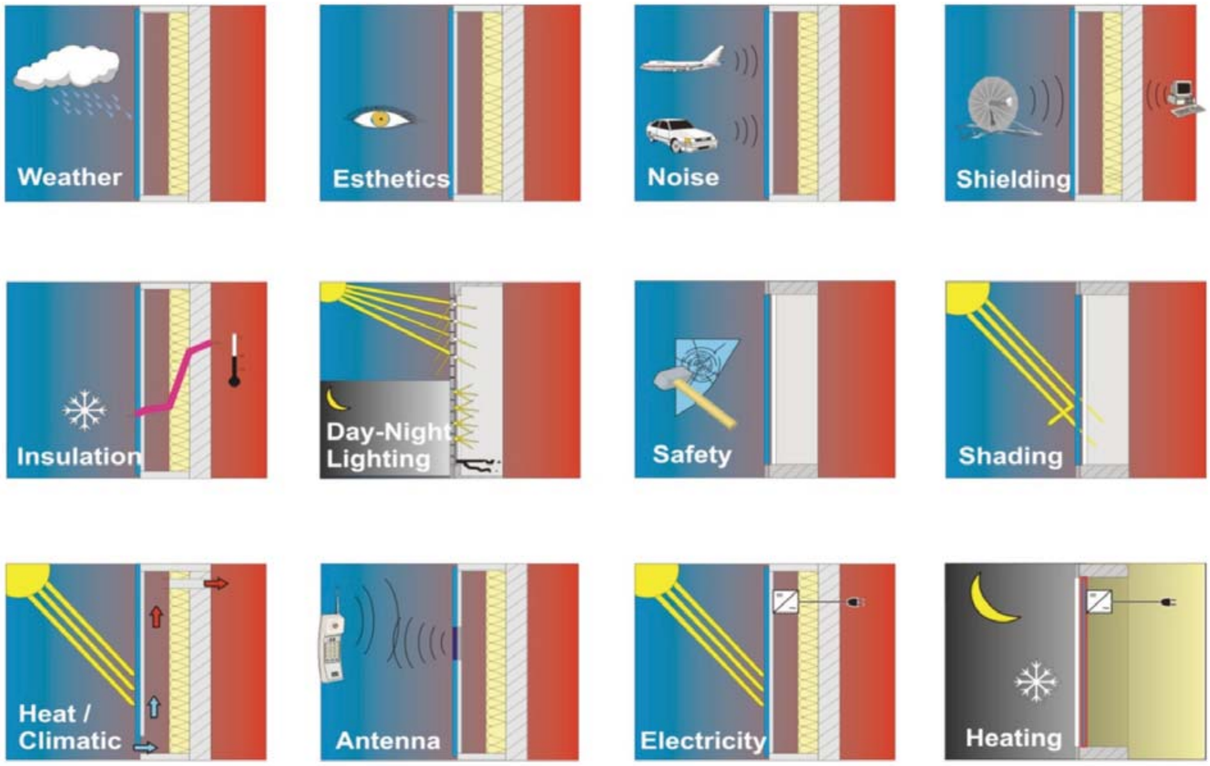
The Sunrise project

Sunrise is a three-year European project which was led by EPIA and conducted together with the International Union of Architects (UIA), the European Construction Industry Federation (FIEC), the European Association of Electrical Contractors (AIE) and WIP-Renewable energies, in close contact with the European Consortium of Building Control (CEBC). It aimed to identify the barriers to the development of BIPV (legal and administrative, technical, perception and market) and reinforcing the cooperation between the PV and construction sectors. In the frame of its mission, Sunrise partners have developed a new evaluation tool for architects to easier calculate the amount of electricity produced by a PV system based on the total module area. More information is available at www.pvsunrise.eu

The BIPV market conditions

National legislation

With this understanding of the great potential in terms of area availability and the capability of the PV industry to keep a steady growth whilst reducing production cost and increasing production capabilities, we need to determine who is going to trigger the demand of BIPV systems.



Courtesy of Fraunhofer IWES.

Figure 2. Multiple functions of PV modules – Project Multielement [3].

At this point it is important to underline the difference between BIPV – where the PV modules are fully integrated in the building structure and fulfil the secondary function of traditional building material as heat insulation, rain protection, shading, etc., and Building Adapted PV (BAPV), where the PV modules are installed on top of the existing building structure and no additional function is provided.

So far, the BIPV market is driven by special support schemes, designed in such a way that BIPV systems are rewarded with a higher tariff per kWh generated than for BAPV systems. This acknowledges the added effort and extra cost of integrating PV as part of the building envelope, particularly in the case of France and Italy where BIPV represents over one third of the annual market. In other countries like Germany and Spain where support schemes have not differentiated between both types of systems, BIPV still represents a very marginal share (<1%) being installed only in those very special cases where cost is not an issue.

European legislation

Looking beyond the current national legislation, the most important European piece of legislation that could significantly affect the deployment of PV in buildings is the Energy Performance of Buildings Directive (EPBD). The EPBD will affect any future construction of buildings in EU-27. It stipulates that any new European building will have to be "nearly zero energy" by 2020, meaning that a very large share of energy consumption will be provided by renewable energy. Solar photovoltaic technologies are amongst the best suited to be integrated in buildings as it is easy and quick to install in housing and has the ability to provide a significant share of the household and commercial energy demand.

The Directive, approved in December 2009 during the Swedish Presidency of Energy Council, still needs to be transposed to national law. EU Member States will have the choice to decide whether this energy needs to be produced on-site (e.g. PV modules or solar thermal collectors) or if it will come from sources not installed in the building (e.g. wind farms). The proper implementation of such a Directive will define the role of PV in future European buildings. The European Community must still work on the definition of such targets for existing buildings, which currently represent about 99% of the building stock.

Strengthening the cooperation between the PV industry and architects

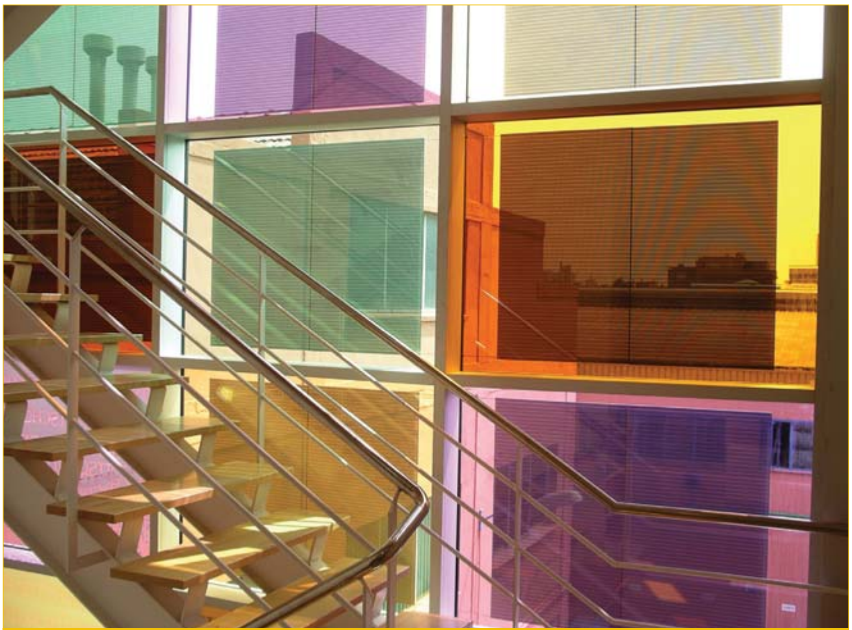
Considering the potential market of BIPV, the construction sector will play a key role in the development of the PV sector. Thus, PV manufacturers need to increase the dialogue and to improve the cooperation with architects, contractors and installers. The objective is to develop the most suitable products which take into account architects' needs in terms of aesthetics

Courtesy of ENEL.

Figure 3. 25KW PV façade for a building's renovation in Cosenza, Italy.

and design and fulfil the needs of builders and regulators in terms of electrical and mechanical characteristics, fire protection and standardized sizes among many others.

Based on this need for an increased cooperation among stakeholders, the European project Sunrise (see box above) has been running for the last three years, understanding firstly the current situation for the development of PV in the building sector and secondly identifying potential solutions to accelerate the diffusion of PV in urban areas.



Courtesy of Architekturbüro Hagemann/Schott Solar.

Figure 4. Semitransparent façade with multicolour thin-film cells in Schott Solar Ibérica SA, Barcelona, Spain.

"PV manufacturers need to increase the dialogue and to improve the cooperation with architects, contractors and installers."

One of the elements that may complicate the cooperation between the PV industry and the building sector is the fact that they use different terminology. At least when it comes to BIPV, the PV industry should adapt to the customs of the building sector. Instead of talking about the installed PV capacity, the predicted annual energy generation in kWh should be communicated as the main figure. The value of kWh is widely spread, which is not the case for the unit kWp outside of the PV industry. Such a transition is neither easy nor straightforward, since the value of kWh/year raises expectations from the user. A standard procedure for this transition needs to be defined that also has to consider various solar cell technologies (crystalline, thin film etc.).

Under the Sunrise project, a toolbox has been developed in order to facilitate the estimation of how much electricity is generated by a PV system without requiring an expertise on PV system technology. Many simulation tools can be easily found in the market for PV system designs and energy output calculations. However, what makes this tool special is that electricity production is calculated based on the module area (m^2) and no longer on the system power (Wp). Furthermore, the user does not need to know the efficiency of the modules or irradiation levels in the location. It has been designed with Excel so it is of easy use and accessible to anyone.

The aim of the tool is to bring PV closer to architects by facilitating their understanding of the technology and presenting its potential. The partners of the Sunrise project have made this as a first step to strengthen the relations between both sectors and assure a bright future for PV.

Courtesy of Isofotón.

Figure 5. PV pergola acting as a skylight in Spain.

It is not all about electricity – BIPV as a multifunctional product

A BIPV system will be integrated successfully if it is incorporated into the building fabric with good design and structure and with a sensible energy concept. Increasing façade performance expectations have led the envelope to become a more complex and multifunctional element of a building. New technological developments allow radical changes to the design of façades and roofs. While designing the building exterior we need to be aware that the use of PV as part of the envelope is important. However, this is only one of a long list of building envelope performance expectations which need to be considered. In order to accomplish all these building performance expectations, PV building products should not only produce electricity, but also be able to fulfil other functions (see Fig. 2).

Furthermore, PV systems can be used as small stand-alone power units. They can be used to regulate the intake of daylight to a building by powering an automatic sun-blind, operate an engine-driven ventilation opening or even as emergency lighting. Another added value of PV is that it acts as a public demonstration of a building owner's green ecological and future-oriented image.

Design possibilities and applications

BIPV is unique; no other innovation allows photovoltaic modules to be built directly into the buildings. The variety of cell types allows great flexibility in construction and the fact that BIPV cells can be colourful means that your wall can sparkle brightly. BIPV modules permit unparalleled creativity as they do not need to be oblong and can be built into, or over:

- **Roofs**. Ideally suited to PV integration. Usually there is less shadowing at roof height than at ground level. Roofs often provide a large, unused surface for integration. A distinction between pitched and flat roofs must be made.

  PV modules can easily be fixed on top of **pitched roofs**. This type of low-cost application is often used for private homes and existing roofs and is known as Building Adapted PV. A more elegant way to integrate PV is to use PV shingles or PV tiles. The PV module is mounted like any shingle or tile and the work can be carried out by a roofing contractor. **Flat roofs** have the advantage of good accessibility, easy installation and provide a free choice for the orientation of PV units.

> "Solar photovoltaic technologies are amongst the best suited to be integrated in buildings."

- **External building walls (façade)**. PV modules can be added to existing walls to improve the aesthetic appearance of the façade and are simply added on to the structure. There is no need to provide a weather-tight barrier as this role is already performed by the structure underneath the modules. PV modules can also be an integral part of the building façade. Glass PV laminates, replacing conventional cladding material, are basically the same as tinted glass. They provide long-lasting weather protection and can be tailor-made to any size, shape, pattern and colour.
- **Semi-transparent façades**. Glass PV laminates can be applied to windows providing a semi-transparent façade. The transparency is normally achieved using either of the following methods:
  - The PV cell can be so thin or laser grooved that it is possible to see through. This will provide a filtered vision to the outside. Semitransparent thin-film modules are especially appropriate for this application
  - Crystalline solar cells on the laminate are spaced so that partial light filters through the PV module and illuminates the room. Light effects from these panels lead to an ever changing pattern of shades in the building itself. The room remains shaded, yet not constrained. Adding layers of glass to the base unit of a semitransparent PV glass module can offer thermal and acoustic insulation, for example.

Courtesy of Tenesol.

Figure 6. Integrated shading system in a façade.

- **Skylights**. These structures are usually one of the most interesting places to apply PV. They combine the advantage of light diffusion in the building while providing an unobstructed surface for the installation of PV modules or laminates. In this type of application, PV elements provide both electricity and light to the building. Modules and support structures used for this type of application are similar to those used in semi-transparent glass façades. The structures, which may be unspectacular from the outside, produce fascinating light hallway walks and floors and allow a stimulating architectural design of light and shadow.
- **Shading systems**. There is a growing need for carefully designed shading systems due to an increase in the use of large window openings and curtain walls in today's architecture. PV modules of different shapes can be used as shading elements above windows or as part of an overhead glazing structure. Since many buildings already provide some sort of structure to shade windows, the use of PV shades should not involve any additional load for the building structure. The exploitation of synergy effect reduces the total costs of such installations and creates added value to the PV as well as to the building and its shading system. PV shading systems may also use one-way trackers to tilt the PV array for maximum power while providing a variable degree of shading.

References

[1] EPIA 2009, 'SET For 2020' [available online at http://www.setfor2020.eu].

[2] EPIA analysis: IEA PVPS Task 7.

[3] Project Multielement [available online at http://www.pv-multielement.de].

About the Author

Daniel Fraile Montoro is a telecommunications engineer and has a Master's degree in renewable energies, specializing in photovoltaics. He has worked for EPIA as scientific officer since 2007, providing advice to the policy department and coordinating international projects for the EC and the International Energy Agency (IEA PVPS). Before joining EPIA, he worked for the Spanish utility Iberdrola in Brussels, where he gained experience in European policies and international cooperation.

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The development and the prospects of BIPV systems in Italy

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ABSTRACT

The current feed-in tariff (FiT) scheme in Italy has so far resulted in a total installed PV capacity just above 760MWp (925MWp considering also the first FiT). The majority of those installations (71%) are building-adapted (BAPV) or building-integrated (BIPV) thanks to the higher incentives provided compared to non-integrated ground-mounted plants. Moreover, there are special premiums on top of the basic FiT, such as when asbestos roofings are replaced with PV modules. On the one hand, this makes the Italian PV market very attractive for those players specialized in roof applications, while on the other, it represents an opportunity and a strong motivation for both the installers and the manufacturers to explore innovative and standardized BIPV solutions and materials. Will this trend continue in the years to come?

From January 1st 2011, a new FiT scheme will replace the current system. ANIE (Associazione Nazionale Imprese Elettrotecniche ed Elettroniche) and GIFI have already elaborated and disclosed a solid proposal that, if fully envisaged by the Italian policy decision-makers, will secure a sustainable growth of all the market segments until the goal of grid parity is reached.

The feed-in tariff currently in force: structure, tariffs and premiums

The Ministerial Decree dated February 19th 2007 defines the rules of the incentive scheme for the electrical energy produced by photovoltaic plants in Italy. It grants a 20-year fixed tariff, which differs according to the size, in kWp, and to the level of building integration of the plant itself. Table 1 shows the FiT scheme valid in 2010.

Moreover, the legislation establishes several rules aimed at adding value to the electrical energy produced by a PV plant, for example the net-metering for installations up to 200kWp of nominal power and the sale (direct and indirect) of electricity in the liberalized market.

On top of the basic tariff, the Ministerial Decree sets a premium of +5% to be awarded to those PV plants fulfilling certain criteria. These criteria mainly favour public institutions such as schools, health institutions and municipalities:

- for non-integrated plants with power over 3kWp, if the owner self-consumes at least 70% of the energy produced by the plant;
- for plants where the owner is a public or parity school or a public health care institution;
- for BIPV plants in buildings and constructions for agricultural use that substitute covers in cement asbestos or containing asbestos;
- for plants where the owner is a local administration authority covering a population of less than 5,000 inhabitants.

The incentives may also be increased if the PV installation is coupled with energy efficiency interventions to the building. The premium, a maximum of 30% of the basic tariff, applies to PV plants that benefit from the net-metering installed in new and existing buildings where the energy performance index is improved by specific interventions.

Results of feed-in tariff in terms of building integration

The Gestore dei Servizi Elettrici (GSE - the Italian electricity services operator) is in charge of granting the FiT and keeps track of all PV installations grid connections nationwide. According to the data made available by the GSE, as of the 31st January 2010, the building integration level of all PV installations can be represented as in Fig. 1.

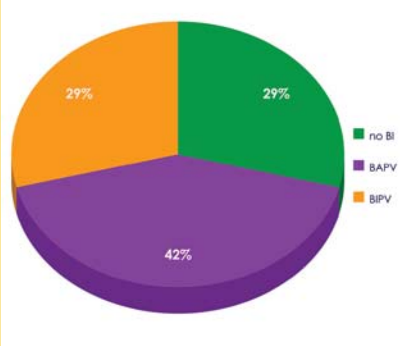

Figure1. Level of building integration in PV plants.

What are the requirements for a PV system to be admitted to the incentives as BAPV or BIPV installations? The GSE has recently updated and published a Guideline for the building integration of PV plants [1]. It represents a unique handbook for those manufacturers, designers and installers willing to develop building integrated photovoltaic

Power (kWp)	Non-integrated	BAPV	BIPV
1 ≤ P ≤ 3	0.384 €/kWh	0.422 €/kWh	0.470 €/kWh
3 < P ≤ 20	0.364 €/kWh	0.404 €/kWh	0.442 €/kWh
P > 20	0.346 €/kWh	0.384 €/kWh	0.422 €/kWh

Table 1. The FiT scheme valid in Italy in 2010.

Owner	Type of installation
Self producer*	Non-integrated with nominal power > 3kWp
Public school	All
Public health institution	All
All	BIPV plants substituting asbestos
Municipalities with up to 5000 inhabitants	All

*Note: a self-producer is a natural or legal person that produces electrical energy and uses over 70% of this output. The label self-producer is not applicable to a subject that benefits from net-metering.

Table 2. Criteria for the +5% bonus as contained in the Ministerial Decree.

systems. This document presents 13 types of interventions, defining minimum requirements, both functional and architectural, that each plant have to fulfil in order to obtain incentives for partial or total building integration.

Types of BAPV installations benefiting from FiTs

BAPV installations in Italy embrace all PV modules mounted on buildings or street structures – such as kiosks, bus shelters and acoustic barriers – without substituting the underlying building materials.

The GSE handbook provides three specific types of BAPV installations:

- PV modules installed on flat roofs and terraces. Those surfaces may have ring elements of different heights. If the height of the ring element (Hr) is below or equal to 50 cm the PV installation has no height restrictions. In case the height of the ring element (Hr) is over 50 cm then the median axis of the PV module shall be always below Hr.
- PV modules installed on top of tilted surfaces (roofs, façades, parapets and balusters) without substituting the underlying material. This is the most common roof installation whereby PV modules have the same inclination of the surface and do not stretch out from the covering lap.
- PV modules installed on top of street structures without substituting the underlying material.

Types of BIPV installations benefiting from FiTs

BIPV installations have similar features to those that fall under the BAPV title. However, in this case, all PV modules completely substitute the covering elements, such as tiles, foil and tin roofings. Generally speaking, in BIPV installations, solar modules must have a dual function, for example waterproofing, protection and thermal regulation or noise reduction.

As for BIPV, the GSE handbook addresses 10 specific types of installations:

- PV modules with the same inclination as that of the tilted surface (roof, façade or sheeting) substituting the covering material and having the same architectural functionality of the surface itself. PV modules should partly or fully cover the tilted surface. From the energy efficiency point of view, the PV installation should not jeopardize the energy performance index of the whole building during either winter or summer.
- PV modules and their mounting structures fully operating as shelters, canopies, arbors or sheds. The design of the installation, especially in regard to the mounting structure and the cable channelling, should not jeopardize the shading function of the whole covering.

Figure 2. Example of BAPV roof installation.

- PV modules partly substituting the transparent or semi-transparent covering material thus allowing the natural lightning of the rooms below. This solution involves the use of both glass/c-Si glass and adequately textured thin-film modules. This solution is particularly suited to 'photovoltaic green houses,' quickly becoming more and more popular in Italy. In order to be certified a BIPV installation, the green house should be permanently ground-fixed and the height of the covering lap should be at least two metres.
- PV modules partly substituting the noise protection modules of an acoustic barrier. In this case the PV modules should be mounted in the upper part of the structure, thus avoiding shading, degradation or breaking effects.
- PV modules powering street lightning devices. As well as general streetlights, this category includes parking meters and advertising plates. Priority is given to lighting devices based on LED technology. However, as the minimum nominal power benefiting from the FiT is set to 1kWp, the application will need to involve an array of street lightning devices in order to satisfy this requirement.
- PV modules and their mounting structures fully operating as shading devices. The PV installation must be mounted in the façade of the building as a shield for the glass surfaces.
- PV modules substituting the covering material of balusters and parapets. These modules should be completely integrated in the supporting structure.
- PV modules partly or fully substituting the glass of windows. This involves the use of glass/glass PV modules, preferably movable, within windows and glass walls.
- PV modules fully substituting the shading elements of blinds/shutters.
- Any of the above mentioned surfaces where PV modules represent the covering formfitting the surface itself. This category is particularly suited to flexible thin-film PV modules installed in any part of the building's covering surface.

When does an installation does not qualify as BIPV?

With these points in mind, perhaps it would be interesting to explain the most frequent design mistakes that can prevent an installation from gaining BIPV status. We will take a look at the first of the 10 installation types just listed (PV modules

Figure 3. Example of BIPV roof installation.

Figure 4. Example of a PV roof installation where the modules exceed the upper line of the roof tiles.

Power classes kWp	Ground-mounted €/kWh (reduction % vs. 2010)	Roof-mounted €/kWh (reduction % vs. 2010)
1-6	0.365 (5%)	0.401 (5%)
6-50	0.339 (7%)	0.375 (7%)
50-200	0.298 (14%)	0.330 (14%)
200-1.000	0.291 (16%)	0.323 (16%)
>1.000	0.277 (20%)	0.307 (20%)

Table 3. ANIE/GIFI proposal for the feed-in tariff after 2010.

with the same inclination as that of the tilted surface (roof, façade or sheeting) substituting the covering material and having the same architectural functionality of the surface itself), which represents the most common roof application.

There are five main errors to be avoided:

- Omitting junction elements such as claddings and flashings for covering both horizontal and vertical discontinuity between the PV module and building elements. This may cause the roof to loose its water resistance and/or thermal properties;
- the positioning of PV modules should fully adapt to the geometric properties of the roof;
- the PV modules should not 'lean out' from the roof;
- the PV module should be positioned no further than its own thickness past the upper line of the tiles.

However, if these 'errors' are unavoidable, the installation can still be qualified as BAPV, thus receiving a minor incentive.

Feed-in-Tariffs after 2010: what to expect?

The current legislation will cease to be valid as of the end of 2010. Will the focus on BIPV remain? The Italian PV Industry Association (Confindustria ANIE/GIFI) has already elaborated and disclosed a solid proposal that, if fully envisaged by the Italian policy decision-makers, will secure a sustainable growth of all the market segments until grid-parity is reached. The basic tariff proposed does not differ from the current one, according to the level of building integration of the PV installation. It refers to only two types of installations: ground-mounted and roof-mounted.

However, the focus on small/medium-sized BIPV installations is preserved. In fact, the association proposes a minor reduction (compared to ground-mounted plants) of a +25% premium for full BIPV systems and a +10% premium for PV modules substituting asbestos roofing. The basic tariff proposed also differs according to the nominal power of the PV system but there are now five power classes instead of three. Table 3 shows the proposed FiT scheme.

Conclusion

BIPV installations are regarded by many experts as the long-term development of the photovoltaic market worldwide. However, in order the keep the adequate balance between all market segments and to secure the production of a large amount of 'green' electricity, utility-scale PV plants should be planned accordingly.

Italy, unlike Spain and the U.S., has a limited availability of land, which is mainly concentrated in the southern territories. At the same time the availability of industrial, commercial and residential roofs is rather large. According to the CNES (National Committee on Solar Energy) report on the potential for PV in Italy, there are, theoretically, 13,000km^2 of roofing surfaces with different levels of solar radiation and sunlight exposition.

In terms of policies, it is evident that the focus of the decision-makers is on roof photovoltaic systems, both BAPV and BIPV. However, in order to achieve a better standardization of PV materials and components, a strong technical collaboration between the building and the photovoltaic sectors is required.

Reference

[1] GSE 2009, "Guida agli interventi validi ai fini del riconoscimento dell'integrazione architettonica del fotovoltaico" [available online at http://www.gse.it/Pagine/default.aspx].

About the Author

Federico Brucciani is the Communication Officer for GIFI, the Italian PV Industry Association based in Milan, Italy. Before joining the association in July 2007, he worked for two years for the Italian Ministry for the Environment as a consultant for European energy policies. He has also served the European Parliament in Luxembourg as an intern. He is the co-founder and the president of the Italian NGO Prorinnovabili and collaborates with Solarplaza, the consultancy firm based in Rotterdam (The Netherlands). He holds a Bachelor's degree in electronic engineering from the University of Pisa (Italy) and from the Technical University of Gent (Belgium).

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Market Watch

UK feed-in tariff announced: payback begins April 1st

The UK feed-in tariff rates have now been finalized, offering residents a financial incentive for producing renewable energy. The government has confirmed the proposed rate, which will begin to take effect from April 1, 2010. Energy and Climate Change Secretary Ed Miliband announced the FiT levels and also published a blueprint for a similar scheme to be introduced in April 2011, which will offer incentives for low carbon heating technologies.

"The guarantee of getting an income on top of saving on energy bills will be an incentive to householders and communities wanting to make the move to low carbon living… The feed-in tariff will change the way householders and communities think about their future energy needs, making the payback for investment far shorter than in the past," said Miliband.

From April 1st, householders and communities who install solar photovoltaic panels of up to 5MW will be paid for the renewable electricity they generate, even if they use it themselves. The level of payment depends on the technology and is linked to inflation (see table). Renewable electricity generators will get a further payment for any electricity they feed back into the grid. The announced scheme will also apply to installations commissioned since July 2009 when the policy was first announced.

Technology	Scale	Tariff level for new installations in period (p/kWh) [NB tariffs will be inflated annually]			Tariff lifetime (years)
		Year 1: 1.04.10-31.03.11	Year 2: 1.04.11-31.02.12	Year 3: 1.04.12-31.03.12	
PV	≤4 kW (new build)	36.1	36.1	36.1	25
PV	≤4 kW (retrofit)	41.3	41.3	37.8	25
PV	>4-10kW	36.1	36.1	33.0	25
PV	>10 - 100kW	31.4	31.4	28.7	25
PV	>100kW - 5MW	29.3	29.3	26.8	25
PV	Standalone system	29.3	29.3	26.8	25

Tariff levels for electricity financial incentives (note: this tariff is available only for 30,000 microCHP installations. A review will take place when 12,000 units have been installed).

Ed Miliband, UK Energy and Climate Change Secretary.

Under the terms of the FiT system, Ofgem will administer the FiT scheme and suppliers will be responsible for paying the reward to their customers. These incentives will be available to UK residents from April 2010. Private customers are also eligible for income tax exemption.

All installers in the UK will need to be registered under the Microgeneration Certification Scheme, which ensures that policies and procedures meet the requirements of the scheme and that the work that has been undertaken is consistent with the system design. This scheme is open to companies involved in the supply, design, installation, set to work and commissioning of microgeneration systems and technologies. Details of the funding for the scheme will be published in the UK Budget 2010.

Domestic Japanese solar sales reach 484MW in 2009

The reintroduction of subsidies and a new feed-in tariff introduced in November 2009 helped to more than double solar sales in Japan in 2009, compared to the previous year. According to the Japan Photovoltaic Energy Association, sales reached 483.96MW in 2009, up from approximately 230MW in 2008. Japanese PV solar cell and module manufacturers also increased exports to the U.S., which were up 21% compared to the previous year, reaching 203.17MW in 2009. Despite being the largest export market for Japanese producers, solar cell and module sales in Europe actually fell by 4.3% to 624.25MW with total shipments reaching 1.143GW.

Monocrystalline shipments of 576.5MW topped the cell type technology categories. Multicrystalline cell shipments reached 419.4MW, while a-Si thin-film shipments reached 120.3MW in 2009.

EPIA had forecasted installations in Japan would reach 400MW in 2009, while Photon Consulting has projected installations to reach 700MW. Sales figures reported by the JPEA are for shipments, not installations, but reflect potential installation figures.

Alstom and Schneider Electric launch new venture capital fund

Alstom and Schneider Electric have partnered to launch a new venture capital fund to finance innovative start-ups in the fields of energy and the environment. The joint venture remains open to the participation of other potential partners.

The fund, Aster Capital, is based in Paris and will progressively receive a capital subscription of €70 million, comprised of €40 million from Schneider Electric and €30 million from Alstom.

Aster Capital's mission is to take minority interests in pioneering start-ups based in Europe, North America and Asia, developing new technologies that could lead to major breakthroughs in the fields of energy and the environment. The two founding partners share the aim to support the development of eligible companies and to look after cooperation and partnerships for their respective markets.

JinkoSolar files for US$100 million IPO

JinkoSolar has filed for an initial public offering with the U.S. Securities and Exchange Commission for up to US$100 million. The company said that proceeds would be used to expand the manufacturing capabilities, for research and development, and for working capital.

JinkoSolar posted revenue of 880 million yuan (US$128.9 million) in the nine months ended September 30th, 2009. This figure is down 42.8% from the same period the year before. It posted net income of 1.72 million yuan, compared with 179.2 million yuan a year ago. The company also posted a 36.5 million yuan loss on the fair value of derivatives in the nine months; this is compared with a 204,000 yuan gain in the same period a year earlier.

Solar and Solyndra top venture capital funding in 2009, says Cleantech Group report

According to new figures from the Cleantech Group and Deloitte, VC investments in companies in the solar sector reached US$1.2 billion or 21% of the share in 2009, making it the largest 'Cleantech' sector for investment. Clean technology venture investments in North America, Europe, China and India totalled US$5.6 billion in 557 deals. However, as these figures are preliminary, the firms expect the final figures could be up by as much as 10%.

"Utilities continue to bring their capital and access to credit to the cleantech sector and are playing a key role in getting more projects off the ground. In 2009 we saw a surge in utility Power Purchase Agreement (PPA) announcements with Solar Thermal and Solar PV accounting for 80% of the total PPAs, while Wind saw increased capacity announcements in the second half of the year aided by the extension of the production tax credit," said Scott Smith, U.S. Clean Tech leader for Deloitte. "Additional project financing came from large corporations whose direct investments in cleantech increased by 14% in the second half of 2009 compared to the same period in 2008. Leading global utilities and non-utilities are likely to continue to see cleantech projects as an attractive investment from an economical and regulatory perspective."

Venture investment was down 33% in 2009, compared to US$8.5 billion in 2008, yet investment in clean technology declined less than other sectors, despite the economic recession. Solar investments in 2009 were down 64% from the previous year, according to Cleantech Group, while investment in 4Q09 (of US$187 million) was a new three-year low for the sector.

The largest deal in all sectors was Solyndra's US$198 million to expand its CIGS thin-film production. The company has since filed for an IPO.

Colexon Energy secures €21 million credit commitment

Colexon Energy has secured a credit commitment of €21 million from the many banks it holds a relationship with. The credit facility, which has a running time of up to four years, will be utilized for working capital, financing project acquisitions and capital expenditure.

With this corporate working capital facility in place, the Colexon group enhances its financial power and has secured financial flexibility and sufficient funds to support its planned growth for the future.

Italian market PV installations disappoint in 2009

Preliminary figures from Italian government agency GSE for solar module installations in Italy for 2009 indicate that the surge late in 2008 was not replicated in 2009. PV installations reached 374MW in 2009, up only 10% from 2008 when 338MW was installed and connected to the grid. The Italian market had often been touted as becoming a major market in 2009, due to the attractive FiT and high cost of electricity in the country, enabling solar to reach grid-parity earlier than in most other European countries.

Installations actually peaked in July 2009 at 40MW, only recovering to that level in October, before falling in November. In December, installations only reached 37MW, significantly below the 136MW installed in the same month of 2008. A problem that some PV manufacturers and project developers had previously noted with the Italian market was bureaucratic delays in obtaining grid connection.

The EPIA had projected installations in Italy to reach 500MW on a 'policy-driven' scenario and 400MW in a 'moderate scenario.' Photon Consulting had projected much more aggressive levels. In its 'Solar Annual 2009' report issued late last year, the market research firm projected installation to reach 900MW.

ReneSola pulls plug on Dynamic Green Energy acquisition

Billed as a fast-track way to build its OEM wafering business and add to its integration efforts, ReneSola has now been forced to terminate its plans to acquire Dynamic Green Energy, which operates through its wholly owned subsidiary Jiawei. ReneSola said that local Chinese government agencies where Jiawei is located had not approved the acquisition, which was a condition in the purchase, without saying what the objections to the deal had been.

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

"Despite the termination of the Jiawei acquisition, ReneSola's downstream strategy remains intact and we continue to witness impressive organic growth in our JC Solar cell and module business," said ReneSola's Chief Executive Officer Li Xianshou. "We are still in a strong position to leverage our wafer manufacturing capabilities and deep customer relationships to quickly expand our downstream business. We expect to see significant top-line and bottom-line growth from our downstream business in 2010."

SolarWorld's Hillsboro, Oregon facility.

SolarWorld tops €1 billion in sales for 2009

Although full financial figures will not be released until late March, SolarWorld has said that provisional results for 2009 passed the €1 billion level for the first time at approximately €1,010 million. The company noted a high demand for branded modules across its major markets, which include Germany. SolarWorld posted revenue of €900.3 million in 2008.

However, the company is waiting for greater visibility into the pricing environment for 2010 and possible further FiT changes in the German market before giving guidance on its revenue forecast for 2010. Despite the current concerns, SolarWorld said it would press ahead with capacity expansion plans and investments in technology to meet expected demand.

Renesola's production facility.





SET FOR 2020

Solar Photovoltaic Electricity:
A mainstream power source in Europe by 2020

Conducted by the European Photovoltaic Industry Association (EPIA) with the strategic management consultancy A.T. Kearney, SET For 2020 delves deeper and is more comprehensive than any other existing study on PV in Europe.

Following an intensive and broad-based analysis of existing data as well as interviews with around 100 key people in industry, research institutes, utilities, regulatory agencies and governments across Europe and other parts of the world over the past months, it provides a unique, wide-ranging combination of facts, figures, analysis and findings, and outlines how photovoltaics can become a mainstream energy supplier in Europe by 2020.

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European Photovoltaic Industry Association

Proposed German feed-in tariff changes highlight PV industry dependency

Mark Osborne
Senior News Editor
Photovoltaics International

The proposed changes to the German Renewable Energy Act (EEG) by the new government have caused great concern to the PV industry, not only in Germany but around the world. As the largest single market in 2009 after the collapse of the Spanish market in 2008, Germany has become responsible for at least 40% if not closer to 50% of all installations in 2009. Official figures from Germany's 'Bundesnetzagentur' (German Federal Network Agency) show that total installations had reached 2.34GW through the first 11 months of the year, with many forecasts pointing to a total of approximately 2.7 to 3GW being reached.

Photovoltaics International has been watching the controversy unfold since the proposals for an extra 15% average cut in the EEG was proposed. From the initial shock, then to a possible compromise on the cuts, through to the announced delays in its implementation to June 1st compared to April 1st, this compilation update is intended to provide an accurate position of the debate and important development so far revealed.

When did it happen?

10th December, 2009
Environment Minister, Norbert Roettgen warned that FiT cuts would be made.

15th January, 2010
Landesbank Baden-Wurttemberg (LBBW) report and the BSW-Solar statement claims that a reduction in FiT rates in double-digit percentage range would not only harm the German solar industry, with company bankruptcy and thousands of lost jobs.

15th January, 2010
Under pressure from the German PV industry and certain states, politicians became more conciliatory to less than 'aggressive' changes.

19th January, 2010
Economics Minister Rainer Bruederle was reported as saying, "the German government could realistically cut between 16% and 17%."

20th January, 2010
BMU announced official changes were proposed for the EEG. (Rooftop: From April 1. -15%, Free field: From July 1. -15% and Free field 'pure farm' and 'Valuable land': -25%).

21st January, 2010
iSuppli forecasts impact of Germany's FiT cuts in 2010.

25th January, 2010
Market research firm Gartner fears thin-film solar fallout from tariff changes.

29th January, 2010
Norbert Roettgen wants to delay his proposed 15% cuts until May 1st.

4th February, 2010
German Solar Industry Federation (BSW-Solar), organises demonstrations across Germany.

4th February, 2010
The International Photovoltaic Equipment Association (IPVEA) recommended 'measured and predictable steps relating to changes in the EEG.'

9th February, 2010
Hans-Peter Friedrich, parliamentary group leader for the Christian Social Union (CSU), the Bavarian sister party to Chancellor Angela Merkel's Christian Democrats (CDU) announced a delay in the tariff cuts to June 1st, compared to April 1st. Rooftop EEG would be cut by 16% from June 1st.

17th February, 2010
Fraunhofer ISE study supports a 6% German feed-in tariff cut but higher cuts jeopardizes PV industry.

What will the impact be on the German PV industry?

The proposed double-digit cuts are regarded by the German Solar Industry Federation (BSW-Solar) to be too aggressive, which would cause a drastic decline in demand. Thousand of jobs would be lost as companies downsized and many going out of business altogether. Manufacturers would lose market share to lower cost producers from Asia.

The study conducted by the Fraunhofer Institute for Solar Energy Systems (ISE) believes that the proposed cuts would jeopardize the entire PV manufacturing industry in the country. A 6% extra reduction would be achievable without significant disruption to the industry.

The report noted that the system prices for solar installations had actually declined greater than the manufacturing costs. This was due to the excess capacity in the market at the beginning of the year, coupled to weak demand as the global financial crisis reached its peak.

However, one of the largest PV system integrators, Phoenix Solar, believes that continued material and product cost reductions would provide the necessary return on investments required to keep the German market strong in 2010, though acknowledged there would be disruptions to the industry.

"There will be changes. We want to introduce the free market and not provide existence guarantees for participants. It'll be a boost for technology."

Norbert Roettgen
German Environment Minister

"Our calculations show that for solar power plants to 30 kilowatts of peak power, a single additional drop of six percent would be appropriate, for installations up to 100 kilowatts a ten percent cut would be appropriate. The proposals of the Environment [Ministry] are far above and would jeopardize the massive solar production industry in Germany."

Prof. Eicke Weber
Director, Fraunhofer ISE

"Germany's decision to cut its solar subsidies in the second quarter will make installations less attractive for the country's consumers. Because of this, German consumers will rush to make solar installations in the first half of the year and then stop in the second half. As a result, iSuppli anticipates the German market will overheat during the first six months of the year and then collapse during the next three months."

Dr. Henning Wicht
Senior Director and Principal Analyst iSuppli Corp.

"That would be very short-sighted – it is precisely in these states [former East Germany] that an implementation of the plans would foolishly jeopardize the market position we have achieved and thus put many jobs on the line. There is bound to be a slowdown in rooftop systems in Germany as well. We are well-positioned internationally, so that we can compensate for this with our sales in other countries."

Dr. Karl Kuhlmann
S.A.G. CEO Solarstrom

EPIA's Photovoltaic Observatory: an in-depth analysis of feed-in tariff schemes

Gaëtan Masson, EPIA, Brussels, Belgium

ABSTRACT

The vital importance of the regulation framework to trigger the development of a PV market has been recognized these last few years in many European countries. For policymakers today, one of the key challenges is making the best choice to initiate and stimulate PV markets. In the aftermath of the financial crisis, EPIA has launched the PV Observatory initiative. This paper describes this new initiative, which aims at analyzing the current state of regulatory frameworks in a set of countries, starting with the main European PV markets.

The PV Observatory Policy Report becomes available in February 2010, and concentrates on identifying the best practices among various policies implemented across Europe in recent years. Three major areas of policies impacting the development of PV markets are assessed: the financial support schemes (with a clear focus on the most effective system: the feed-in-tariffs, or FiTs), the administrative processes and the grid connection.

The 'sustainable PV market development' recipe results from an appropriate combination of these three policy areas. The best support scheme will not trigger any substantial development if the administrative barriers discourage investors or if the grid codes do not favour electricity from renewable sources. The other way round, the best administrative framework will never trigger any development without an appropriate financial support.

In summary, EPIA's Photovoltaic Observatory Policy Report analyses all the elements of this global recipe to present the best practices extracted from the most relevant European PV markets.

Feed-in-Tariffs pave the road to market development

First of all, it is of utmost importance to remember that feed-in-tariffs should be used only during a temporary pre-competitive period, i.e. the period before grid parity is reached. Approaching grid parity, and beyond, other support mechanisms should be put in place. Tariffs allow the market to develop and the industry to decrease PV costs, as was clearly demonstrated in the past years. In a few years' time, investment costs will be low enough to be paid off without the need for the support of any feed-in tariffs.

Assuming the temporary measure status of feed-in-tariffs begs the question: what parameters do authorities have to consider when setting up such a financial incentive?

The first thing to consider is what type of market authorities wish to develop: large-scale ground mounted PV systems, distributed rooftops or building-integrated solutions, or a mixture of each. The structure of the tariff segments and the level of the feed-in tariffs will depend largely on this primary decision. The choice will depend on policy choices as well as the market structure: small households' rooftops and large ground-mounted power plants do not require the same investment and installation capacity. In times of uncertainty regarding the financing of investments, diversification remains the key word for PV segmentation. Nevertheless, the specifics of each country (geography, grid topography, other policy choices...) will finally prevail in shaping the segments.

"The feed-in tariff is often not the only support measure available for PV and is often combined with other financial instruments."

What is the best tariff level?

Proper support design is a crucial task for policymakers as it shall guarantee a sustainable PV market development, thus permitting consistent market growth, national value chain development, but also preventing possible speculation when financial returns are excessively high.

As a matter of fact, the feed-in tariff is often not the only support measure available for PV and is often combined with other financial instruments such as soft loans, fiscal incentives and beneficial credit terms, made available either at national or regional level. The combination of these instruments determines the overall financial attractiveness of the PV investment.

Using the Internal Rate of Return (IRR) is a rigorous analytical way of comparing the level of PV support across countries. It allows the synthesis of the financial support provided by different mechanisms in one single figure and the assessment of its appropriateness. Regarding the private investors' perspective, the IRR is considered as 'sustainable' when within it falls between 6% and 10%. Below this range, IRR is considered too low to ensure an adequate market expansion; above this range, IRR is considered too high, as it creates a risk of market overheat. For business investors, the recommended IRR values should be slightly higher as shown in the Table 1.

Therefore, a very important criterion to define the level of the tariff is to make sure it is sustainable in the long run. Using the IRR analysis is the best way to help qualify best practices and assessing the quality of a support scheme.

Potential issues with FiTs?

Behind the feed-in-tariff lies the idea that the market will develop if private and institutional investors consider PV as a competitive investment. Meanwhile, money is not the single aspect of the decision and investors may decide to overreact for psychological reasons. The financial crisis that forced governments all over the world to support the banking world could have triggered an appetite for PV in some countries (as a stable and

Evaluation logic	Insufficient support	Sustainable support	Unsustainable support
Private investor	<6%	6-10%	>10%
Business investor	<8%	8-12%	>12%

Table 1. Recommendations for financial support levels provided by IRR.

Source: PV Observatory Policy Report, EPIA.

predictable investment) and destroyed the market in others. Moreover, the fast price decline that was experienced in 2009 challenged some markets as well by doping the demand.

As we have seen before, the support scheme is not intended to last forever. Its goal consists in supporting market deployment during PV pre-competitive phase, progressively being phased out once grid parity is reached. In this way, control methods can be used to keep the market within reasonable boundaries.

Unsustainable market growth

What kind of growth can a country's market sustain? We define sustainable growth as the development process that will allow industry, including local market players, to grow continuously, creating long-term employment and added value in the country itself. The installed capacity must remain in line with the capabilities of the installers and producers, as well as the investors. The graph in Fig. 1 represents three different growth scenarios. In the first scenario ('insufficient'), IRR is too low to generate market demand and leads to market stagnation. The second scenario ('sustainable') shows that market growth rate progressively increases as IRR increases; the third scenario ('unsustainable') shows an overly generous IRR resulting in an explosive growth followed by a market collapse.

This situation, without recovery of the market after the bubble's explosion, reflects that the confidence of all stakeholders could be destroyed for a long period of time due to an inadequate management of the growth. We assume that overly generous IRRs can provoke an explosive growth in a short period of time (a few months) when all other conditions of development are met.

The very principle of feed-in tariffs is that they do not cost money to the government budgets. The feed-in tariff concept bases itself on a repartition of the added PV costs across all electricity consumers. Therefore, the taxpayers' money is not impacted while a redistribution mechanism is built inside the electricity market itself. The global cost of this mechanism can be limited using a predefined market CAP. This solution brings a theoretical maximum extra cost to the electricity bill, but it also constraints the market; today in Europe no example of a market, truly constrained by a fixed CAP, has led to a successful sustainable PV deployment.

> "The feed-in tariff concept bases itself on a repartition of the added PV costs across all electricity consumers."

The self-regulated method relies on defining upper and lower boundaries in terms of market volumes. A predictable increase or decrease in the attractiveness of the financial support (for instance in reducing or increasing FiT digression rate) will allow stimulation, or on the contrary, moderation of the market growth if boundaries are crossed downwards or upwards. This method, when used with caution and reasonable assessment periods, can be considered as the best practice.

Stability and predictability

Stability in time and predictability of future tariffs is an essential component to ensure the investor's confidence. In 2009, the rapid price evolution rendered obsolete almost all of the calculations made at the beginning of the year. A good regulation implies forecasting such changes and being able to adapt the feed-in tariff accordingly. Otherwise, given the average time to decision, the level of uncertainty felt by investors can threaten the market growth. Therefore, we strongly recommend avoiding a *stop & go* policy, which works to the detriment of the sector.

Two points must be taken into consideration:

- The uncertainty about the tariff evolution can lead investors to anticipate or delay their investment, causing a market overheating or a market collapse. Authorities should clearly anticipate the price variations and communicate in due time their intentions.
- Rapid price evolution can transform an adequate tariff into an unsustainable one. Regular assessment and adaptation of the support level should be foreseen to ensure IRRs of support schemes actually reflect system prices' evolution and remain at all time within the predefined sustainability range.

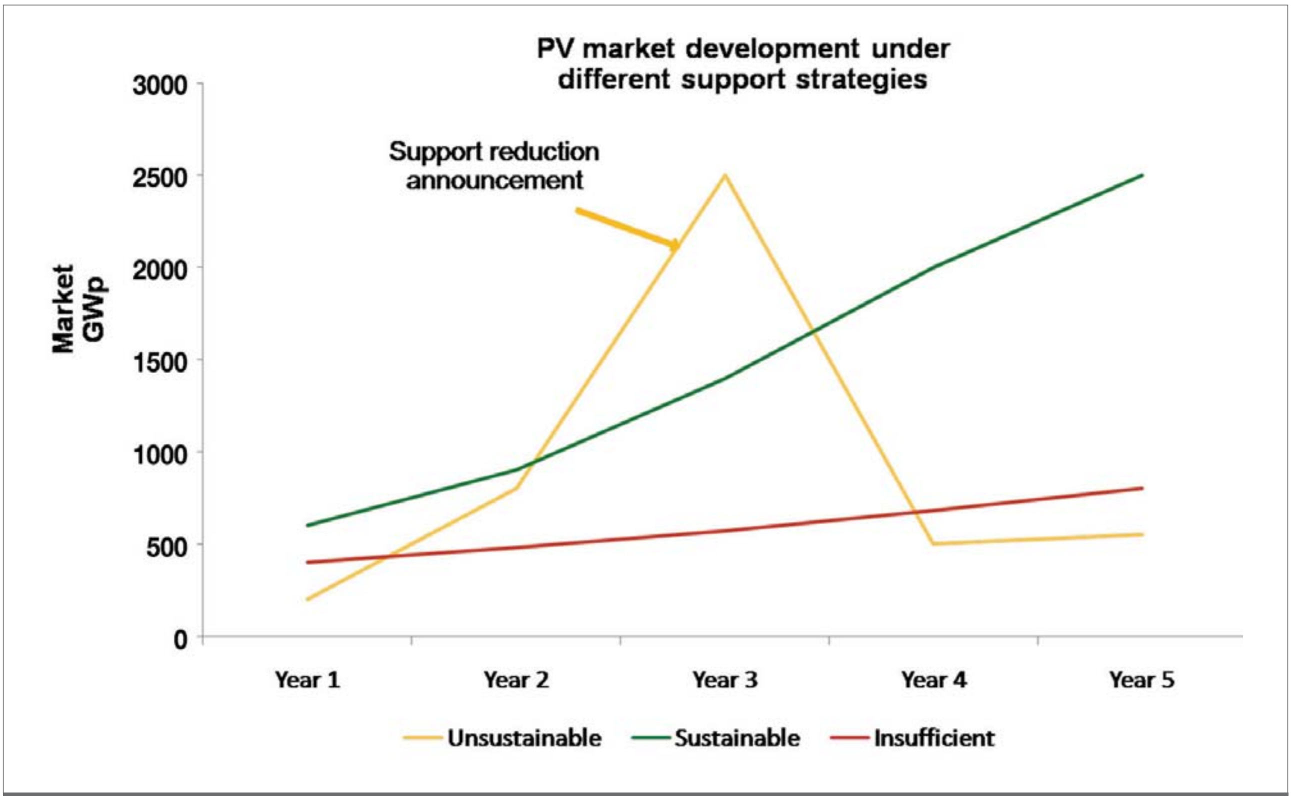

Figure 1. CAP or self-regulated method?

The future of feed-in tariffs

In the mid-term, support schemes have to evolve as PV is transitioning into a competitive technology. This process is gradual and needs to reflect differences by customer segment and region.

> "Stability in time and predictability of future tariffs is an essential component to ensure the investor's confidence."

The pre-competitive phase, which reflects the current status in most markets, is ideally governed by FiTs with digressive levels of support. These can be supplemented by support from various instruments (tax credits, subsidies, loans, etc.) but overall should not exceed sustainable support levels. Efficient administrative procedures (e.g. for licensing and building permits) as well as short grid-connection times are key conditions that still need to be realised in several markets. Significant R&D support and cooperation for basic and applied research is equally important in this phase.

During the transition phase, as we have seen before, support for PV should move towards a gradual adaptation of FiTs to ensure sustainable growth; FiPs (Feed-in Premium for direct electricity auto-consumption) to increase incentives for self-consumption, and the inclusion of PV in regulations such as, for example, zero-energy or energy-positive building standards that are supplemental policies/measures to ensure continued deployment.

Some policy support for PV will also be needed during the competitive phase, as investment competitiveness alone does not automatically provide sufficient incentives to overcome switching costs and resistance. The most important long-term policy target should be the full implementation of time-of-use electricity billing and net metering in Europe, as this will ensure compensation for PV's favourable attributes as a peak power generation technology. Furthermore, the maintenance of low FiPs might be necessary in some markets or for certain segments, as long as the investment threshold warranting sustainable IRRs is not reached.

> "Support for PV should move towards a gradual adaptation of FiTs to ensure sustainable growth."

EU-wide introduction of time-of-use electricity billing and net metering

A mid-term objective of the EU should be the EU-wide introduction of time-of-use electricity billing and net metering. Time-of-use electricity billing allows an adjustment of pricing to load conditions, thereby providing consumers with the right incentives to optimize system costs. It will require the installation of smart meters able to measure when electricity is consumed.

Net metering allows the sale of excess electricity to the grid. It will require the installation of smart meters capable of measuring how much of the produced electricity is fed into the grid. For instance, a Southern California utility uses a bi-directional smart meter to measure and/or track the 'net' difference between the amount of electricity produced and the amount of electricity consumed during each billing period.

Summary of feed-in-tariff core elements

In summary, the core elements of a well-designed feed-in tariff are as follows:

- **A temporary mechanism**. The feed-in tariff should be introduced in order to stimulate the market and should be reduced progressively as parity is reached, then replaced by another compensation scheme (e.g. net-metering).
- A **self-regulated feed-in tariff with predictable changes** is the key to stability and sustainability of market development.
- **Consideration for taxpayers**, as the money financing the incentive comes from a limited extra amount taken from the monthly electricity bill.
- **The driver for further cost reductions and economies of scale**: by creating volume, and driving price reduction through well-designed digression rates.
- **Ensures high quality PV systems** and good performance as the return on investment depends on the performance of the system.
- It should be provided **for a long time** (typically 20 years or more) to create secure conditions for potential investors.
- It should be accompanied by **an ambitious national industrial policy** in order to develop a national industry and thus maximize the effect of developing a local industry and creating local wealth.

About the Author

Gaëtan Masson joined the EPIA team in November 2009 as Senior Economist. After working as an electromechanical engineer, he graduated in political sciences and recently completed a Master's degree in environmental sciences at the Université Libre de Bruxelles. His career path has been mainly dedicated to the finance industry.

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Production stimulant: Of $2.3 billion in new U.S. manufacturing tax credits, solar firms score a cool billion and change

The Obama Administration has injected Recovery Act stimulants into the clean-energy sector yet again, this time with the eagerly anticipated news of $2.3 billion in advanced energy manufacturing tax credits awarded to 183 projects. Also known more wonkily as Section 48C credits, the investment tax breaks have been a cornerstone of the White House green team's – and the industry's – strategy, touted as a way to kick-start more domestic manufacturing and create thousands of desperately needed jobs.

The credits will be worth up to 30% of each planned project, which the Feds say "will leverage private capital for a total investment of nearly $7.7 billion in high-tech manufacturing in the United States." Projects must be completed by 2014, and, coincidentally, as many as 30% of them may be done this year.

An Energy Department spokesperson told me that there were a total of 470 applicants under consideration, accounting for $10.6 billion in credits representing some $25 billion in total investments. This means roughly 39% of those who applied for the credits received them. For the "losers," the well is dry for now: she said the manufacturing ITC is capped at $2.3 billion.

The big news here: the list of recipients reveals that solar PV and thermal companies garnered a sizeable chunk of the credits – at least $1 billion.


Photo by Tom Cheyney

The spreadsheet of recipients is divided between applicants who chose to offer some specifics about their projects, and those that gave the legally required minimum of company name and credit amount. Still, the vast majority of solar winners provided brief descriptions of their projects as well as the planned locations of the facilities.

Forty-four projects are cited with more details, and approximately 14 with the bare minimum. Why approximately? Because certain companies – like DuPont – play in several different cleantech sectors and may/may not have won certain awards for solar stuff. Plus about a dozen companies received more than one credit award.

My rough calculation finds more than $840 million in credits for the 44, and another $325 million or so (again, with the aforementioned qualification) for the others, so to call the total solar nut "more than a billion dollars" seems entirely plausible.

Of that, the majority of solar credits went to projects using the "P" technology, as in PV. Of those photovoltaic recipients, the beneficiaries come from the crystalline silicon, thin-film, and concentrator PV camps.

Dow Corning gets the largest cumulative awards, with its Hemlock Semi unit receiving $141,870,000 for its polysilicon plant in Michigan. The silane plant being built nearby earns the parent company its other morsel of tax benefits – $27.3 million.

Garnering the largest single credit is REC Silicon, who will earn a $154.8 million tax break, probably for its Moses Lake, WA, poly plant. Another large solar-sector amount – $128,482,287 (how did they come up with that exact figure?) – also goes to a materials-oriented facility: Wacker Polysilicon's site being constructed in Charleston, TN.

Other big winners in the materials space include DuPont ($50,730,000 for its Circleville, OH, factory producing polyvinyl fluoride films for module backsheets) and Dow Chemical ($17,814,261 for making solar shingles and other building-integrated PV products). On the opposite end of the monetary spectrum, the smallest solar award also goes to a materials project – $149,100 for PPG Industries' antireflective coating films.

Fortunately, the multinational conglomerates did not walk away with most of the tax credits. Far from it. Smaller companies also got some big breaks.

CIGS developer/manufacturer MiaSolé pulls down more than a whopping $101 million in credits; UMG silicon cell producer CaliSolar receives $51.5 million; printed CIGS innovator Nanosolar scores $43.5 million; stealthy Stion (which is described as making "CIGS on glass") sees $37.5 million; and flexible thin-film-silicon upstart Xunlight earns $34.5 million.

Some cell and module biggies also got in on the 48C action. First Solar gets a $16.3 million credit to help complete its Perrysburg, OH, expansion; SolarWorld nabs a cool $82.2 million to help with its Hillsboro, OR, buildout; SunPower benefits from >$10 million in credits; and BP Solar receives $11.67 million in breaks.

Just what those last two companies will be using their tax credits for remains unknown, since they declined to provide more details (although SunPower plans to build a module plant in the U.S., BP's recent flight from U.S. manufacturing makes its award a bit perplexing). The spreadsheet also may have inadvertently tipped the hands of a few companies before they had a chance to formally announce their plans.

Yingli Green Energy Americas is apparently building its first domestic moduling plant in Phoenix, if the info is to be believed, and will get an ITC of $4,534,320 to help move things along. An outfit named Centrosolar Oregon LLC (gee, any idea who might own them?) will receive $4,740,000 for its c-Si panel plant in Gresham. CPV pioneer Amonix – which nabbed two credits totaling more than $9.5 million – will be using those benies for facilities in Las Vegas and Phoenix.

The more nationalistically inclined reader might note another trend among the tax credit beneficiaries: many of them are not American companies, but the U.S. operations of foreign companies. In addition to Wacker, SolarWorld, Yingli, and Centrosolar, overseas outfits cashing in include a gaggle of "S" companies like Suntech, Sumco, Sharp, Schott, and Saint Gobain.

This column is a revised version of a blog that originally appeared on PV-Tech.org.

Tom Cheyney is U.S. Editor for the *Photovoltaics International* journal and writes news and blogs for PV-Tech.org.