Eighth Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS

UMG silicon: IBM & NREL discuss the pros and cons

China Sunergy presents fine-line metallization techniques

PI Berlin takes a closer look at PV module power measurement

DERlab puts single-phase inverters to the test

Enerplan: how will the new FiT impact the French market?

Second Quarter, May 2010

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Front cover shows UMG silicon solar-cell processing. Photo by Ed Shvartzman, courtesy of Calisolar, Sunnyvale, CA, USA.

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Publisher's foreword

It's official: Germany reached 3.8GW of solar installations in 2009, while the market as a whole reached 7.2GW worldwide. Despite a tough economic year, the PV industry still shone through. But something had to give, and the German parliament's plans to reduce the FiT by up to 16% on July 1st are being mirrored by talks in Italy during the recent SolarExpo in Verona that will inevitably lead to tariff reductions in early 2011.

While attending the SNEC exhibition in Shanghai, the question I was asked most frequently by module manufacturers was in regard to what effect the reduction of tariffs will have on the German market. The Chinese are interested in their major market as almost 60% of modules installed in Germany last year were of Chinese origin – a figure that is set to increase in 2010.

The answer is that the tariff changes will indeed affect the market. There will be a positive result in the first and second quarters of 2010 as we see a rush for installations to be connected before the deadline. Interestingly, Phoenix Solar has been forced to use modules other than those of First Solar in an effort to get their 15.8MW solar park near Würzburg completed in time.

Another major factor driving market demand in Germany is the dramatic drop in module ASPs, which saw a dip of almost 55% in 2009. This means that even with the increased digression, the reduction in cost still allows a good margin for systems integrators and the ability to discount system costs to maintain demand for the future.

Once again, cost is thrust to the forefront and, as with every issue, we are delivering timely and expert editorial to help manufacturers and large-scale system integrators understand and take advantage of technological advancement. We re-examine the cost advantages of UMG silicon with **IBM** and **NREL** (p.38) using actual data in an in-depth 11-page report. We follow on with an in-depth industry assessment of wafering cost reduction strategies for mc-Si (p.52).

China is the heartland for c-Si manufacturing and in this issue for the first time we welcome a contribution from **China Sunergy** (p. 82). The paper looks at applications for new metallization technologies being tested in the fab, providing evidence of an underlying trend in the movement of R&D activities away from Europe and the U.S. toward China.

Besides manufacturing cost, module yields play a vital role in overall system payout. Improvements in system lifetime are created through better quality control, and in this issue we assess cell quality with **Q-Cells** (p. 88), module power output with **Photovoltaik Institut Berlin** (p. 139), module failure rates and temperature effects with **TÜV** and **ASUPTL** (p. 146), and put single-phase grid-connected inverters through their paces with **DERlab** (p. 166).

In the context of developing markets, we asked **Enerplan** to help us analyse the impact of a revised French FiT (p. 184) and we take an in-depth look at the emerging UK opportunities (p. 187).

The *Photovoltaics International* team will be on the road from June, so catch up with us at Intersolar Europe and North America, as well as at the esteemed IEEE PV Specialist Conference in Hawaii. We always welcome feedback, and if you are currently working on any new and exciting technology-related projects, please get in touch for possible contributions online and/or in print.

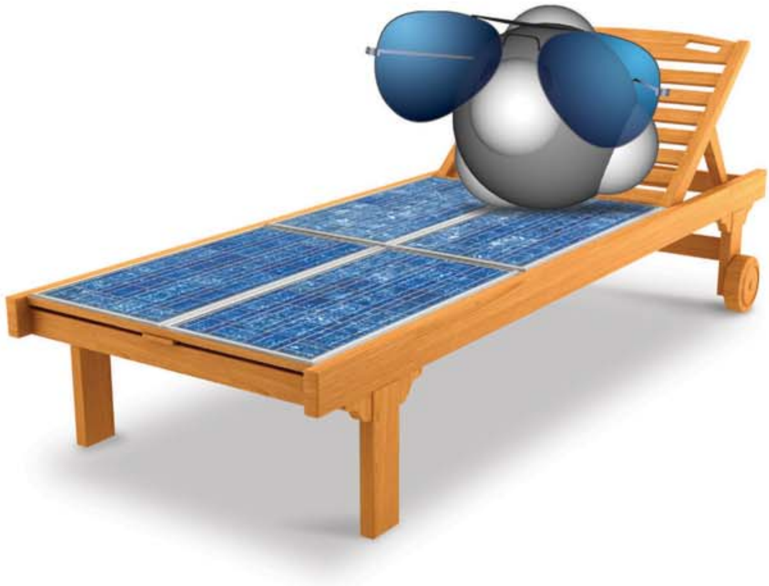
Thank you for your continued support and constant encouragement. Our combined online and print readership is now approaching 90,000 PV professionals worldwide, largely due to your recommendations to colleagues and customers.

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.



Fab and Facilities

News

Moser Baer increases capacity due to solar sector success

Moser Baer has announced plans to raise Rs300-400 crore over the next couple of months to fund expansion to increase the crystalline silicon capacity of its photovoltaic business from 140MW to 240MW. The expansion will take place in two phases. Phase two of the expansion will involve an increase in the combination of both thin-film and crystalline silicon facilities.

"Our immediate plan or phase one of the expansion is about our crystalline silicon capacity. In PV, for the second consecutive quarter, we have been able to achieve strong shipments and corresponding revenue. We are now actively implementing our expansion plans of the crystalline silicon facility," said Yogesh Mathur, Moser Baer CFO.

Moser Baer has commissioned its largest thin-film solar farm at Chandrapur in Maharashtra, India, with an installed capacity of 1MW. It has announced further plans to commission two more solar farms in the country. The first 5MW farm will be located in Tamil Nadu, and involves an investment of US$20 million (Rs90 crore) while the second will be set up in Rajasthan.

Moser Baer's 1MWp field installation in Maharashtra, India.

Capacity News Focus

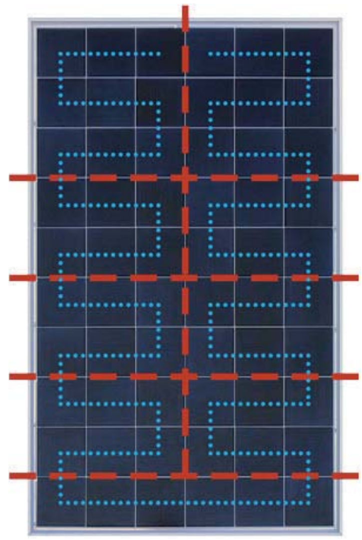
Day4 Energy expands European production capacity

Day4 Energy is to expand its third-party manufacturing facility in Europe. The company is increasing production from 50MW to 120MW per year to meet increased demand for its photovoltaic products. The first 75MW of capacity expansion was scheduled for completion by the middle of May with the remaining 120MW to be completed by the end of June.

The expansion plans include increasing productivity from five to seven days a week as well as the addition of new commercial lines dedicated to the production of the newly introduced 60MC-I module (pictured) with Guardian Technology. The current production mix at the facility is focused on the company's 48MC-S module. However, Day4 Energy expects that demand for the new 60MC-I module will require 80% of production capacity by the third quarter of 2010.

Heraeus to expand production capacity for PV products by 300% in 2010

Citing unprecedented global demand for its range of PV manufacturing-related products, Heraeus is set to expand production capacity by 300% in 2010. The company recently completed a 30% capacity increase and expects another 30% expansion by the end of May. Overall, the company is adding additional production and technical personnel to meet demand.



Day4 Energy's 60MC-I modules use 'Guardian Technology'.

BP Solar, Tata Power JV ups capacity by 62%

BP Solar and Tata Power's joint venture, Tata BP Solar, has added a new production line of 32MW of solar photovoltaic cells at its plant in Bangalore. The total cell manufacturing capacity of the company has now reached 84MW, with a module capacity of 125MW. The company initiated this expansion through a US$100 million investment throughout 2008.

BP Solar CEO Reyad Fezzani said, "Tata BP Solar has had profitable growth over the last 20 years. Global demand for solar is expected to grow over 80% in 2010, and in India it is likely to grow five-fold to 150MW. In the longer term, the Indian market is poised to become a world-scale market by 2022 stimulated by the supportive policies announced by the Government of India."

Solutia expands Saflex PVB manufacturing facility in Suzhou, China

Solutia has announced plans to expand its manufacturing plant located in Suzhou, China. The site is used for the production of the company's Saflex polyvinyl butyral (PVB) interlayer for laminated glass. The Suzhou plant expansion includes the addition of a second manufacturing line for enhanced capabilities to serve the

Saflex's PVB interlayer production.

architectural, photovoltaic, and automotive markets in China and the broader Asia-Pacific region.

"This additional expansion improves our ability to serve the needs of laminators and glass fabricators supplying the rapidly growing Chinese automotive, architectural and photovoltaic industries and the broader Asia-Pacific markets", commented Timothy Wessel, president and general manager of Solutia's Saflex business.

The company's second production line will significantly increase the annual capacity of the Suzhou plant and is scheduled for completion by the end of 2011.

Aide Solar celebrates grand opening of China facility

Aide Solar, a subsidiary of the Panjit Group has opened its Xuzhou, China, solar cell/module production facility. At over 1 million square feet, the new facility is reported to be able to increase the company's poly- and monocrystalline silicon PV module capacity by 40% — a grand total of 350MW per year. The new plant has 12 solar cell production lines and brings the Aide Solar employee count to 1,184 people worldwide.

Sputnik Engineering moves to Lyon, expands facility

Sputnik Engineering is changing location from Paris to Saint Priest near Lyon. The managing director aims to continue to expand the sales and service of SolarMax products in France, improve responsiveness to customer needs, and expand the training program. In order to achieve this goal, Sputnik plans to expand its partner network to cover the market for medium-sized and large-scale plants and sales in French overseas territories.

"The south-east of France has the largest number of solar plants, especially in the Rhône-Alpes region. Lyon has also become a magnet for the solar industry. Roughly half of all French PV installation companies have their headquarters in this region", said Didier Jeannelle, head of Sputnik's French subsidiary.

Twin Creeks Technologies to construct solar panel manufacturing facility in Mississippi

Twin Creeks Technologies is constructing a solar panel manufacturing facility in Senatobia, Miss. The 250,000 square foot production facility, which will use the company's proprietary technology to produce crystalline-silicon photovoltaic modules, represents a company investment of more than US$175 million.

The state of Mississippi provided US$50 million loan assistance for the facility through the Mississippi Major Economic Impact Authority for this project. The state and the city of Senatobia will also provide US$4 million for infrastructure improvements at the site.

Voltaix to open new manufacturing facility in Pennsylvania

Voltaix, materials provider for the enhancement of semiconductor chip and solar cell performance, has announced its plans to open a new manufacturing facility in Northampton County, Pennsylvania. The plant will be constructed at the Portland Industrial Park in Upper Mt. Bethel Township.

The Lehigh Valley Economic Development Corporation worked with Voltaix and the Governor's Action Team to secure a US$2,764,000 funding offer from the Department of Community and Economic Development for the project. Plant construction is scheduled to begin in the second quarter of this year, with operations commencing in 2011.

Other News Focus

Linde Gases encourages its customers to "go green" with on-site generated fluorine

In an effort to continue environmental conservation efforts, Linde Gases has announced to its customers the opportunity to diminish their CO_2 emissions by a quarter of a million tons this year by switching to on-site generated fluorine (F_2) from the more traditional nitrogen trifluoride (NF_3).

"Fluorine offers the rare combination of sustainable solar module production and profitability by removing any risk of unabated emissions, reducing non-productive cleaning time and improving throughput," said Ian Travis, global product manager fluorine for Linde Gases division.

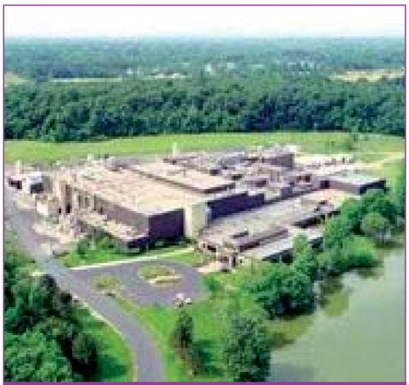
Interest in the on-site F_2 is growing throughout the electronics industry with LG Display in Korea, for example, boosting its on-site F_2 capacity by 20% in 2009. As a direct result, Linde is investing more into its Inju plant's F_2 manufacturing infrastructure.

Last year also marked the first time that Linde's on-site F_2 was effectively tested on all major thin-film PV OEM platforms. Malibu and Masdar PV were some of the first companies to announce and implement the on-site F_2 as their cleaning gas of choice for the manufacturing of large-scale PV modules.

Linde fluorine generator.

Sumco offers Ohio wafer fab to solar industry

Following in the footsteps of Komatsu Group, which successfully sold a redundant semiconductor wafer fab to SolarWorld, Sumco Phoenix has offered its wafer fab facility near Cincinnati, Ohio, to the solar industry. The 70,000-square-foot cleanroom (Class 100) is housed in a 200,000-square-foot building on a 100-acre site that can accommodate future growth. ATREG, a division of Colliers International, has won the contract to sell the facility on behalf of Sumco. The facility has undergone recent expansion and comprehensive modernization.



Sumco's facility near Cincinnati, Ohio.

Von Roll establishes Solar Centre of Excellence

Solar cell manufacturer Von Roll has announced that it will now perform all of its activities in the Solar Centre of Excellence headquartered in Tägerwilen in the canton of Thurgau, Switzerland. The Centre will combine the production of Von Roll solar cells and other company research and development projects.

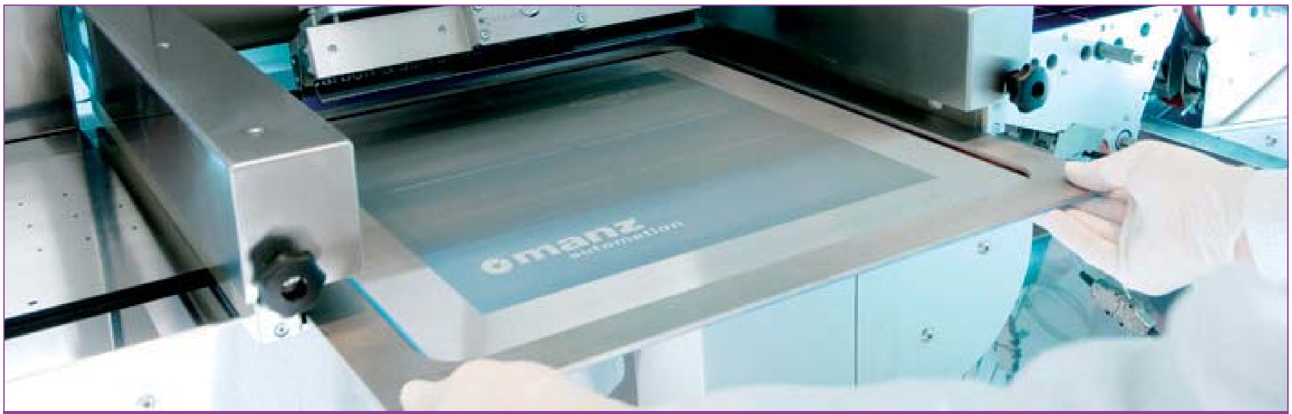
Thomas Limberger, Von Roll CEO said, "Our aim is to launch an extremely competitive product onto the market with our third-generation solar cell. We are on the right track in this respect and we have already received positive feedback from potential customers. The challenge now is to make our product marketable as quickly as possible."

The company expects to launch a prototype of the solar cell by the end of 2010 and production should begin in the second half of 2011.

Energy start-up Green2V to construct US$500m PV manufacturing plant in Rio Rancho

Start-up energy company Green2V has announced that it will spend US$500 million over the next five years to build a 1 million-square-foot plant in Rio Rancho that will potentially provide 1,500 jobs in the area. The company will use the facility to manufacture solar cells and modular glass frames and will design, install, operate and finance the systems.

The project involves the sale of 124 acres of land held by the New Mexico State Land Office to the city of Rio Rancho, which will purchase the three separate tracts from the state Land Office for US$6.9 million with finance provided by Green2V. The proceeds from the sale will go into the state's Land Grant Permanent Fund. Initial funding for the project will come from GP3 in Los Angeles, and its CEO George Peters. The firm has committed to purchase the first round of IRBs issued by Rio Rancho.



Metallization equipment at Manz Automation.

Green2V hopes to begin delivering its solar energy systems to customers by the summer of 2011.

Manz Automation opens development centre for vacuum-coating technology

Manz Automation has opened a development centre for vacuum-coating technology in Karlstein, Germany. All of the company competences needed to develop vacuum-coating equipment and processes will now work from this location. Manz has also announced plans to set up a technical lab to develop and test new coating methods and technologies.

The future share accounted for by the machines developed and produced by the Manz group for both technologies will increase to approximately 90%. The company will produce the machines at its facilities in Europe and Asia making initial contributions to increasing revenues from mid-2011.

Solar Power, Inc. selects site for U.S. manufacturing facility

Solar Power, Inc. has selected McClellan Business Park as the site for its U.S. manufacturing facility, subject to the finalization of building agreements. The company has received an initial commitment of US$24.7 million in Recovery Zone Facility Bonds (RZFB) from Sacramento County and plans to use the proceeds from the sale of these bonds to help finance renovation and outfitting of the solar panel manufacturing facility.

A portion of the RZFB bond proceeds will go towards the development of a 10MW utility-scale photovoltaic solar system in Sacramento County with an estimated value of US$50 million.

The proposed manufacturing facility at the McClellan site will be approximately 100,000 square feet with an annual production capacity of 50MW the company's solar panels. The company expects to receive the bond proceeds and begin construction on the new headquarters and manufacturing facility in July 2010 for completion in early 2011.

Product Briefings

AEG Power Solutions

AEG's 'Thyrobox M' power solution reduces energy consumption per kilogram of polysilicon

Product Briefing Outline: AEG Power Solutions has introduced 'Thyrobox M,' which, it claims, is the most compact power solution that offers increased reliability and stability for the polycrystalline silicon deposition process. With advanced process monitoring capabilities, a 0.95 power factor and more than 99% energy efficiency, the Thyrobox M also reduces installation, commissioning and maintenance costs for the entire energy supply as well as building costs due to its smaller footprint compared to previous designs and competitor offerings.

Problem: Energy consumption remains a key cost contributor to polycrystalline silicon production. Efforts to reduce energy costs while also increasing production are vital, as is enhancing purity while reducing operating costs for energy consumption per kilogram of polysilicon.

Solution: Engineered with a modular design, the Thyrobox M is the world's most compact polysilicon power supply. Depending on the type of reactor, its footprint is about 25% smaller than older Thyrobox solutions and up to 70% smaller than competing products. The compact design reduces installation, commissioning and maintenance costs for the entire energy supply as well as building costs. Warning system and troubleshooting features also minimize the risk of process interruptions in case of silicon rod cracks or melts. An integrated medium-voltage ignition enhances process stability. Ongoing data collection and analysis through monitoring of energy consumption and silicon rods weight increase energy efficiency.

Applications: Polycrystalline silicon deposition process.

Platform: System solutions from AEG PS are designed to interface with the electrical power grid and to offer power solutions for mission-critical applications in harsh environments, such as power plants, offshore oil rigs, chemical refineries, and utility-scale renewable energy plants.

Availability: Currently available.

Pfeiffer Vacuum

Pfeiffer Vacuum's HiPace 60 turbo pump allows mounting orientation flexibility in integrated applications

Product Briefing Outline: Pfeiffer Vacuum has brought to market the HiPace 60, a new robust turbopump that is characterized by a high level of cost-effectiveness and flexibility in all mounting orientations. The HiPace 60 has an improved rotor design, offering high pumping speeds and high gas throughputs, and is insensitive to particulate matter and dust. Moreover, its proven bearing concept makes this pump suitable for use in punishing industrial applications.

Problem: Innovative materials are required in such pump systems to allow for a reasonable service life, which, coupled with cumbersome and costly cabling, can make installation and running of the pumps a costly and problematic affair.

Solution: A variety of drive versions are available that do not cause any increase in physical size (e.g. Profibus and DeviceNet). Their functional aluminium housings make these pumps extremely lightweight, while a sealing gas connection safeguards the bearings against particulate matter or reactive gases. This affords optimal integration capabilities. The mature rotor design and precise sensory technology of the HiPace pumps afford the highest level of safety. Remote and sensor functionalities enable pump data, such as temperatures, to be analyzed.

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

Platform: Lightweight aluminium housing. Surface structure design offers significantly improved cooling. A sealing gas connection safeguards the bearings against particulate matter or oxidizing gases. Mean time to failure > 200,000 hours.

Availability: Currently available.

Oerlikon Leybold Vacuum

DRYVAC pumps from Oerlikon Leybold Vacuum cover a variety of processing applications

Product Briefing Outline: Oerlikon Leybold Vacuum has launched DRYVAC, a new range of dry vacuum pumps. Incorporating many large and small design innovations, all models in the DRYVAC platform have been designed and adapted to the special needs of processes in the photovoltaic production chain, including coating applications and various industrial manufacturing processes.

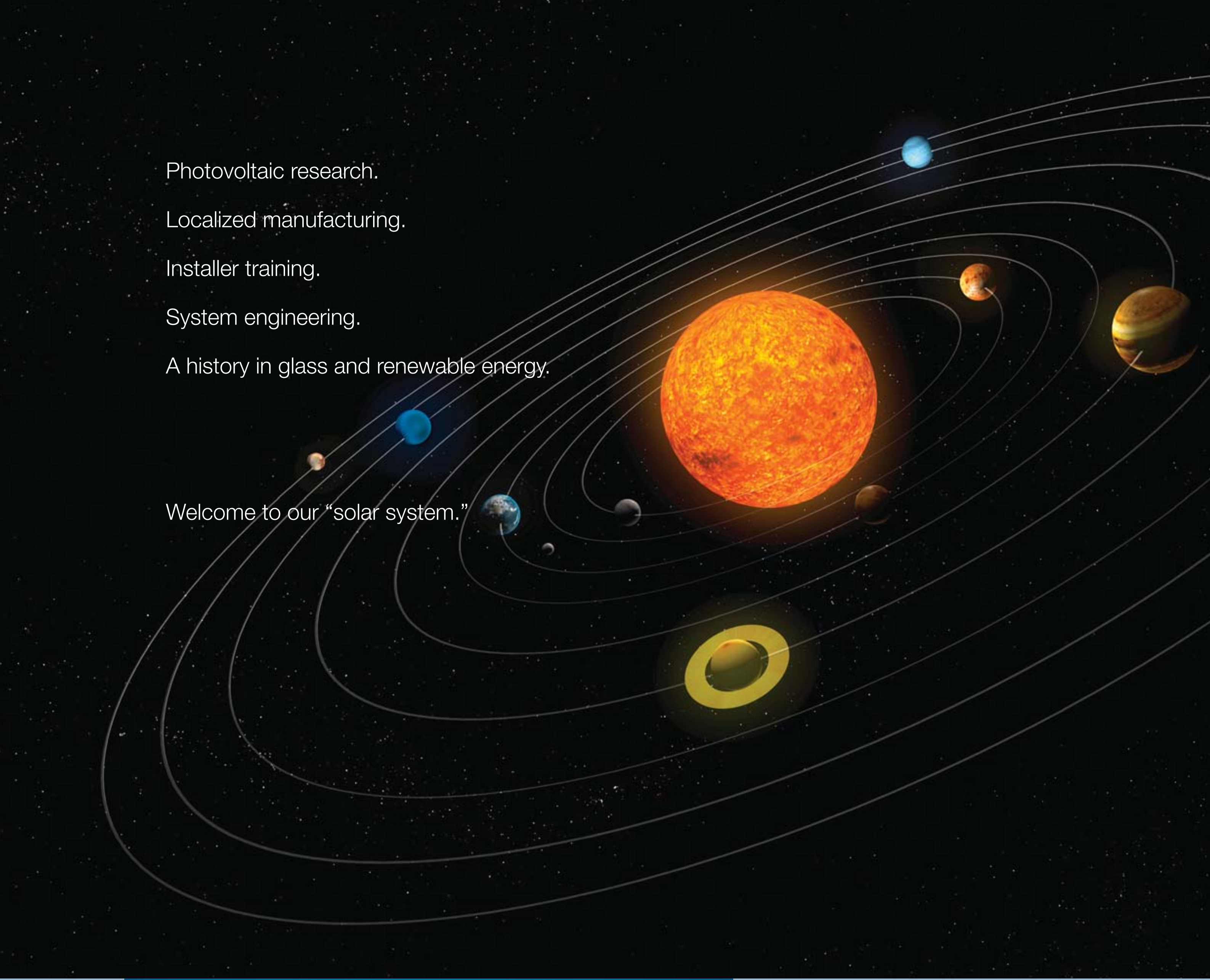
Problem: Vacuum pumps are used in a wide variety of processing applications within c-Si and thin-film production. Low energy consumption is becoming increasingly important to lowering the overall cost of ownership. However, small and flexible combinations with high system uptimes are also required as processes evolve and change.

Solution: DRYVAC Sprinter and Enduro versions have optimized pumping speeds at all pressure ranges from 10-2 mbar up to atmosphere, which means they are ideal for fast pump-down times and specially suited for load lock applications. DRYVAC Enduro pumps are said to cover all typical features needed for process industry applications. Models from the DRYVAC Champion range have been designed to provide the highest reliability in harsh process duties. These pumps are optimized for handling typical gases from the production process in the photovoltaic and flat panel display industry. The DRYVAC range comprises the following models: DRYVAC 650 S; DRYVAC 650 S-i; DRYVAC 5000 RS-I; plus multiple system combinations with roots blowers from the RUVAC series.

Applications: Wide-range of c-Si and thin-film manufacturing process applications.

Platform: DRYVAC pump systems and "-i" versions include housing, castors, frequency converter, PLC and touch screen display as standard. Control and monitoring can be visualized via intuitive menu navigation, software and field bus.

Availability: Currently available.



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Building Information Modelling: improving facility project delivery

Allan D. Chasey, Arizona State University, Tempe, Arizona, USA

ABSTRACT

Building Information Modelling (BIM) is an approach that is fast gaining traction in the architect, engineer and construction (AEC) industries. BIM combines the construction of a virtual model with all aspects of a facility, from design (space planning) to construction (cost and scheduling), and from operations to maintenance (planning and asset management). BIM is also a process as well as a project. Even though the technology for implementation of BIM will change, and probably change rapidly, the process and underlying concepts will likely change very little. This paper outlines the guiding principles of BIM and its ability to enhance the project delivery process of the AEC industries.

Introduction

BIM directly relates to a project team's ability for visualization, understanding, communication and collaboration [1]: visualization to see the project; understanding to know the project elements, communications to ensure the understanding, and collaboration to receive all the necessary input at the proper time. The benefit of collaboration and working together will likely pose the greatest challenge. BIM requires openness amongst the team players for sharing information that supports the goals of the project.

With the definition of BIM as a process, a product, and a lifecycle management tool come a variety of additional properties. As a process, BIM covers business drivers, automated process capabilities, and open information standards for information sustainability and reliability; as a product, it is a digital representation of physical and functional characteristics of a facility, serving as a shared knowledge resource for information about a facility forming a reliable basis for decisions during the facility lifecycle from inception onward; as a lifecycle management tool, it provides important information exchanges, workflows, and procedures which teams can use as a repeatable, verifiable, transparent, and sustainable information-based environment throughout the building lifecycle [2].

BIM has become a valuable tool in many sectors of the capital facilities industry. The fundamental characteristic of BIM is its development through an information feedback loop. The development of the visual model and the relevant project information is iterative in nature as different project team members develop the project. During the course of a project, the information gradually increases in scope, depth and relationship to the project. A coordinated and intelligent project will grow out of the building and project information that is continually cycled through the BIM as more and more detailed information is added and coordinated [1].

Many of the benefits of BIM can be viewed as direct benefits, although the greatest benefits are actually indirect benefits. Direct benefits include such items as improved visualization and the centralization of project and building information. The indirect benefits include the necessity of collaboration and the resulting better project understanding and reduction of project risk, which is brought about by improved understanding, coordination, and material use in the management of the project as well as reduced construction conflicts, construction waste, and project cost.

> "The fundamental characteristic of BIM is its development through an information feedback loop."

Aspects of Building Information Modelling

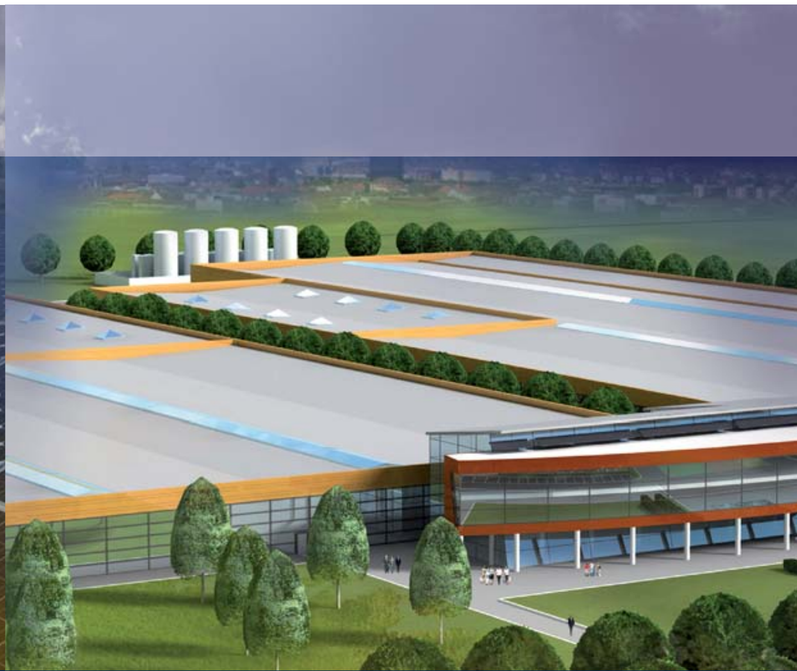
As noted, BIM is a process as well as a project. As a process that continues through the facility's lifecycle, aspects of the model and process are developed for additional uses and process. For example, most construction is still accomplished utilizing the conventional two-dimensional (2D) drawings. With the visualization aspect of the project becoming more intuitive through the use of software, the third dimension (3D) is added to allow a virtual facility to be constructed and modelled for understanding the facility/project composition.

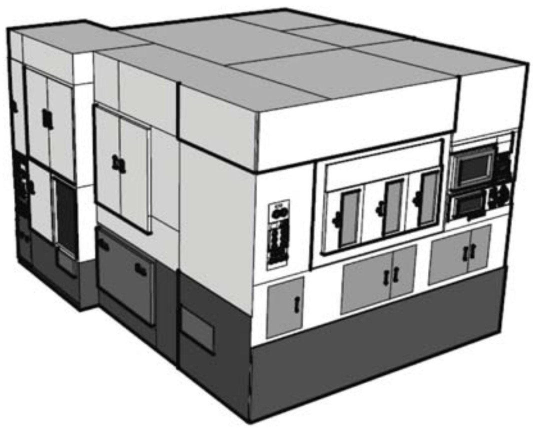
With an added dimension of time, the fourth dimension (4D), a sequence of activities can be determined that will allow the visualization of a facility/project in time, i.e. build the facility on 'paper' before commitments are made in the field. This allows the investigation of system and structure interference (clash detection) and development of effective construction sequencing. With the development of project models, quantities take-off become easier and more accurate due to the dimensional accuracy of the virtual model and estimating can be accomplished with greater accuracy and with less time.

It should be noted that only quantities can be extracted from the model, which means that the productivity (labour hours, equipment, etc.) will still need to be determined by an individual company based on their resources. Sustainability ideas can be researched using a model to investigate shading, acoustics, daylight and energy usage. Much of the desired resource conservation can be investigated during the preconstruction period saving more than just energy, but materials, labour, and time. The virtual model can then become the basis for operations and maintenance information to track installed equipment, maintenance schedules, maintenance and operating information. Extending a virtual as-built model to the next step as an intelligent facility model would allow integration of the facility operations with manufacturing operations. This incorporation of an intelligent facility model would provide decision support tools that could reduce lifecycle cost and increase manufacturing effectiveness, provide real time O&M information exchange, automate critical performance factors, simulate facility performance and develop predictive maintenance/performance models.

Challenges of Building Information Modelling

Improvements fostered by the introduction of BIM technology into the work process will also bring several challenges as well as changes in practices and relationships. While BIM offers new methods of collaboration, it will introduce other issues with respect to the





Data Sheet Number	Data Sheet Title
100	Equipment Identification
200	Environmental Conditions
300	Physical Characteristics
400	Electrical Power
500	Water
600	Bulk Chemicals
700	Drains
800	Gases
900	Vacuum
1000	Exhaust

Figure 1. Building Element Model – Intelligent Tool Model.

development of effective teams. Today, project teams are engaging in information handovers on a daily basis. Many are even exchanging BIM data. However, this process is neither automated nor seamless. It works if a motivated team devotes several weeks to defining the information to be exchanged and the protocols for doing so. Often, the BIM is incomplete for its intended downstream use and must be augmented by verbal or text explanations and information [3].

Contractual arrangements will also require and facilitate increased collaboration between the designers and constructors, providing greater advantages to owners when BIM is used. The project delivery methodology most supportive to BIM and collaboration is the Design-Build and Integrated Project Delivery (IPD) process. The most difficult challenge that will be faced is the implementation of a shared model as the basis for all work processes, and collaboration as the question of who owns the model will arise.

Developing BIM data

BIM involves the definition of a facility as a composed set of objects. The BIM will be a project simulation consisting of 3D models of the facility components or objects, which links all the required information to the project's planning, construction or operation. These objects can be pre-defined by the BIM modelling tools due to their fixed geometries and defined parameters. As a design is developed, object definitions become more specific according to the project use or expectations. With the BIM modelling tools, it is possible to define an object once and use it for multiple purposes. The challenge is to develop an easy-to-use and consistent means of defining objects and instances appropriate for the current use and for later use.

The objects developed are Building Element Models (BEMs) that are 2D and 3D geometric representations of physical products, usually doors, windows, equipment, furniture and/or high-level assemblies such as walls, roofs, ceilings and floors (see Fig. 1). This also could apply to manufacturing equipment and over time, the knowledge encoded into these model libraries will become a strategic asset for an owner. They will represent the knowledge available as they incrementally improve and encompass information based on project use and experience. The risk of errors and omissions will decrease as higher quality models are developed and utilized.

> "With the BIM modelling tools, it is possible to define an object once and use it for multiple purposes."

The complexity and investment that will be needed to develop Building or Tool Element Models (Intelligent Tool Blocks) and content will require a tool for management and distribution that allows users the ability to find, visualize, and use the model content. Model Intelligence means that information is contained in the 3D virtual model. According to Eastman [4], the new Omniclass classifications being developed by the Construction Specifications Institute (CSI) will provide a more detailed object-specific classification and access mechanism. It will then be possible to organize Intelligent Tool Blocks for access by any number of classification schemes such as products, materials, form, function, phases, or process. A well-designed library management system could then support the flexibility needed to navigate a classification scheme of Intelligent Tool Models.

As BIM becomes more standard in the construction industry, building products (fabrication tools) can be inserted directly into a model in electronic form, including hyperlinked references for parts lists, operating and maintenance manuals, and vendor information. Contractor- or subcontractor-developed components can be incorporated into the model to ensure more accurate quantities and cost estimates and analysis. Because the BIM includes comprehensive 3D geometric definitions, it allows visualization of facility appearance, function and context. This visualization capability is extremely powerful in expediting design decisions and communicating with all stakeholders [3].

As the intelligent models evolve, more sophisticated, even intelligent product specifications will provide information for such areas as structural analysis, LEED compliance or installation specifications. Intelligent Tool Blocks can become the core information source for quantities of work, material, construction methods and resource utilization. They can even play an important role in collecting data for construction control as well as manufacturing process and layout planning and control.

Intelligent Project Modelling

Pervasive computer use is inevitable; consequently, most AEC companies will use an intelligent 3D software model for the design process. Whether the approach used is BIM, single building modelling, parametric modelling, or any other type of computer modelling, it comes down to using data-rich 3D models in an intelligent fashion. This data may be physical (dimensions, location) or parametric (distinguishing one object from another similar object). Because these intelligent or smart models are solid models, they allow the incorporation of more information

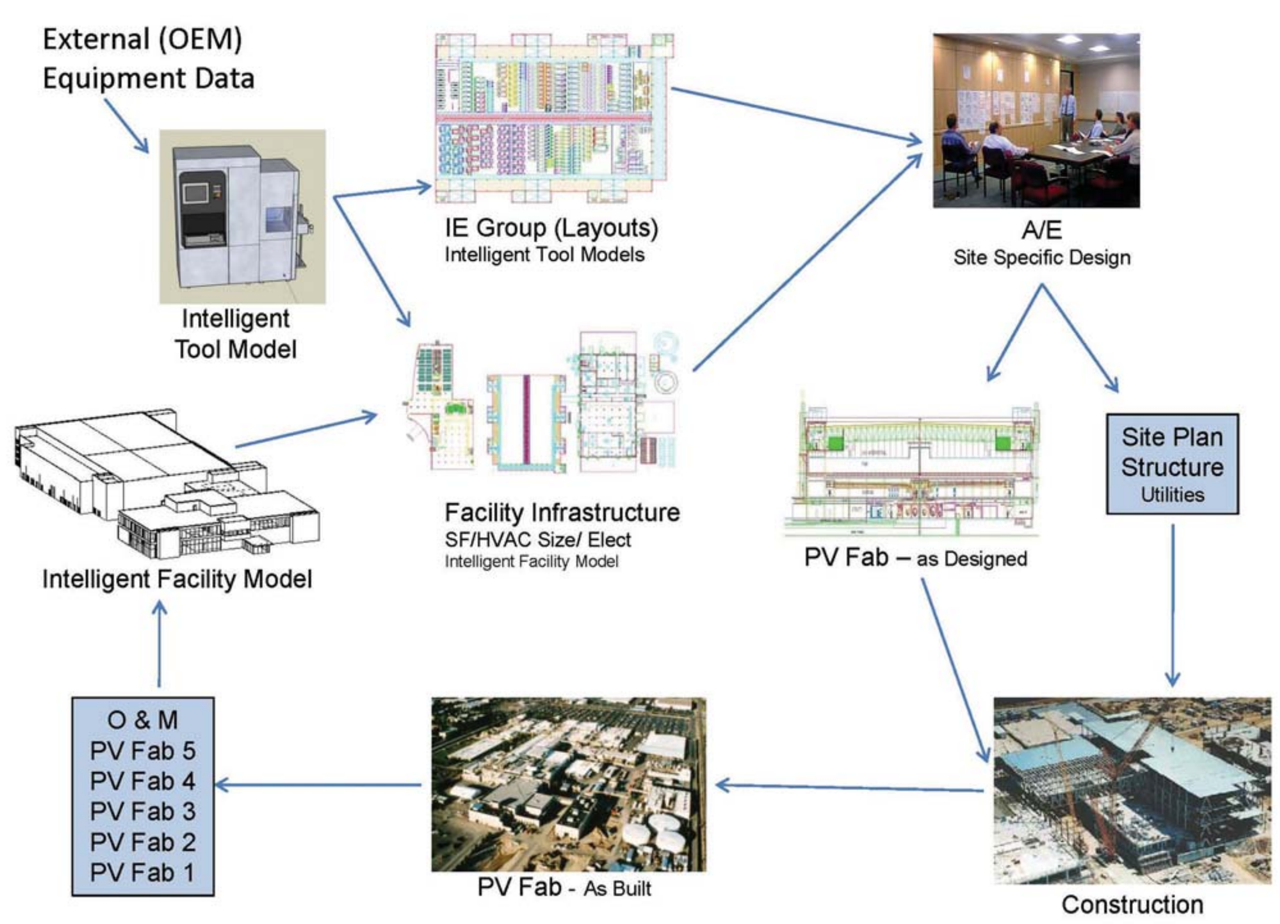


Figure 2. Intelligent Facility Design and construction process schematic.

than merely the visual aspects of an object through surface models. With the available technology, solid models can also generate 2D views that can be used for conventional construction documents.

The activities conducted throughout the lifecycle of any facility generate an enormous quantity of data that needs to be stored, retrieved, communicated, and used by all parties involved. Advances in technology have increased the opportunities for gathering, providing access to, exchanging, and achieving all of this information for future reference. These advances have also raised users' expectations about the ways this information ought to be made available and how quickly that access should be provided.

Continuing advances in Smart Building Technologies, BIM technologies and construction practices have not only increased the amount and detail of data generated and exchanged, but have also further raised expectations about its use and value as an asset. This increase in the amount and types of information generated – and the AEC industry's subsequent reliance on it – requires an organizational standard that will enable and add certainty to information communicated between parties separated by miles, countries or continents.

The AEC Industry has begun to realize that a greater degree of harmonization in classifying information is now necessary – and possible. This harmonization and reuse of information for multiple purposes is at the heart of value and cost savings presented by the BIM approach.

"The BIM will allow clash detection models to be run and the potential conflicts to be fixed before construction begins."

As shown in Fig. 2, data is required throughout the design and construction process. For a new manufacturing facility implementation, the process would begin with the request for data regarding manufacturing tools or tool set from a manufacturer's database. This data (in the form of a tool database) would be downloaded from the manufacturer's web site as generic data in an intelligent tool block. This intelligent tool block would contain all the information regarding the tool (physical characteristics, utility requirements, tool specifications, etc.) that could be used by an Industrial Engineering Department to develop a tool layout concept to review for supporting the process requirements.

The tool utility requirements would also be available to a Facility Engineering Department to determine infrastructure requirements based on the tool data and the process tool layout. Iterations of the process layout and facility layout could produce a locally specific design package that would be placed in a data repository. Once in the data repository, the models could be available to the A/E for a site-specific facility model based on the data model provided. The intelligent tool blocks form the basis for tool installation design packages that would be embedded in the final facility BIM.

The A/E would generate a BIM for the facility project. For this process to be most effective, the entire design and construction team should be involved in the model development. During design, the construction manager should be developing cost and schedule models and major subcontractors can begin developing shop drawings for the major mechanical systems such as HVAC, plumbing and process piping. The BIM will allow clash detection models to be run and the potential conflicts to be fixed before construction begins.

From the construction model, a final as-built model is provided for use by the Operations and Maintenance Department and for development of an Intelligent Facility Model that is used for ongoing energy analysis, trend modelling, maintenance simulation, and future modification analysis. For future facilities, the intelligent facility model would form the basis for the next generation fab and is integrated with the process layout for concept and specific design package development.

Conclusion

Productivity increases for the construction industry will be needed to ensure that capital projects are continued to be provided in a cost-effective manner to meet the needs of owners. Building Information Modelling is proving to be a promising technology that will have an impact on the project delivery process of the architectural, engineering and construction community. It is a significant improvement in the way architects, engineers and contractors have traditionally worked. BIM allows visualization of a building design along with implementation of a methodology to determine conflicts and develop clash-free installations. Scheduling and estimating data can also be added to make a complete facility model providing important information attached to each building element. With this model, the goals of a better, faster, and more cost-effective building can be achieved, making BIM a key tool for the future of construction.

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About the Author

Dr. Allan D. Chasey is an associate professor in the Del E. Webb School of Construction, at Arizona State University. He is the Director of CREATE, Construction Research and Education for Advanced Technology Environments, a research and education consortium representing advanced technology design and construction industry. Dr. Chasey is a registered Professional Engineer in Arizona and a LEED AP.

Enquiries

Allan D. Chasey, Ph.D., P.E., LEED AP
Associate Professor
Del E. Webb School of Construction
School of Sustainable Engineering and the Built Environment
Ira A. Fulton Schools of Engineering
Arizona State University
PO Box 870204
Tempe, AZ 85287-0204
USA

Tel: +1 480 965 7437
Fax: +1 480 965 9842
Email: achasey@asu.edu
Website: http://create.asu.edu

Considerations for polysilicon plant expansions and upgrades

Jon Bill, **Greg Heausler** & **Scott O'Briant**, Dynamic Engineering, Inc., Houston, Texas, USA

ABSTRACT

As polysilicon producers perform expansions and upgrades to increase production and improve operations, plant safety remains critical. Companies should routinely review their safety policies and effectively plan their projects to ensure uninterrupted product supply and create a safe environment for employees and the communities in which they operate. Both the design and the execution of expansion and upgrades to projects are critical as companies strive for minimal down time so that productivity is not affected. Such hazards and scenarios that may hinder and delay start-up, specifically in relation to polysilicon plants, are highlighted in this paper. Furthermore, the paper outlines how best to avoid these situations, offering methods of execution to achieve the three key measures of success: safety, high purity and minimal downtime.

Review of chemical hazards

This section reviews the hazards of the chemicals that are used in a polysilicon plant every day, and as a result may be assumed as safe. Polysilicon production requires the use of several hazardous chemicals, including trichlorosilane (TCS), dichlorosilane (DCS), and hydrogen (H_2), which are highly flammable. Silicon tetrachloride (STC) is corrosive when exposed to moisture. Some plants use hydroflouric acid (HF) and nitric acid (NHO_3) for polysilicon etching or pipe cleaning. In some processes, pyrophoric (self-igniting in atmospheric moisture) polymers and precipitates are generated, creating another hazard.

This summary reinforces the need for careful review of the applicable Material Safety Data Sheets (MSDSs) especially during expansion and maintenance projects, which bring huge potential for releases, fire and exposure. In regard to the chemicals discussed in the following sub-sections, general fire fighting recommendations are to use positive pressure self-contained breathing apparatus and full fire-fighting turnout gear.

STC

STC is a non-flammable liquid that reacts vigorously with water to form hydrogen chloride (HCl). The reaction of STC with water can form dense white clouds of silica particles and hydrogen chloride fumes. Hydrogen chloride may then in turn react with metal, producing highly flammable hydrogen. Hydrogen chloride vapours are extremely irritating and burn skin and eyes on contact. In the case of a release, personnel should evacuate from the danger area.

TCS and DCS

TCS and DCS are flammable liquids or vapours depending on storage conditions. The boiling point of TCS is 31.9°C, while DCS is only 8.4°C. TCS and DCS ignite with a rapid flashover at the liquid surface and generate very little or no noticeable flames. Burning DCS and TCS produces HCl and possibly H_2 in the white smoke of SiO_2, but only small amounts of radiation heat.

"Proper design and precautions for fire prevention are extremely important."

The best way to extinguish a TCS or DCS fire is to stop its flow, as attempting to extinguish the fire without stopping the flow may permit the formation of explosive mixtures with air. Foam (water with 6% solution of Hazamat II foam) is the recommended extinguishing medium. The use of foam reduces spreading of the flammable liquid and reduces the temperature of reaction, mitigating the incident. The water in the foam will react to create the by-products hydrogen and HCl, possibly creating hydrogen bubbles in the foam which can ignite during clean-up. There is always a high risk of re-ignition after extinguishing these fires. The HCl created in the foam is corrosive and its discharge may be restricted. A facility that houses such processes is best designed for containment with the grade sloped toward collection points.

Proper design and precautions for fire prevention are extremely important. This not only includes the design of equipment to prevent release, but also the implementation of measures to minimize sources of ignition. These include:

- Personnel ban on smoking
- Ventilation to remove vapours
- Design sloped surfaces to collection points away from equipment and buildings
- Use of electrical classifications for certain equipment
- Purge and inert equipment and containers
- Control static electricity
- Control cutting, welding and other "hot work"
- Control other potential ignition sources.

Silane (SiH_4)

Silane (SiH_4) is pyrophoric and spontaneously reacts with oxygen in air at concentrations greater than 3 mol % (molar percent), resulting in fire. Silane, a dual hazard to health and flammability, can be handled safely as long as proper design, construction and maintenance are implemented. In addition to the recommendations for DCS and TCS, the following actions should be considered:

- Bond and ground all lines and equipment

Figure 1. Crushed polycrystalline silicon.

Figure 2. Engineer working in a plant wearing appropriate safety gear.

- Use restrictive flow orifices (RFOs) to control the purge for anything containing silane
- Install thermal sensing devices and alarms
- Require personnel to use self-contained breathing apparatus.

Hydrogen and hydrogen chloride

During maintenance activities when flushing and purging vessels or piping, it is important to remember that TCS and DCS react with water to produce hydrogen and hydrogen chloride. Care must be taken even when dealing with leaks of TCS and DCS due to the presence of hydrogen. During leaks, moisture in the air can produce hydrogen and hydrogen chloride.

Both anhydrous hydrogen chloride and hydrochloric acid are extremely corrosive. Hydrogen chloride is corrosive and irritating to the eyes, skin and mucous membranes. Inhalation may result in lung damage and water in the lungs and could be fatal. HCl can also attack most materials of construction in the presence of moisture, and reacts with many metals to release hydrogen gas. Careful planning should be made such that HCl contact with incompatible materials is avoided. It is best to control HCl maintenance activities so that any releases are directed to a scrubber.

Hydrogen is extremely flammable: with a lower explosive limit (LEL) of 4 vol % and an upper explosive limit (UEL) of 74.5 vol%, hydrogen can easily cause an explosion. As it burns with an invisible flame and gives off low thermal radiation, fires involving hydrogen may not be immediately detected and personnel may unknowingly enter a fire area. If a hydrogen fire occurs, the source of the leak must be isolated since fire-fighting methods may not stop an immediate recurrence.

Cleaning and passivation fluids

Piping and equipment are chemically cleaned and passivated to prevent process contamination. The chemicals used are aggressive in leaching impurities out of base metals in a controlled environment. These chemicals are highly corrosive and/or toxic.

Caustic (~50% sodium hydroxide)

Caustic is typically used to remove scale and organics from new, unused carbon steel. Due to exothermic reaction and splash risks, caustic must always be added to water slowly and in small amounts – never add water to caustic. Additionally, care should be taken to ensure only proper materials contact the caustic solution. Aluminium, zinc, or materials galvanized with zinc can produce hydrogen gas.

Caustic will cause severe burns and deep ulcerations on direct contact with skin. Eye contact may cause blindness. Inhalation can cause severe respiratory damage. Therefore, the work area where caustic solutions are being used should be well ventilated. Workers and spill responders should wear impervious gloves, boots, coveralls, goggles, full-face shield, and a NIOSH/MSHA-approved self-contained respirator when in close proximity to the container.

Dilute hydrochloric acid

Hydrochloric acid is typically used to etch carbon steel to remove free iron from new carbon steel already treated with a caustic solution or re-used carbon steel after proper decontamination. The safety issues mentioned herein regarding hydrochloric acid should be adhered to in these cases.

Dilute hydrofluoric acid

Hydrofluoric acid (HF) is used to etch stainless steel and is highly toxic. In low concentrations, exposure to HF may not be noticed for up to 36 hours. However, upon initial contact, health treatment must be initiated immediately or the exposure can be fatal, as HF penetrates human cells and rapidly dissociates into hydrogen and fluoride ions. The fluoride can penetrate and bind with calcium, magnesium, sodium, and potassium in the human body. The result is demineralization and systemic deficiency of calcium and magnesium with excess potassium. Because of the potentially life-threatening defects resulting from such exposure, medical treatment should be sought immediately.

Due to the severity of the hazards involved with hydrofluoric acid and the inability on the part of the affected subject to feel immediate contact, it is recommended that a dilute solution of HF with dilute nitric acid (HNO_3) be used. The HNO_3 provides an immediate burning sensation indicating when exposure has occurred, prompting immediate attention.

Workers and response personnel should be well trained in proper first-aid use and proper application of calcium gluconate gel for HF exposure as, for example, excessive application of calcium gluconate to the eyes can cause permanent blindness.

Dilute nitric acid

Nitric acid (HNO_3) is a strong oxidizer used for passivating stainless steel. HNO_3 is also extremely corrosive in the presence of aluminium and copper, and reacts violently with water to generate heat and toxic, corrosive, and flammable vapours. A water mist will help to control the vapours, and residue can be neutralized with a dilute solution of sodium carbonate.

HNO_3 burns on contact and is easily absorbed through the skin and respiratory tract. Exposure, even below 2ppm, can cause skin burns and penetrating ulcers, sight loss if contacted with the eyes, gastrointestinal tract burns and perforation of the digestive tract if ingested, and respiratory tract burning and pulmonary oedema if inhaled. Among other dangers, repeated inhalation can cause chronic bronchitis and kidney failure. Even in low concentrations, exposure can be fatal.

Therefore, extreme care must be taken when handling HNO_3. Even in well-ventilated areas, workers should wear impervious gloves, boots, suit, goggles, full-face shield, and NIOSH/MSHA-approved self-contained respirators when in close proximity to the container. Responders should wear the same in addition to a self-contained breathing apparatus.

Water

As discussed, water reacts with chlorosilanes to produce hydrogen and hydrogen chloride. However, another reaction product that must be taken into consideration is silicon dioxide. When starting up systems after a maintenance activity, equipment should be dried to a low dew point in order to avoid the corrosiveness of HCl and the damage it causes to the structural integrity and high purity condition of the equipment. This action also limits the formation of silicon dioxide which can form precipitates that clog up equipment, reduce the available surface area of heat exchangers, or spin around in pumps like shot blast until the pump casing is damaged. Therefore, it is very important to verify that all equipment and piping is drained and dried before going back into service.

We don't know what the stuff was, but it's pyrophoric!

Although the MSDS might not have documented advice and safety on each and every compound, there have been enough safety-related incidents in this industry to support the assumption that any piece of equipment in the TCS production and first stages of TCS purification may contain pyrophoric precipitates. Some reboilers are known to have them, and the design may include double block and bleed valves and spares for ease of maintenance, while others have no design features to accommodate the situation.

> "Any piece of equipment in the TCS production and first stages of TCS purification may contain pyrophoric precipitates."

The standard procedure prior to a maintenance activity is to drain the equipment, and purge it out with nitrogen prior to opening. It is possible to bleed a little steam into the nitrogen to see if there is a temperature rise in excess of the steam addition, indicating the presence of a pyrophoric compound. If a temperature rise does occur, one option is to continue the steam bleed until the compound burns itself out, but often that may take too long. Some prefer to close up the equipment, move it to a special fire watch yard equipped with a scrubber, and let it burn itself out in a controlled situation. Additional strategies are discussed in the following sections, but whatever the approach and whatever the strategy, a flaming condenser should not be taken off the top of a tower at any time.

Review of safety regulations and standards

There are many regulations provided by various governmental authorities and industry associations that cover the safe practices of designing and dealing with the hazardous chemicals of our industry. A partial list of standards providers includes those listed in Table 1.

Hazard Communication – U.S. Department of Labor, Occupational Safety and Health Administration (www.osha.gov)
NIOSH Pocket Guide (www.cdc.gov/niosh)
High Pressure Gas Safety Law of Japan KHK, Sumitomo-Tranomon Bldg., 4-3-9 Toranomon, Minatoku, Tokyo 105-8447
Toxic Gas Ordinance No. NS-517.445, Santa Clara County, California
The EEC Safety Sheets Directive 93/112 EEC
NFPA Standards, National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269
SEMI Standards (Semiconductor Equipment and Materials International), 3081 Zanker Road, San Jose, CA 95134
SEMATECH (SEMATECH Inc./International SEMATECH Inc.), 2706 Montopolis Drive, Austin, TX 78741 (www.sematech.org)
Compressed Gas Association, 1725 Jefferson Davis Highway, Suite 1004, Arlington, Virginia 22202
Uniform Fire Code, UFC, 5360 South Workman Mill Road, Whitter, CA 90601
The High Pressure Gas Safety Institute of Japan (KHK), Application Guide for the High Pressure Gas Safety Law
SSA Journal, Volume 11 No. 4, Winter 1997, SSA Journal Headquarters 1313 Dolly Madison Blvd. Suite 402, McLean, VA 22101
Factory Mutual Property Loss Prevention Data Sheets, Factory Mutual Engineering, PO Box 9102, Norwood, MA, 02062 (www.fmglobal.com)
Centre Européen des Silicones (CES), Avenue E. van Nieuwenhuyse 4, Box 2, B-1160 Brussels – Safe Handling of Chlorosilanes Material Safety Data Sheets

Table 1. Partial list of providers of standards for designing and dealing with hazardous chemicals in the PV industry.

Methods of planning for safe expansion

Proper expansion planning begins at the design stage of the original plant. Engineers must anticipate the need for future expansions and improvements as bottlenecks and design limitations are identified in the design phase of the original plant design, or subsequent expansion designs. Statements such as, "We will buy TCS and install a TCS Synthesis Unit later", or "Throughput of the Purification Unit is limited to 120% of design capacity, but our next phase will be 200% of current capacity", are common during original design phases. Others ask, "Do we modify the existing Off-Gas Recovery to increase capacity or duplicate the existing design?" or similar questions. These considerations underscore the need to plan the expansion in the original plant design.

Regardless of the considerations, one point is vital: do not restrict the options. Good plant designs provide flexibility to anticipate expansions and modifications without restricting options or disrupting ongoing operations.

The cost of planning for an expansion that might not occur for years can be difficult to take on board. Value engineering may try to limit the number of valves to reduce cost. A DN200 split-

Figure 3. It is critical that the controller coordinate the plant expansion work with the personnel for the areas impacted.


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Figure 4. Chemical plant fire.

body stainless steel ball valve can be very expensive in itself. Cleaned for high purity service in a double-block-and-bleed arrangement, two DN200 valves and a DN25 drain valve are extremely expensive. However, compared to stopping production, decontaminating, purging, installing the modification, cleaning, purging, and re-starting in order to make a tie-in for an expansion, the payback is immediate the day the pre-installed expansion valves are finally used. Since the existing system is not opened to atmosphere or exposed to construction activities, the risk of injury from corrosive or flammable contents is reduced, and operating product purity is not sacrificed.

> "Good plant designs provide flexibility to anticipate expansions and modifications without restricting options or disrupting ongoing operations."

This only works if the designers have the forethought to install tie-in valves in the required location, assuming the valves, piping, and equipment were sized for the increased capacity. For example, Dynamic Engineering was requested to reduce a header size from DN200 to DN150. Considering the owner's long-term production objectives, the options were presented as follows: 1) installing another DN150 pipe in a congested pipe rack later on in the expansion, or 2) keep the planned DN200 pipe with tie-in valves. The owners lamented the additional cost, but decided for flexibility. Two years later, the owners were praising their forethought.

Another consideration is installing flange connections at direction changes in the piping, which provides an easy location to tie in without cutting and welding. The downtime required to install a prefabricated, pre-cleaned, flanged spool versus a welded assembly is significant. Considering the impact on product quality, cutting and welding on pure process systems always diminishes product quality.

Not everyone's crystal ball can forecast the future needs of a plant. Tie-ins to existing operating systems are inevitable. With proper planning, design, decontamination, logistics, coordination, and control, the tie-in can be accomplished safely and quickly while minimizing effects on plant quality.

During a tie-in, the first thought should be to avoid hazardous chemical exposure. Care must be taken to decontaminate the system and create an inert atmosphere. Depending on the specific hazard, the process chemical(s) must be removed. Systems that are suspected to contain pyrophoric polymers should be flushed with STC, the remainder of which can then be heated and vented to the scrubber. STC works well to pacify and to soften the various pyrophoric polymers. The system can then be purged with nitrogen until acceptable testing conditions are met. Similarly, other hazardous systems can be drained and purged with dry nitrogen until acceptable testing conditions are met.

After decontamination, care should still be exercised. Always assume that the full hazard is still present. Refer to the MSDS for proper personnel protective equipment. Fireproof blankets, fire extinguishers, flange covers, and emergency medical personnel should be at the work site during tie-in activities. The system should be broken at flanges to ensure that residual liquids are removed, and the flange facings should then be immediately covered with fireproof blankets. Bear in mind that the system is an oxygen-deficient environment.

Construction begins

Once the expansion needs and hazards have been identified, construction activities are ready to begin. All materials – be they definitely required or not – should be staged to accomplish the goals for all projects in the area with minimum relocation effort. Only trained, experienced, supervised personnel should be employed when working these hazardous or pure process systems. An experienced controller should coordinate to accomplish the project goals as safely and quickly as possible. To ensure the multi-faceted project is orchestrated, the controller should communicate the plan and review with all plant personnel and contractors involved. Everyone needs to understand their role, and how it affects others.

Planning begins months before the event. The coordinator needs to request that all plant and project managers submit their requests three months in advance, or earlier if long lead items are required. Ten weeks ahead of time, the initial list of activities should be distributed. Production and project managers, supervisors, operators and maintenance should be involved in the review process, and 'finalize' the plan four weeks ahead of time. Instrument and equipment failures will occur after the plan is 'final,' and will need to be addressed. These should be anticipated by allocating space and resources to accommodate the unknown.

> "Once the expansion needs and hazards have been identified, construction activities are ready to begin."

The second step of planning after the activities are defined is the dedication of specific areas for them such as equipment lay down, hot work zones, acid washing, staging for bulk nitrogen trucks, routing for temporary scrubber connections, and any other requirements. These should be assigned to specific areas to allow emergency access to all of the plant. Timing of these activities also needs to be considered to prevent activities from interfering with each other.

Finally, a logistics safety and contingency plan should be developed, taking into consideration each activity and potential hazards. For example, a condenser may have unknown pyrophoric precipitates that catch fire when opened. In such a case, fire equipment should have been staged, and the lay down area situated so the smoke plume does not prevent workers from accessing their work.

During expansions and upgrade projects, the perceived success or failure of a project might have nothing to do with the design or construction of the project. The success of a project is often determined by the time required to meet purity requirements, but the rewards of a fast-track project are wasted if the short cuts taken cause extensive delays (sometimes up to several months) for the system to reach acceptable purity. Furthermore, expansions and upgrades that interact with existing production may jeopardize its previously reliable quality. If a project is completed ahead of schedule and under budget, but the resulting polysilicon quality is not suitable for

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sales for several months, the project would be deemed a failure.

In order to ensure project success, after pressure testing, a thorough cleaning procedure should be used to minimize time to product purity and maximize reliability of results. There are several qualified procedures available for cleaning metals for high-purity applications. For example, ASTM A967-05e has procedures for cleaning stainless steel in high-purity applications. However, in selecting a specific procedure, care must be taken to ensure that the chemicals and components used do not introduce undesired contaminants. Some ASTM A967-05e procedures allow the use of stabilizers and inhibitors which may contain phosphorous, an impurity of concern for polysilicon. Each chemical and application should be evaluated for the required results.

Cleaning equipment and piping for high-purity service will be wasted if not properly protected. The chemicals used for cleaning and passivation must be thoroughly removed. Simply flushing with water may not remove the residual from the grain structure of the metal. Steam cleaning is often used to flush any embedded, residual chemicals from within the metal grain structure, a step that should be followed immediately by drying with inert gas. Omitting this step might cause localized embrittlement and premature failure. Finally, the dried system should be sealed under a positive pressure, inert environment to prevent moisture ingress or airborne contamination. Whether using a dip-cleaning or circulation method, these steps are required to ensure long-term operation of the process with minimal time to reach product purity.

A start-up, whether for a new plant, expansion or upgrade, is challenging enough for any chemical process. Commissioning activities, the urgent need to start production and lack of experience in operating a new system add to safety concerns. The plant must be assembled cleanly, commissioned without leaks, started up without incidents and must produce a high-purity product in a timely manner.

Similar to the design and construction phases of a project or expansion, nothing is better for start-up than early and thorough planning. Successful planning should include the following: a detailed start-up program; sufficient people and resources on hand prior to start-up; training that covers the new process; a contingency plan for upsets and emergencies; a commitment from management to allow time to effectively complete the project.

After cleaning and inert verification, start-up of a polysilicon process employs the steps of introduction of chemicals, circulation and production. Each must be thoroughly planned and communicated to every member of the start-up team. Any shortcut or omission can create problems that would require maintenance, and consequently the re-introduction of potential for exposure and contamination.

Upsets and emergencies create the greatest potential safety concerns during a start-up. Operator training must include not only the specialized procedures for high purity operation, but response to upsets and emergencies to prevent chlorosilanes release or equipment damage. Training programs should include standard operating practices that have been well reviewed with 'what-if' approaches of HAZOP.

Emphasis should be placed on handling the corrosive and flammable chemicals and the methods for achieving and maintaining high purity without sacrificing safety or efficiency. With so many new polysilicon manufacturing facilities under development, the experience necessary to handle upsets and emergencies may not reside with the employees in the plant. Use of experienced third parties can greatly reduce the learning curve both in the planning and operating stages.

Conclusion

Though polysilicon production brings with it a multitude of hazards, projects can be implemented to ensure product supply and create a safe environment for employees and the communities in which they operate. Execution planning is critical for projects to achieve the three key measures of success: safety, high purity and minimal down time.

In addition to the guidance provided herein, a producer should always consult with their local fire department, insurance carrier and any other regulatory agencies or body to ensure that they are in full compliance for local regulatory requirements for personnel and environmental protection. A steep learning curve is dangerous and costly.

About the Authors

Jon Bill is the vice president of Technology and Engineers at Dynamic Engineering, Inc. Before joining Dynamic in 2001, he worked for 12 years at Bayer Corporation in various engineering and process development positions. He is a licensed Professional Engineer and holds a B.S. from Purdue University in chemical engineering.

Greg Heausler, P.E. is the director for Startups and Services at Dynamic Engineering, Inc. He worked for 30 years in various engineering and management positions before joining Dynamic. He holds a B.S. in chemical engineering from Louisiana State University and is a Professional Engineer and Project Management Professional.

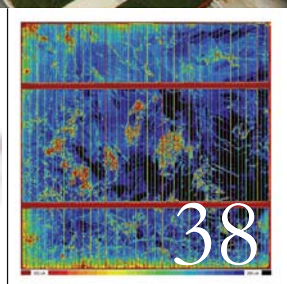
Scott O'Briant, P.E. is a lead mechanical engineer at Dynamic Engineering, Inc., before which he worked for Mitsubishi Polycrystalline Silicon and for Shunda Holdings. His experience includes mechanical design, evaluation, and installation of processing systems and equipment, as well as research and evaluation of composite materials. He holds an M.S. and a B.S. in mechanical engineering from the University of South Alabama.

Enquiries

Dynamic Engineering, Inc.
654 N. Sam Houston Parkway E.
Suite 200
Houston TX 77060
USA

Tel: +1 281 617 0099
Emails: jbill@dynamicengineer.com
sobriant@dynamicengineer.com
gheausler@dynamicengineer.com
Web: dynamicengineer.com

Materials

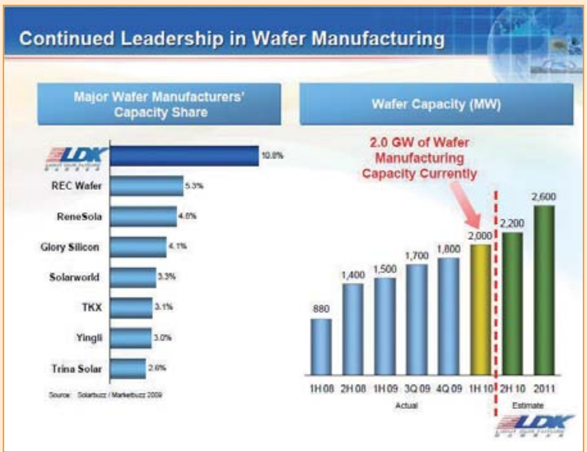


News

LDK Solar becomes largest wafer producer

At an investor event held at LDK Solar's main solar wafer manufacturing complex in Xinyu City, China, the rapidly scaling integrated PV producer noted that it had reached an annualized wafer capacity of 2GW, claiming to be the largest solar wafer producer in the world. In a series of presentations the company highlighted that wafer capacity would rise to 2.2GW in the second half of 2010 and reach 2.6GW by the end of 2011. The company also updated plans for polysilicon production and manufacturing costs as well as solar cell production start-up and ramp. Significantly, LDK gave insight into its technology roadmap plans that include multi-crystalline solar cell efficiencies targeting between 19 and 21% in 2014.

Highlighted developments at the analyst event included the expected start of solar cell production in the third quarter, which will initially have a capacity of 60MW. However, LDK Solar plans rapid expansion to 240MW in the fourth quarter of 2010 and by the end of 2011 reach a solar cell capacity of 480MW. Solar cell production is for its internal module requirements which will help to reduce module costs as the ramp increases through the year.



LDK Solar wafer capacity ramp (2010).

Polysilicon News Focus

Polysilicon problems to persist, according to new report from Bernreuter Research

According to a new report from Bernreuter Research, entitled 'The Who's Who of Solar Silicon Production,' despite strong solar module demand, pressure on the silicon prices rising will likely be limited this year. Bernreuter Research estimates that global polysilicon production will reach 250,000MT in 2012, with approximately 80,000MT produced in China alone, making up about one-third of global production.

Johannes Bernreuter, founder of the research firm, told PV-Tech that polysilicon supply/demand dynamics this year would translate into spot pricing in the range of US$45 to US$50/kg. However, this price decline will cause problems for many of the new and smaller polysilicon producers, according to the research firm.

"The Chinese polysilicon industry will undoubtedly become an important player in the global market," noted Frank Haugwitz, photovoltaics consultant in Beijing and co-author of the report. "However, about 20 smaller manufacturers, which had an annual production capacity of only 1,500 MT or even less at the end of 2009, are the first potential candidates for consolidation."

Bernreuter clarified the issue of 'consolidation,' suggesting many would simply go out of business. This is due only in part to manufacturing cost disadvantages compared with significantly larger competitors, but can also be attributed to smaller producers' financial strength and ability to survive a period of loss-making while prices fell below manufacturing costs.

Bernreuter explained that, as a rule of thumb, smaller start-ups would be able to achieve production costs of above US$40/kg in the first and second year of ramp up. All those who are still in this phase in 2011 will start to suffer financial problems.

What isn't clear yet is whether the expected consolidation will have a meaningful impact on polysilicon overcapacity and potentially lead to a rise in prices. Solar energy demand dynamics is also a contributing factor, which because of its volatile position makes such a call even more difficult.

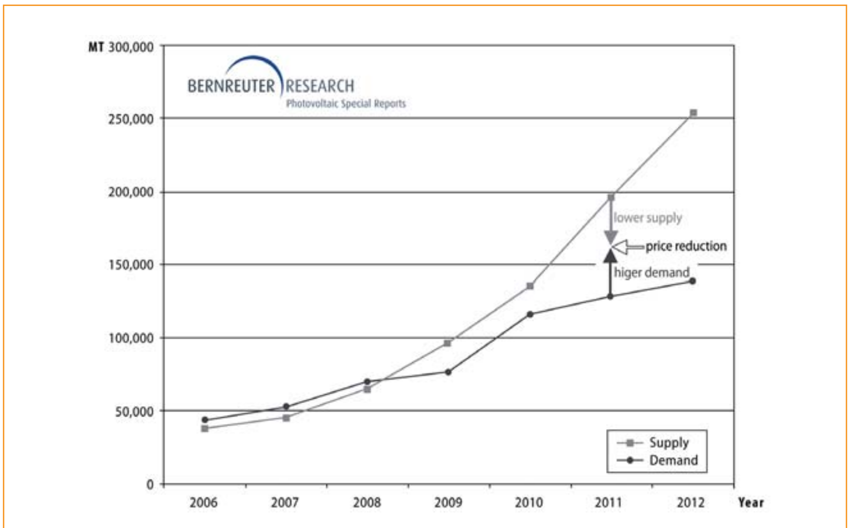
Perhaps more controversial is the report's claim regarding different technologies fighting to compete with the traditional Siemens process for polysilicon production.

Bernreuter Research examined nine alternative production methods to the standard Siemens process, noting that "none of them will challenge the Siemens process in the short term. In particular, fluidized bed reactor technology has not delivered on its promise of lower manufacturing costs."

Bernreuter believes that the high capital investment costs of developing and scaling FBR processes are at the root cause of the technology not meeting a 30% lower manufacturing cost compared with the Siemens process. The resulting high depreciation drives up total manufacturing costs, according to the analyst.

However, he recognised that both Wacker and REC have functional reactors now, so the technical challenges are behind them. It should be noted that MEMC has been using the FBR process successfully and was a pioneer in its use.

As far as upgraded metallurgical-grade (UMG) silicon, the research firm projects the technology will only play a marginal role with a market share of less than 1% through 2012.



Bernreuter Research: polysilicon supply and demand forecast

News

Wacker's Burghausen site facilities now officially on stream

Wacker Chemie's Burghausen site is now complete with additional polycrystalline-silicon production facilities officially on stream. All 'Expansion Stage 8' deposition reactors are up and running with the company expecting the plant's full nominal capacity of 10,000MT a year will be reached before the end of Q2 2010.

Wacker is investing around €500 million in this expansion stage, creating approximately 200 new jobs. The new facilities manufacture material for both the solar sector and the semiconductor market. Expansion Stage 8 has increased Wacker's annual polysilicon production capacity to over 25,000 tons.

A further plant with a 10,000-ton annual polysilicon capacity is currently being built at Wacker's Nünchritz site. This will bring Wacker's total investment in its capacity expansion program, which began back in 2000, to around €2 billion.

REC expects better financial performance in second-half of year

Massive investments in polysilicon through to solar cell and module expansions in three continents over the last couple of years are finally coming to an end and Renewable Energy Corp. (REC) expects to benefit from significantly lower production costs across its fully integrated business model. That was a key theme of its first-quarter financial conference call. But declining prices throughout the production chain mean that execution will be a key factor to better financial conditions going forward.

The company has been losing money since the economic crisis took hold in the fourth quarter of 2008. However, losses have been falling quarter-on-quarter, with REC posting a loss of NOK 125 million in the first quarter.

President/CEO Ole Enger noted that customers are not only demanding better pricing but higher quality polysilicon and wafers. Polysilicon contracts pricing has remained under pressure though not as intensively as in 2009. The demand for higher quality wafers is due to the balanced supply and demand dynamics as well as the need for PV manufacturers to boost conversion efficiencies with the help of higher-grade polysilicon and wafers.

Total polysilicon production in the first quarter was 3,322MT, of which 2,441 MT was solar and electronic grade. Fluidized bed reactor (FBR) production continued to increase, reaching 1,721MT in the quarter. However, approximately 700MT was below acceptable grade and was sold at a significant discount, because of the need for further refining by customers to reach solar-grade specification. This could have therefore contributed to the 14% decline in polysilicon prices in the quarter.

REC Singapore's new integrated PV plant.

Higher wafer capacity and improving utilization saw wafer production increase to 272MW in the first quarter, of which 9MW came from its new advanced facility in Singapore. REC produced just 16MW of monocrystalline wafers from its new plant in Glomfjord but there was no production from the pullers producing five-inch wafers in the quarter. As with polysilicon prices, wafer ASPs declined 16% in the quarter, indicating perhaps that slowing price declines often muted because of strong end-market demand have not actually been as widespread as touted.

LDK Solar continues to ramp its 15,000MT annualized capacity polysilicon production plant

LDK Solar's second 5000MT train in its 15,000MT polysilicon plant has now achieved mechanical completion and will begin ramping production. The first train is operating at capacity in full closed-loop mode and is on track to produce at the annualized capacity of 5000MT.

"This achievement confirms the design basis of our polysilicon plants. Our experience in ramping the first 5000MT train will enable us to more quickly ramp the second 5000MT train to full production capacity," stated Xiaofeng Peng, chairman and CEO of LDK Solar. "The combined annualized production capacity of 10,000MT for our first and second trains will provide economies of scale with low power consumption through 48 rod reactors and continue to drive down production cost. We look forward to continuing to expand our polysilicon output throughout the year."

LDK Solar polysilicon rods produced by advanced Siemens process.

Hoku Materials manufactures first polysilicon at Idaho plant

Hoku Materials has announced the successful production of polysilicon at its manufacturing facility in Pocatello, Idaho. The company produced the material after completing a comprehensive system commissioning protocol, which culminated in deposition runs in a select number of its installed polysilicon reactors.

Hoku Materials explained that the primary purpose of the testing was to confirm system integrity and validate operating procedures and that it had operated the reactors continuously for approximately five days during the final phases of the commissioning procedure. During the live reactor runs, Hoku utilized trichlorosilane purchased from third-party suppliers.

"This is an historic day for Hoku," said Scott Paul, president and chief executive officer at Hoku. "We have completed the first step in our planned production ramp-up and successfully manufactured our first batches of polysilicon."

Yingli's Fine Silicon unit completes most of production trials, remains on track for mid-2010 ramp

Yingli Green Energy says it has completed most of its polysilicon and silane production trials at its in-house polysilicon manufacturing facility, Fine Silicon. The company's plans remain on track to achieve fully integrated polysilicon production at the 3000MT capacity plant by mid-2010.

Fine Silicon successfully commenced the three steps of trial production - which consist of silane production, trial operation of the CVD reactor, and associated process

News

steps - and reached certain key technology and operating milestones in December 2009. Yingli said it has completed approximately 75% of the trials for the polysilicon production process, including successful trial operation of the reactor, and nearly half of the trials for the silane production process.

Wafer News Focus

Ceradyne expanding ceramic crucible production in China to meet global demand

Vertically integrated ceramic crucible producer Ceradyne is expanding capacity in China to meet global demand for crucibles used in the production of multicrystalline ingots for the PV industry. Ingot production is being rapidly expanded across fully integrated PV manufacturers as well as pure-play wafer producers. Ceradyne is a leading supplier of advanced ceramic crucibles to the PV industry.

Specifically, Ceradyne is increasing its capacity during the first half of 2010 at its existing facility, Ceradyne Tianjin Technical Ceramics. The 98,000 square foot facility in Tianjin, China became operational in June 2007. Construction of a new 218,000 square foot facility in Tianjin for Ceradyne Tianjin Advanced Materials is already under way at an estimated cost of US$34 million and is expected to come onstream in early 2011. The company also has production capacity in Atlanta, Georgia.

When this phase of expansion is complete, the combination of existing and new capacity will enable Ceradyne to remain a leader in global supply with the ability to readily distribute crucibles to any location in the world, the company said. All three facilities will have the capability to supply the traditional crucible sizes such as for 450kg ingots but are also equipped to produce custom and next-generation sizes as well.

Ceradyne ceramic crucibles.

Consistent with its existing facilities the new plant will incorporate proprietary technology to apply a silicon nitride release coating to any crucible as an option for customers who desire the flexibility to cost effectively optimize their internal facility utilization.

Ceradyne in recent years has developed a proprietary silicon nitride coating designed to act as a barrier between the molten silicon and the crucible, eliminating ingot sticking and fracture which promotes improved production consistency and reduction in wafer losses.

Ceradyne Tianjin Advanced Materials will also include technology and equipment from Minco and ESK, two of Ceradyne's other global entities. From Minco's facility in Tennessee, which supplies engineered systems to the precision investment casting (PIC) industry as well as all fused silica raw materials for crucible production in both China and the U.S., grinding and blending technology will be incorporated.

ESK, headquartered in Kempten, Germany, will supply process technology to the facility for silicon nitride and boron carbide ceramic components and coating systems.

PV Crystalox wafer shipments up, revenue and profits down: wafer capacity to expand to 600MW

Suffering from the rapid price declines for solar wafers in 2009, PV Crystalox Solar saw revenue and profits fall, despite a small increase in wafer shipments, according to its 2009 financial report. PV Crystalox posted revenue of €237.3 million, down 13.4% from 2008 when revenue reached €274.1 million. However, profits were down approximately 70% (€42.5 million in 2009, compared to €147.2 million in 2008) due to the collapse in wafer prices, despite long-term pricing contracts. Total wafer shipment volume was 4% higher than in 2008 at 239MW.

Japan and Germany continued to be the company's major customer base with 76.9% (2008: 84%) of revenues obtained in these two countries. However, the company noted that China was now accounting for a larger percentage of its business, increasing from 6% in 2008 to 9% in 2009.

Green Energy Technology remains at full capacity despite ingot expansion

In releasing monthly sales figures, Taiwan-based Green Energy Technology (GET) noted that it was still at full capacity utilization after further capacity expansions. This is the third consecutive quarter the company has been at 100% utilization. GET said that its annual capacity for ingot growing had reached 410MW, up from 360MW in Febraury, 2010. Wafer slicing capacity had also reason from 300MW in February, to 360MW.

GET reported net sales for March of NT$ 1,202 million (US$38.1 million), an increase of 15.8% from the previous month and a 126% increase YoY. First quarter sales totalled NT$3,300 million (US$104.6 million). The company reiterated that its expansion plans to 500MW during the second quarter were on schedule.

Mosel Vitelic headquarters.

Mosel Vitelic cancels wafer supply contract with LDK Solar

According to reports, Taiwan-based Mosel Vitelic has cancelled a five-year solar wafer contract with LDK Solar and is seeking US$46 million in refunds of its downpayment and compensation for noncompliance with the contract, which was signed in 2007. Mosel Vitelic also claimed that during peak demand cycles, LDK Solar was unable to meet contracted wafer quantities, resulting in business being turned down. Mosel Vitelic has a 60MW production capacity for crystalline solar cells.

Mosel Vitelic signed a wafer supply deal with South Korean wafer supplier Nexolon in 2008, which means Mosel had sufficient wafer supply from sources other than LDK Solar.

1366 Technologies completes NREL PV precincubator ahead of schedule, starts ARPA-E program

1366 Technologies said it has completed its National Renewable Energy Laboratory PV Technology Preincubator program six months ahead of schedule. The crystalline-silicon photovoltaic equipment company signed the contract with NREL in October 2009 for the development of its "Direct Wafer" technology, a "kerfless" approach which produces silicon wafers directly from the silicon melt without casting or sawing and has the potential to reduce wafer production costs by as much as 70%.

The $500,000 NREL preincubator grant was the first of two government awards received by the Lexington, MA-based company to develop Direct Wafer: the technology was also the only PV-oriented recipient of an award (worth $4 million) from the Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) program.

By completing the NREL program early, the company says that it was able to begin its ARPA-E efforts in March, positioning the company to start building a factory in 2011.

IQE develops new 6" wafer capability for CPV solar applications

IQE, a global supplier of advanced semiconductor epitaxial wafer products and wafer services to the semiconductor industry, has developed epitaxial processes for producing high-efficiency, triple-junction concentrator PV solar cells with comparable results on both 6-inch (150mm) diameter germanium (Ge) and gallium arsenide (GaAs) substrates.

The group has been working with a number of key partners over the last two years to develop advanced, multijunction solar technologies for the provision of large-scale renewable energy.

Chemicals and Gases News Focus

Air Liquide bags exclusive sales agreement with SiXtron

An exclusive agreement with SiXtron Advanced Materials will allow Air Liquide to offer advanced coating materials that tackle light-induced degradation (LID) problems for crystalline-silicon solar cells, which compliments Air Liquide's own advanced precursor materials. The Silexium process solution combines

SiXtron Advanced Materials' solar cell coating.

proprietary precursor molecules with SiXtron's 'SunBox' gas generation system to deposit solar cell films. Financial details of the deal were not disclosed.

"This global partnership with SiXtron demonstrates Air Liquide strategic interest to provide its photovoltaic customers with the safest, most advanced and lowest cost-of-ownership gases and precursors solutions in the market," noted Francisco Martins, Vice-President World Business Line Electronics of the Air Liquide Group.

PV materials firm Voltaix scores US$10M in financing from MissionPoint

Photovoltaics and semiconductor materials provider Voltaix has received US$10 million in equity financing from private investment firm MissionPoint Capital Partners. Voltaix previously announced that it plans to build a manufacturing facility in Northampton County, PA, with construction set to begin in the second quarter and operations projected to ramp in 2011.

Solar polysilicon start-up Hoku Materials inks deal with Evonik Degussa for trichlorosilane supply

Polysilicon manufacturing start-up Hoku Materials has a supply agreement with Evonik Degussa for the purchase of trichlorosilane, a key process chemical. Hoku said it plans to use the TCS supplied by Evonik, together with TCS from other potential suppliers, to support the first phase of commercial production at its polysilicon facility in Pocatello, ID. Financial details of the deal were not disclosed.

The agreement calls for Evonik to supply Hoku with a guaranteed quantity of TCS during the initial contract term of approximately one year. The polysilicon company will have the option to request quantities of the chemical in addition to the monthly guaranteed take or pay amount.

Dynamic Engineering, PST enter into polysilicon alliance

Dynamic Engineering (DEI) has formed a strategic alliance with Polycrystalline Silicon Technology (PST). DEI now offers PST's advanced hydrochlorination technology as well as its fully closed-loop chlorosilane and silane technology.

Prior to this agreement, the majority of DEI's TCS reactor licenses were based on chlorination technology. While both technologies are broadly used in the polysilicon industry, in some cases hydrochlorination can offer lower capital investment and operating costs due to the more efficient chemical conversion of STC versus thermal conversion.

Product Briefings

KUKA

KUKA's Advanced Wire Saw Machine series offers thinner wafer slicing

Product Briefing Outline: KUKA's fully integrated wafer lines and single machines for silicon slicing have been developed to meet the demand for high-quality wafers and high technical availability of the production machinery. The 3800 and 4800 series Advanced Wire Saw Machines (AWSM) are characterized by innovative technical features and numerous advantages, such as slicing of a wide range of hard materials.

Problem: With increasing pressure on wafer and cell ASPs and greater upfront capital cost for capacity expansions, factors such as production yield, product quality and machine uptime are key to reducing production costs. Continuing cell and module price declines require thinner wafers and/or higher wafer quality to reduce material costs and improve conversion efficiencies.

Solution: KUKA's AWSMs can use different wire types for the sawing process. This is in line with the trend towards finer saw wires and the fact that diamond wire is becoming more popular. The integrated capstan wire tensioning device also optimizes and controls the wire tension, thereby significantly increasing the service life of the principal mechanical components, which reduces downtime and maintenance time of the saw, optimizing the spare parts requirements and minimizing operating costs. The optimized ingot loading offers ergonomic advantages, as does an optionally available swivelling unit that enables suspended unloading.

Applications: The 3800 series is a fully automatic three-wire guide saw machine for slicing hard and expensive materials such as ingots of silicon, germanium, GaAs, InP and other materials. The 4800 series is a fully automatic four-wire guide saw machine for slicing hard and expensive materials up to 18" in diameter.

Platform: The design of the machines utilizes advanced methods for improving stability parameters and long service life of the parts subjected to higher stress (bearings, shafts, wire guide etc.).

Availability: Currently available.

GT Solar International

DSS450HP ingot growth furnace from GT Solar provides 15% faster process time and reduced energy consumption

Product Briefing Outline: GT Solar International has launched the 'DSS450HP,' a high-performance ingot growth furnace with a thermally optimized, second-generation hot zone for improved throughput while delivering excellent crystal quality. Current users of GT's DSS450 can easily migrate to the new DSS450HP with a field upgrade kit.

Problem: Lowering the cost of ingot manufacturing is critical to helping reduce the overall cost per watt. With high investment costs in the wafering sector that has also suffered from high price declines, the need for improved productivity, lower cost of manufacturing and increased yield and product quality is even more crucial.

Solution: The high-throughput DSS450HP furnace produces large ingots rapidly – down to 52 hours – resulting in a 15-20% improvement in productivity. Silicon is directionally solidified into a square ingot and later cut into 25 bricks. GT Solar's innovation and expertise in mechanical design, vacuum and high-pressure chambers, control system design, and crystal growth modelling, provide a technologically advanced system that is claimed to consistently produce high-quality ingots that optimize mass ingot yield. Furnace output is calculated at 8MW per year (assuming 15.8% efficiency from 156mm cell lines).

Applications: Directional Solidification System (DSS) furnaces that cast multicrystalline ingots.

Platform: Dimensions: w x l x h: 3823mm x 4774mm x 5105mm (151" x 188" x 201"). Ceiling height: 6000mm (236"). Power for entire system: 200kVA, 400-480V, 3 Ph, 50/60 Hz. Power factor: Ave 0.93. Cooling water: 120 to 130 litres/min at 3.4 to 4.5 bar. Argon: 65m^3 per ingot. Helium (optional). Weight approx.: 10,200kg (22,440lb)

Availability: Currently available.

Triulzi Cesare

Triulzi's glass washing and drying system reduces water consumption

Product Briefing Outline: Triulzi Cesare has introduced a new system for glass washing and drying that is claimed to produce higher quality PV panels at a reduced cost, using reverse osmosis water treatment. The SY.1610.6.3.4 is a horizontal solution to panel cleaning but is also available in a vertical solution.

Problem: Effective cleaning of substrates and cover glass is required to ensure solar cells can operate at maximum performance. Increasing attention to reduce water consumption is required for environmental and production cost requirements. The monitoring of the water quality feature is essential.

Solution: The machine is supplied with inlet roller conveyor, prewash section, washing section with three pairs of cylindrical brushes using a reverse osmosis cascade system and heated water system. Drying is done by four air knives fed by a high-pressure fan fitted on the top of the machine into a sound-proofed box to reduce noise level and final outlet roller conveyor. The machine is equipped with an energy saving system and PLC controls. A conductivimeter is used to maintain the correct water parameters and constantly refreshes the water in the tanks using a cascade system.

Applications: Glass preparation, pre-lamination and after the process where required.

Platform: Working width from 660 to 3400mm. Strong welded construction: beams support rollers and collection tank, while the parts that are in contact with water are made of stainless steel (bolts and nuts, pipes, pump, filters included). Stainless steel tray removal for glass scrap recovery; rubberized vulcanized and rectified conveyor rollers; upper prewashing uses four cylindrical brushes; drying by four blowers. The high-pressure fan is located in a soundproof acoustic enclosure.

Availability: Currently available.

Advantages and shortcomings of UMG silicon in photovoltaic device production

Rainer Krause, **Harold Hovel**, **Eric Marshall**, **Gerd Pfeiffer**, **Zhengwen Li**, **Larry Clevenger**, **Kevin Petrarca**, **Davood Shahrjerdi** & **Kevin Prettyman**, IBM Corporation, Yorktown & Fishkill, New York, USA & Mainz, Germany; & **Steve Johnston**, NREL, Golden, Colorado, USA

ABSTRACT

Upgraded metallurgical-grade (UMG) silicon is a lower cost and lower quality form of solar-grade silicon that is capable of producing solar cells at over 16% efficiency. This paper presents some of the economic advantages and technical concerns and solutions associated with producing silicon based PV from UMG, as well as preliminary solar cell results using this material. Results are based on a comparison of cells made in a turnkey line (Schmid Group) using alloy blends of 10%, 20%, 30% and 100% UMG, mixed with solar-grade Si before ingot growth. Detailed characterization was carried out on these finished cells according to lifetime, LBIC, diffusion length and luminescence imaging to determine correlations of performance with basic parameters. Requirements for material cost and cell performance necessary for UMG solar cells to be cost competitive are also presented.

Introduction

Several years ago, the price of silicon-based PV devices was significantly higher (1.5-3.5x, depending on spot vs. locked in prices) than they are today. Due to the plethora of government subsidies in the industry, particularly in Europe, 'high' average selling prices (ASPs) often provided manufacturers with healthy profit margins. However, the amount of subsidies has been decreasing at a significant rate, some to the point of elimination. Additionally, price pressures on silicon-based PV cells and modules from thin-film manufacturers have resulted in costs below US$1/watt.

Roughly half of the cost of a silicon-based cell can be attributed to the cost of raw materials, specifically silicon, which was constrained across the globe due to the large number of new cell producers entering the market, bringing with them a corresponding increased need for the limited silicon. At that point in time, the price of silicon was extremely high, with some spot prices hitting above US$350 per kg for solar-grade material. Longer-term contracts could be locked in at around US$70 per kilogram if the buyer was fortunate.

An alternative then appeared on the scene, one that demanded further technical exploration before it could be used as a silicon source on a large scale in the PV industry. That alternative material was UMG silicon, which, at the time, cost as relatively little as US$30-35 per kg for UMG vs. >US$70 per kg for solar grade. With such a severe price differential, significant cost decreases could be achieved if UMG could provide or could be made to provide the same or nearly the same solar efficiencies and reliability as solar-grade silicon.

Experimental data and findings

The experimental approach used in this review involved the comparison of cells made in a turnkey line using alloy blends of 10%, 20%, 30% and 100% UMG, mixed with solar-grade Si before ingot growth. Measured minority carrier lifetimes ranged from 2 to 8 microseconds in finished cells. Diffusion length maps were not well correlated with lifetime maps on these same cells. A possible explanation is that since the measured diffusion lengths of 200–250 microns (except for the 100% UMG at 140–180 microns) are comparable to the wafer thickness, the measured value may become insensitive

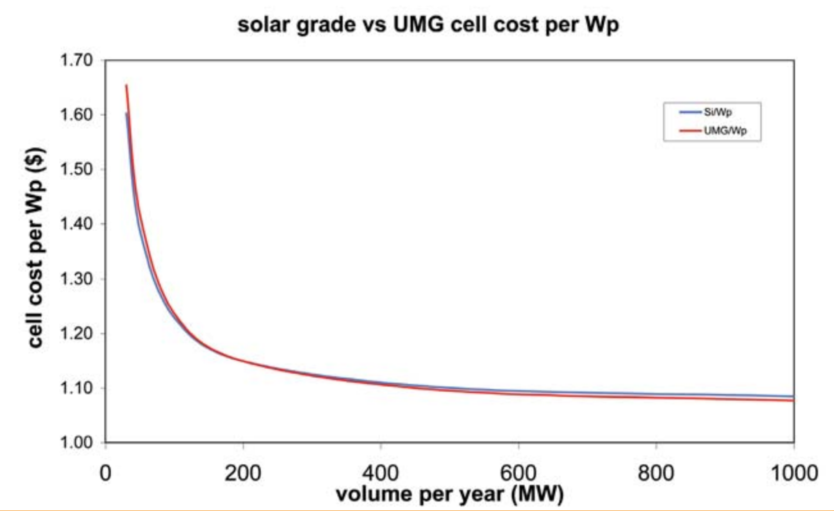


Figure 1. Typical learning curve showing cost vs. factory volume. Cell cost is compared per Wp between solargrade and UMG wafer material.

Source: IBM cost model.

Composition	Resistivity (ohm-cm)	Lifetime (μsec)	Fill Factor (%)	Efficiency (%)
100% UMG	0.5-0.7	1-2	74.1	14.5
30% UMG	1.6-2.7	7-8	73.6	14.6
20% UMG	1.2-3.1	N/A	73.0	14.7
10% UMG	0.7-2.8	N/A	75.2	15.0
Solar Grade	1.8-2.3	8-9	73.2	14.1

Table 1. Comparison of cell parameters for various blends of solar-grade (MEMC) and UMG material.

to the actual value. Similarly, the lifetime values may be adversely influenced by the cell's metallized backside, even though the excitation and detection are both carried out on the wafer fronts. Initial quantum efficiency measurements were also somewhat insensitive to position on the wafer, whether measured in low or higher lifetime regions.

> "With the lifetimes measured after gettering, efficiencies comparable to typical solar grade of >16% are expected for UMG-based material."

Forensic loss analysis is being used to ascertain major contributors and detractors to device performance. Optical losses in the blue-coloured surfaces amount to between 8 and 9%. All solar cell parameters were lower than normal: V_{oc} values are 610–620 millivolts, with photocurrents of 31 to 33mA/cm² and FF values of 0.72 to 0.75. High shunt conductances may account for the low fill factors and V_{oc}s, while slightly high series resistances may account for lower short circuit currents. However, the low photocurrent values are consistent with the measured lifetimes and diffusion lengths. Solar cell modelling was used to investigate the reasons for the lower performance, which was mostly due to the poor lifetime values.

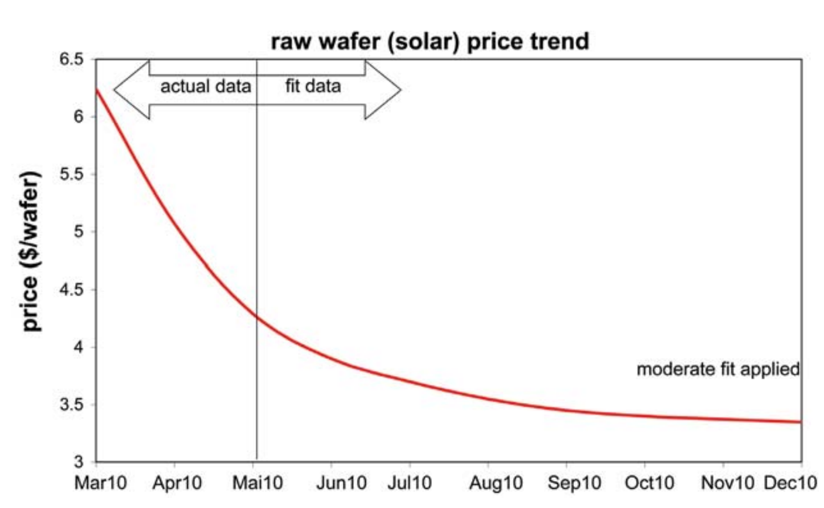
Phosphorus gettering at 840 to 900°C for 30 to 90 minutes raised the starting effective lifetime to as much as 110 microseconds in the 20% UMG blend (20% UMG/80% solar grade) and 70 to 80 microseconds in all other blends. The 100% UMG was the exception, where lifetimes of only 20 microseconds were obtained. Lifetime maps show that larger grain size regions exhibited the largest lifetime improvement while small grain regions closer to the wafer edge showed the least improvement. Lifetimes of 10–20 microseconds are consistent with the diffusion lengths of 200–250 microns observed. A lifetime of 20 microseconds in the 100% UMG material after gettering would have boosted the diffusion length in that material by a factor of two, raising the efficiencies to the 15% observed in the UMG/solar-grade blends. With the lifetimes measured after gettering, efficiencies comparable to typical solar grade of >16% are expected for UMG-based material.

Economics and justification for investigating UMG

There are a number of UMG producers in the market providing a product that potentially could produce a cost advantage over competitors, inside and outside of the silicon-based PV industry. It is necessary for UMG to have acceptable (equivalent?) efficiency and reliability, comparable to devices made from semiconductor or solar-grade material, which had been in use for nearly 30 years. One such producer of this material is New York-based Globe Specialty Metals (GSM).

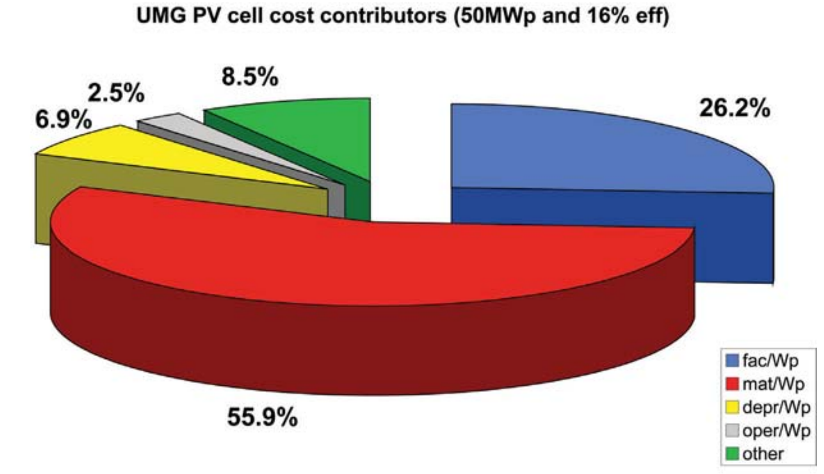
Efficiency is a relatively simple and quick measurement to make and a producer's claims can be easily verified. Reliability measurements are not quite so simple, however. Claims are often made in the industry regarding a product's longevity with very little data available to back them up. Since there are so many relatively new companies producing PV devices, very few have cells that have been operating for the 20 to 30 years often expressed in the warranty. Relatively little work has been done in acceleration studies often used in the semiconductor industry in order to determine the Weibull plots and parameters needed to predict failure within a population. Temperature and humidity chambers needed for the studies exist, but the mathematical relationship between the various parameters are often not well understood.

If one could show that UMG is or can be made less expensive with an efficiency on par with solar-grade material, and have an acceptable reliability, then the 'holy grail of grid parity targets often discussed by those in the industry would be closer to being achieved in multiple geographies.



Source: BDEW, pvXchange & solarserver.

Figure 2. Solar-grade wafer cost data and future projection for 2010.

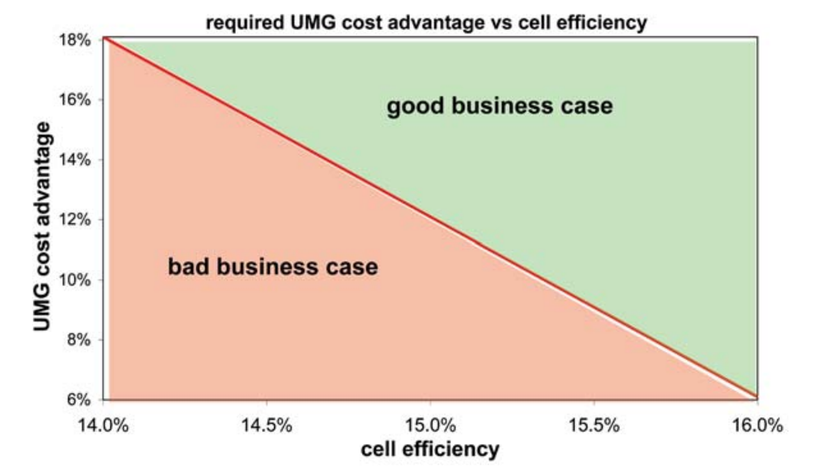


Source: IBM cost model

Figure 3. Cell cost contributors for silicon and UMG wafers.

	solar grade 16% eff.	UMG 16% eff	UMG 15.5% eff	UMG 15% eff	UMG 14.5% eff	UMG 14% eff
$ cost/wafer	3.3	3.1	3	2.9	2.8	2.7
Wp/cell	3.89	3.89	3.77	3.65	3.53	3.41
Δ UMG/Si	0%	6.1%	9.1%	12.1%	15.1%	18.1%

Table 2. UMG data for solar-grade matching cost conditions.



Source: IBM cost model

Figure 4. Break-even cost advantage needed for lower solar efficiencies in UMG cells, assuming gettering processes and equipment are included in a manufacturing line.

Cost

Cost estimation and comparison between cells made from UMG and cells made from solar-grade material were performed for this study. Although our initial investigation showed roughly equivalent measured parameters between UMG (ungettered) and solar-grade cells (see Table 1), a worst-case scenario is assumed in this analysis, where gettering is considered necessary to achieve equivalency. In Table 1, efficiency was relatively low for all compositions since all cells were made in a non-optimized lab. The importance of the data is shown in the insignificant delta between the various blends, indicating that UMG has a potential path forward, especially if process and material enhancements already known for solar grade are also applied to UMG.

If the worst-case scenario is assumed for this economic analysis, a UMG line would require additional equipment which has to be considered in the cost estimate. The additional capital investments include a phosphorus diffusion furnace as well as a chemical etch bath. The diffusion furnace can be in-line if only relatively short diffusion times are needed, or off-line if diffusion is done before cell production begins. This off-line diffusion operation could be done at the cell producer's facility or at the wafer provider's facility before delivery. This particular diffusion is a phosphorous getter in which impurities are pulled to the surface of the wafer [2] and then 5-20µm (less if after saw damage etch; more if before saw damage etch) is etched off to remove the high impurity layer. With these two additional processes, the entire lead time could be extended by around 1.5 hours. Fig. 1 shows a cost comparison for solar grade vs. UMG at year end 2010, taking into account the lower cost UMG wafer's needs for additional process time and equipment. The following assumptions were made for the cost comparison:

- Manufacturing yield: 95%
- Line utilization: 90%
- Solar-grade Si wafer cost: US$3.3
- UMG wafer cost: US$3.1
- Base efficiency assumption for solar-grade material: 16%
- Base efficiency assumption for gettered UMG: 16%

Although not immediately apparent from the graph in Fig. 1, when UMG material is ~7% less expensive than a solar-grade wafer, overall cell cost is shown to be equivalent. A UMG wafer with an even larger cost differential to solar grade would present a positive business case for using UMG. Solar-grade wafer price data used to perform this cost estimation are shown in Fig. 2.

If this simulated curve is not followed and solar-grade material price does not

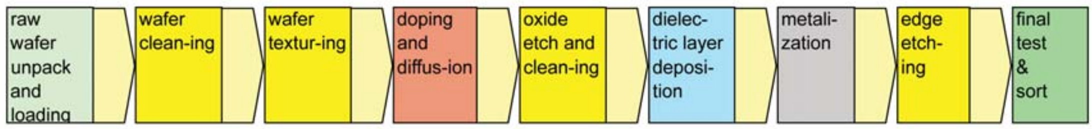


Figure 5. Typical Si turnkey manufacturing flow.

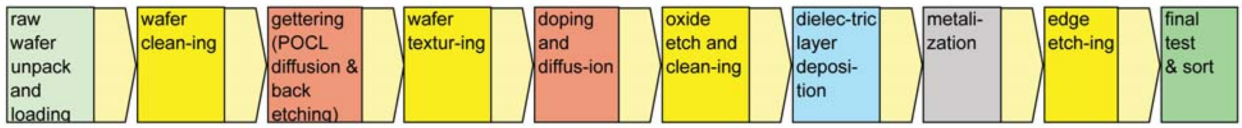


Figure 6. UMG turnkey manufacturing flow.

decline as rapidly as shown, reaching US$3.3 per wafer by end of year, then an even better business case exists for running a line with UMG rather than solar-grade material. The estimated numbers for end of year 2010 used the US$3.3 per wafer cost. Current (April 2010) wafer cost is US$5.07 US with May's cost estimated to be at or near US$4.29. The graphs in Fig. 3 show the cell costs broken down by contribution.

The pie charts show, as discussed previously, that in the case of UMG the material cost is reduced but depreciation and facility-related costs are higher. The lower material cost must at least compensate for the higher depreciation and facilities costs.

If the assumption is made that UMG-based cells have a lower solar efficiency than solar grade even with the gettering process implemented, the cost advantages have to be even better, as shown in Table 2. The solar-grade reference assumes a 16% solar efficiency. This data is presented graphically in Fig. 4.

This figure shows that UMG material operating at 14% efficiency needs at least an 18% material cost advantage in order to compete with solar-grade material operating at 16% efficiency.

Characteristics of UMG and comparison with solar-grade material

Polysilicon feedstock used to produce solar-grade multicrystalline wafers has traditionally relied on scrap material from semiconductor wafer production or semiconductor-grade 'poly' produced directly for this purpose. Semiconductor-grade Si is obtained by processing metallurgical-grade Si through the Siemens process where impurities are removed chemically by conversion to chlorosilane compounds with multiple distillations. While the Siemens process is effective in removing impurities down to the ppb level ($10^{13}cm^{-3}$), its energy budget at approx. 200kWh/kg is substantial, which in turn drives high costs for the finished product.

An attractive route to reducing material costs in PV applications is to avoid the Siemens process and purify metallurgical-grade (MG) Si using alternative processes. This has to be done at lower cost and improved energy efficiency while still reducing impurities to levels of 1 ppm ($10^{16}cm^{-3}$) and below, a level that is necessary for building solar cells at efficiencies similar to standard solar-grade material. Critical impurities are boron (B) and phosphorous (P) in terms of dopant level control and carbon (C), oxygen (O), iron (Fe), titanium (Ti) and calcium (Ca).

To purify MG Si, a number of strategies [3] have been developed to extract impurities from liquid molten Si, producing upgraded MG (UMG) Si. The actual impurity level of MG Si to be refined depends on the purity of the quartz raw material and the reduction process used. The UMG process may have to be adjusted to the specific properties of the MG used. All UMG is not equivalent, and it is assumed to have had unexpected results for more than one manufacturer of solar cells. Impurity levels in the low ppm range and below are shown in Table 3. UMG feedstock is used in a standard casting and wafering process to produce multicrystalline wafers for use in PV manufacturing. Several cell manufacturers are now in high-volume production using UMG-based wafers.

Element	B(Wet)	Na	P(OES)	Ca	Ti	V
ICP-MS (PPBw)	586.345	737.70	2,230.0	2,159.12	49.424	19.307
Element	Cr	Mn	Fe	Ni	Cu	Zn
InCP-MS (PPBw)	24.39	0.042	2,403.47	25.266	33.67	998.44
Element	As	Se	Rb	Sr	Zr	Nb
ICP-MS (PPBw)	0.130	0.023	14.556	78.485	163.76	1.958
Element	Mo	Ru	Cd	Sb	La	Ce
InCP-MS (PPBw)	3.556	4.779	0.021	8.508	0.229	1.395
Element	Pr	Nd	Sm	Gd	Tb	Dy
InCP-MS (PPBw)	0.339	0.131	0.007	0.029	0.002	0.055
Element	Er	Tm	Ta	Re	Pb	U
InCP-MS (PPBw)	0.084	0.055	3.615	0.01	0.034	0.177

Table 3. Elemental analysis UMG material from Solsil Corp.

For comparison, we show impurity levels measured on a commercial solar-grade wafer in Table 4, where it is apparent that the solar-grade sample contains significantly higher concentrations of Cu whereas Fe is higher in this particular UMG. Ni is in the same range for both materials. These elements are expected to be key contributors to carrier lifetime degradation due to charge carrier recombination.

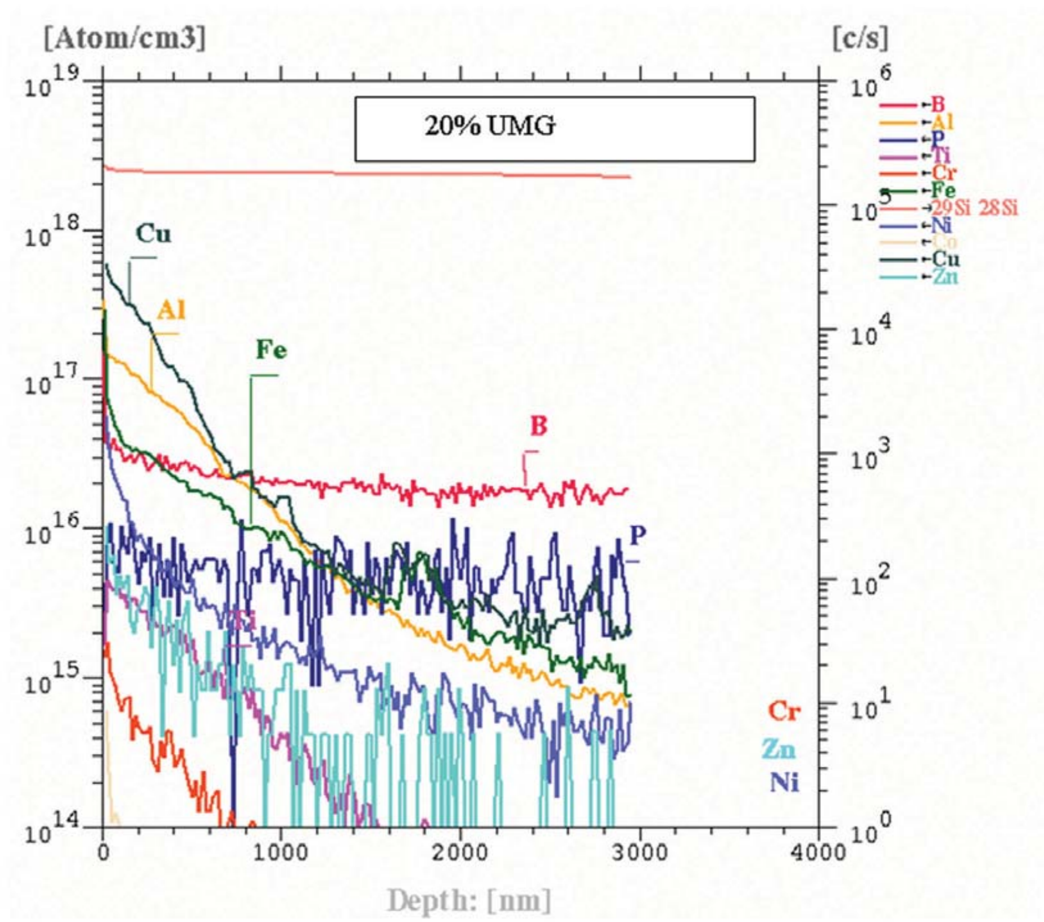
One avenue to further improve the properties of UMG material is by blending it with solar-grade material, which has been demonstrated recently by blending the two materials at the ingot casting step [1]. As discussed, this approach holds promise for accelerating the adoption of UMG Si in PV manufacturing.

Manufacturing with UMG

The use of a regular turnkey manufacturing line requires solar-grade wafer material to manufacture solar cells. A typical Si turnkey process flow is shown in Fig.5.

Element	Concentration (PPBw)
Al	39
Fe	394
Ni	42
Cu	2630

Table 4. Contamination SIMS analysis of a commercial solar-grade wafer performed by IBM.



Source: IBM cost model

Figure 7. SIMS profile of 20% UMG starting material.

The typical turnkey line is capable of manufacturing cells with an average efficiency level of around 16%. The yields are typically at 95% with line utilization of around 90%. A turnkey line that can handle UMG material could require some enhancements to prepare the UMG wafers for further processing. Here, we assume that the gettering previously discussed is incorporated in-line in order to reduce the metallic content within the UMG material. A possible line layout is shown in Fig. 6.

In this case, the gettering is applied after the first cleaning step. The additional process steps have an impact on lead time. The doping and diffusion could be performed using $POCl_3$ or H_3PO_4 technology to apply phosphorous doping, resulting in a lead time of at least one hour to achieve a doping depth of ~1μm. The subsequent PSG glass removal by HF etching would then be used before KOH etching of the gettered, high impurity material, at which point the wafers would continue in the normal cell processing sequence.

The additional process steps in the UMG manufacturing flow could add about 1.2 hours to the cell process time and, again, would require additional investments into phosphorus furnace and etch bath equipment.

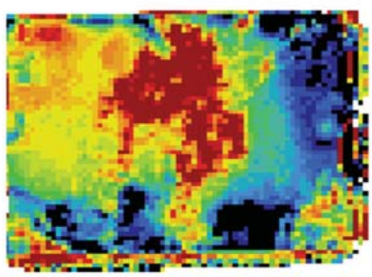


Figure 8. Minority carrier lifetime map of 20% UMG starting material.

UMG casting and manufacture of starting material

When producing multicrystalline Si wafers for PV, solar-grade or UMG material is melted in a specialized furnace and then, through a process of controlled solidification termed 'casting', an ingot is prepared. The ingot is cut to dimensions appropriate for the desired wafer cross-section (for example, 156mm x 156mm) and individual wafers are then cut from the block or brick by wire saw in the wafering process. Ingot casting is a critical step in the process where key parameters of the mc material structure and electronic properties are defined. There are a number of different approaches to casting technology including controlled directional solidification, electromagnetic casting and the heat exchange method.

> "Materials prepared by different methods typically show differences in some of the relevant properties."

Materials prepared by different methods typically show differences in

Material	B	P	Fe	Ti	Cu	Ni	Zn	Cr	Al
S.G.	1.8E16	1E15	9E14	9E14	1E16	3E14	7E14	1E14	3E15
10%	2E16	1E15	2E15	<1E15	1E15	2E14	5E14	1E14	5E14
20%	2.5E16	5E15	3E15	<1E14	1E15	5E14	1E14	<1E14	1E15
30%	3.5E16	2E16	1E15	<1E14	2E15	3E14	1E14	<1E14	5E14
100%	1.5E17	5E16	7E15	3E14	6E16	4E14	3E14	<1E14	3E15

Table 5. Impurity densities in various UMG/solar-grade blends.

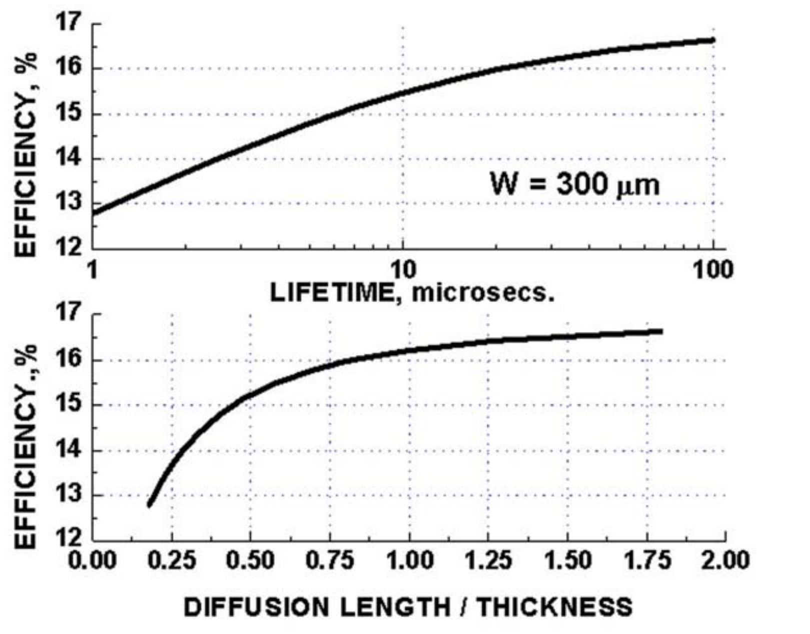


Figure 9. Simulated effect of minority carrier lifetime on efficiency (top), and the effect of the diffusion length to thickness ratio (bottom). (No selective emitter, no back surface field other than Al alloying used.)

some of the relevant properties such as crystallite grain size and distribution, grain boundary structure and defects, dislocation density within the grains and concentration of C, N and O as well as residual metal impurities (for example, Fe, Cu, Ti). Sources of impurities are the feedstock starting material and the furnace and heater surfaces (typically Si_3N_4 and graphite) which come in contact with Si material at high temperature. Impurity segregation during the crystallization process leads to inhomogeneous impurity concentration profiles along the length of the ingot, which in turn leads to variation in cell efficiency of wafers cut from different positions within the same ingot. By managing segregation, ingot sections can be produced with impurity levels lower than the starting feedstock while concentrating impurities at the end portions, which are usually not usable.

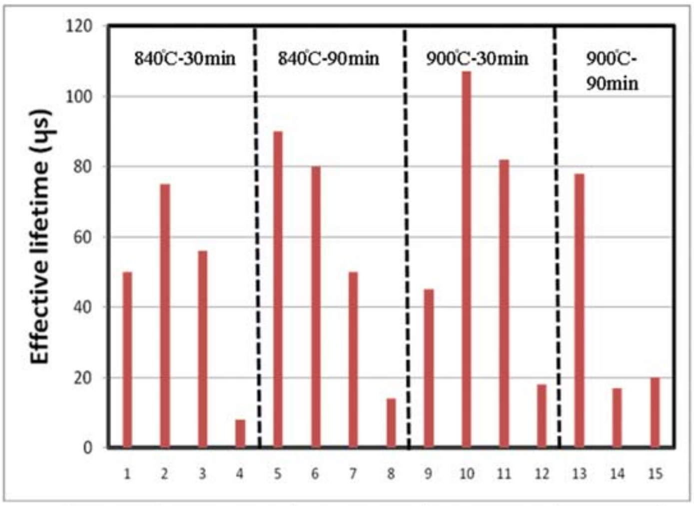
From a cost perspective, it is obviously important to maximize the portion of usable ingot, and industry data show that yields in the range from 70-90% have been achieved. During the crystallization process, precipitates of SiO_2, Si_3N_4 and SiC can be formed in the melt and the ingot. While SiO_2 precipitates are useful in terms of being able to getter metallic impurities, Si_3N_4 and SiC are assumed to degrade cell efficiency [4]. Metal decoration of intergranular defects plays a major role in limiting carrier lifetime. This means that for UMG material, the control of metal-related defects during the casting process is critical to improving efficiency.

Characterization of starting material and devices

In order to optimize the lower cost benefits of UMG material, solar cells made from this material should be at least comparable in efficiency to devices made from the higher cost solar-grade starting wafers. As with any solar cell fabrication, characterization of the starting wafers can allow removal of the poor quality material before any value-added device processing takes place. The most important pre-process characterization of the starting material is an evaluation of the minority carrier lifetime, assuming there are no critical cracks, indentations, broken corners, or other physical failure mechanisms existing in the wafer. The lifetime depends on impurity content, grain boundaries, dislocation networks, and other types of defects. Relative oxygen content will also play a role, especially in subsequent light-induced degradation associated with boron and iron content [4].

Table 5 shows impurity content of selected elements as measured by SIMS for the various composition blends used in this study ranging from solar-grade material (S.G.) to 100% UMG. Fig. 7 shows a SIMS plot for 20% UMG material. The total heavy metal population is around low $10^{16}cm^{-3}$, similar to the boron dopant concentration. The exception is the 100% UMG material, which exhibits impurity densities 5-10x higher than the other blends for boron, iron and copper. All the blends of solar grade and UMG were p-type with resistivities of roughly 0.5–1Ω/cm. Impurity levels appeared much higher at the surface compared to the bulk, but it is possible that this measurement is influenced by surface roughness.

The oxygen is usually in the low $10^{17}cm^{-3}$ range in solar-grade materials and likely to be comparable in the UMG/solar-grade



SolarGrade	1	5	9	13
UMG20	2	6	10	-
UMG30	3	7	11	14
UMG100	4	8	12	15

Figure 10. Phosphorus gettering results for solar grade and for several UMG blends.

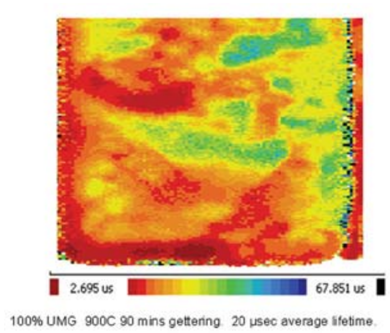


Figure 11. Lifetime map of gettered 100% UMG starting material after 90 minutes phosphorous diffusion.

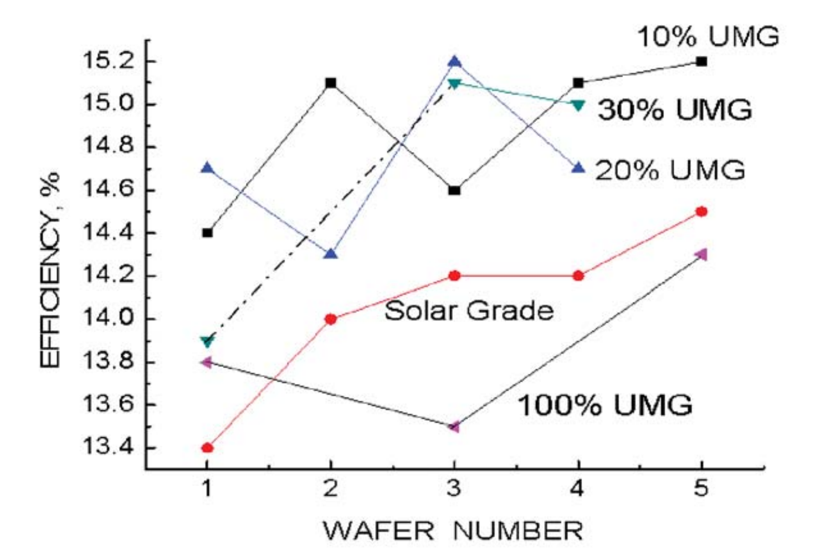


Figure 12. Efficiencies of cells made from the different UMG blends.

blends, although results were inconclusive when those measurements were made. Further investigation is merited in this case.

As mentioned earlier, the minority carrier lifetime plays a crucial role in the performance of the devices. This manifests itself in calculations of efficiency versus lifetime and/or efficiency versus the diffusion length/wafer thickness ratio. As the wafers become thinner, light trapping becomes increasingly essential. An acceptable degree of light trapping for wafers several hundred microns thick or below is typically provided by texturing, causing light entering the Si to travel at oblique angles.

For UMG blends, the starting lifetime can be relatively low before impurity gettering. Efficiency is a strong function of lifetime. A lifetime map of 20% UMG starting material using microwave photoconductivity decay (μPCD) is shown in Fig. 8. Lifetimes of 1 to 1.5 microseconds are typical of the UMG material and also of some solar-grade material as received from wafer vendors. Pockets of lower and higher lifetime are observed in these maps, possibly associated with dislocation networks at smaller grain boundary intersections.

Even small improvements in lifetime can dramatically improve the device performance. If the lifetime is improved sufficiently for the diffusion length to exceed the wafer thickness, the performance becomes both higher and less sensitive to changes in lifetime. These observations are shown in Fig. 9, which shows efficiency versus thickness and efficiency versus the diffusion length/wafer thickness ratio for a range of lifetime values as they would exist in finished devices. Improving the starting lifetime from a typical value of 1-2 microseconds up to 10-20 microseconds or higher has a substantial benefit. Simulations depicted in Fig. 9 do not include the benefits of a local back-surface field or a double emitter, which could potentially enhance the device performance by as much as several percent.

"As the wafers become thinner, light trapping becomes increasingly essential."

Type	<J_{sc}>	<V_{oc}>	<FF>	<J_{01}>	<J_{02}>	<R_{SH}	R_{SER}	Effic.
Sol. Grade	32.1	.590	.744	2.65^{-12}	1.08^{-7}	3110	0.79	14.1
10% UMG	32.3	.6064	.760	1.52^{-12}	6.79^{-8}	4490	0.695	14.9
20% UMG	31.9	.6044	.763	1.70^{-12}	6.03^{-8}	3780	0.667	14.7
30% UMG	32.1	.6027	.760	1.72^{-12}	8.10^{-8}	5030	0.695	14.7
100% UMG	30.3	.621	.740	5.51^{-13}	9.38^{-8}	4750	0.631	14

Table 6. Solar cell parameters from UMG blends using process 3.

As discussed, lifetime can be improved significantly by gettering. Experiments were carried out to determine what improvements could be obtained for the various UMG blends as a function of anneal conditions. Gettering was carried out by $POCl_3$ diffusion between 840 and 900°C for 30 to 90 minutes. Prior to gettering, the wafers were saw damage etched and cleaned with CP4 ($HF:HNO_3$: acetic acid) and RCA etch ($HCl:H_2O_2:H_2O$) before loading into the $POCl_3$ furnace. After the anneal, the phosphor silicate glass (PSG) oxide was etched off and the samples were measured with iodine passivation.

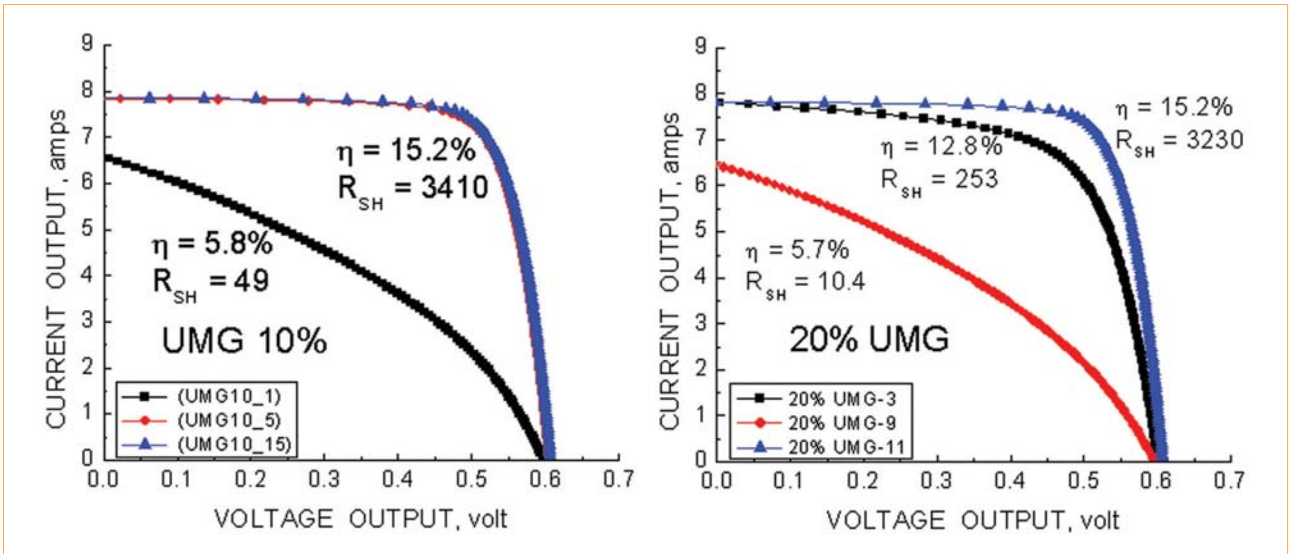


Figure 13. Current-voltage behaviour under 1 sun illumination for 10% and 20% UMG cells.

Fig. 10 shows the lifetime results for UMG blends 0%, 20% 30%, and 100% UMG, and Fig. 11 shows a lifetime map measured by µPCD on the 100% UMG material. Gettering had a dramatic effect on improving the lifetime, which increased to 50 to 80 microseconds for the 20% and 30% blends, respectively, even exceeding 100 microseconds at one point. All the UMG blends performed well but 100% UMG was not as receptive to the gettering as the others. From Table 3, the 100% UMG is shown to have from 5 to 10x more impurities than the other blends, so a lower response to the gettering of these impurities would be expected. More extensive gettering is probably needed.

"The implication is that UMG feedstock could be mixed with solar grade to obtain equivalent device performance at somewhat lower cost."

If lifetimes greater than 20 µsecs can be obtained in 100% UMG, efficiencies exceeding 16% are obtainable, comparable to present-day multicrystalline cell efficiencies as obtained in turnkey fabrication lines. Advanced device designs, which include selective emitters and improvements in back-surface fields, would be expected to increase the efficiencies to higher values in UMG just as in solar-grade material.

Characterization of finished devices

Wafers from 10%, 20%, 30% and 100% UMG blends and solar-grade controls were processed in the solar cell fabrication turnkey line at Schmid GmbH using H_3PO_4 mist as the diffusion source, along with PECVD SiN passivation/AR coating on the acid-textured surface and screen-printed Ag (front) and Al (back) contacts. The wafers were 156 x 156mm squares but only 15 wafers of each blend were available. These were divided into three process sequences: 1) standard emitter diffusion to 50Ω/⊗; 2) double-sided phosphorus diffusion also with 50Ω/⊗ and the rear side diffusion etched off; 3) one-hour phosphorous diffusion at 865°C. N^+ layers were removed from both sides, and the wafers continued as in process 1 (see [1] for further details).

The efficiencies, I-V behaviour, spectral response, and diode properties of the wafers were measured both at Schmid and at IBM. Lifetime, diffusion length, LBIC (light beam-induced current) and reflectance maps were made using a µPCD – LBIC mapper (Semilab Corporation). Photo and electroluminescence, and DLIT (dark lock-in thermography) maps were made at NREL.

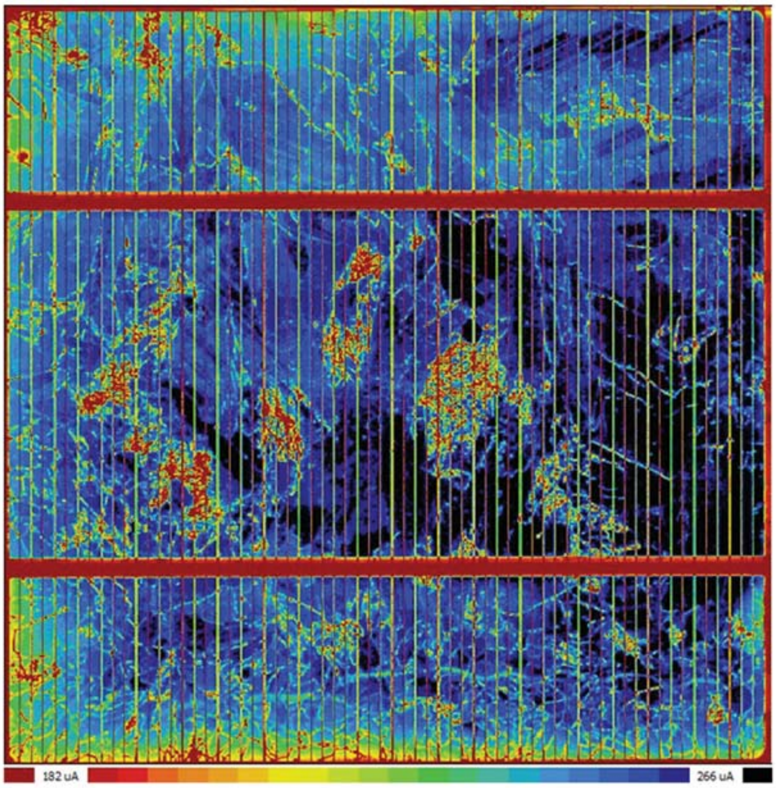


Figure 14. LBIC map of a shunted 10% UMG cell showing patches of higher dislocation density.

Table 6 shows average device parameters for the four blends and solar grade using process 3 in each case, so some degree of gettering was present. The lifetimes in the finished wafers were around 8 microseconds [1]. Electrical parameters from all the materials are nearly the same except for the 100% UMG, which exhibited lower photocurrents due to poorer lifetimes and higher V_{oc}, most

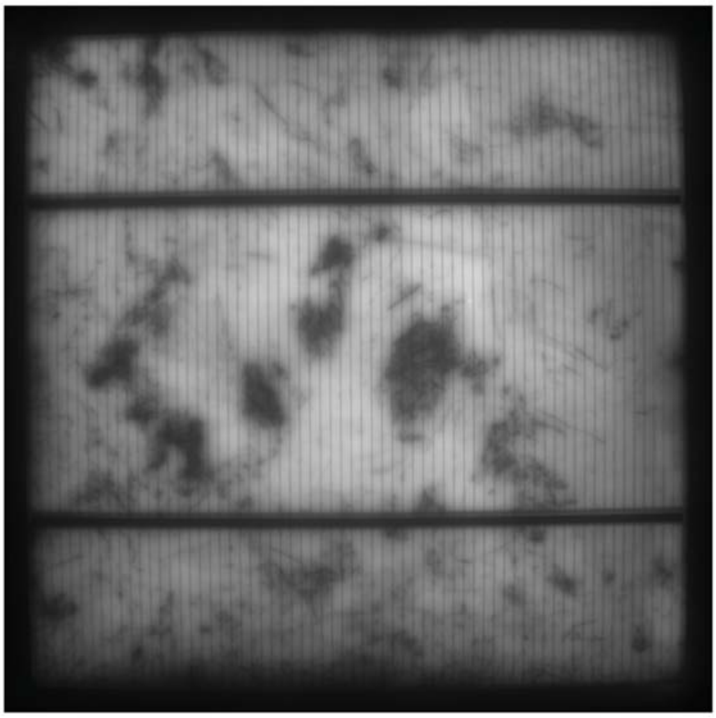


Figure 15. Photoluminescence map of the shunted cell shown in Fig. 8, indicating exact correspondence with regions of lower photocurrent (= lower lifetime).

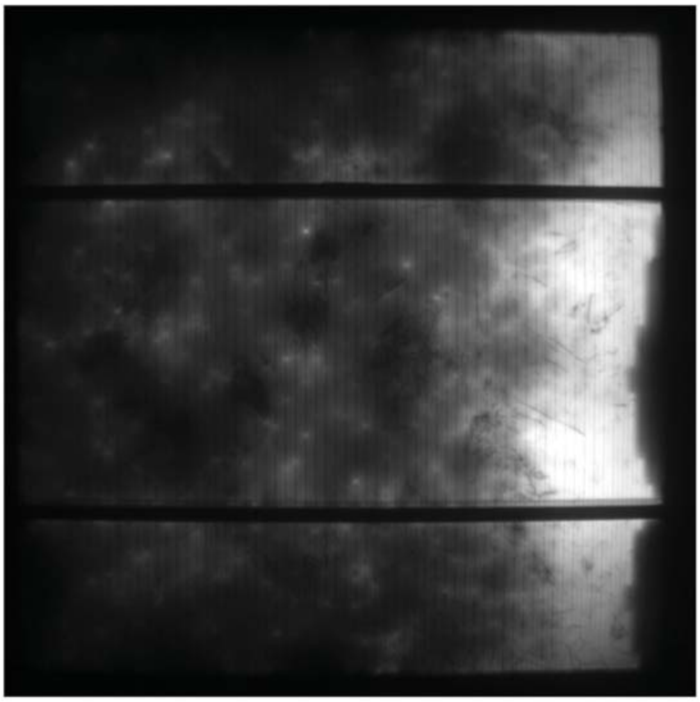


Figure 16. Forward bias electroluminescence map of the shunted cell in Figs. 8 and 9. Dark areas are regions of low lifetime and low current.

likely due to lower bulk wafer resistivity. Fill factors, J_{01} and J_{02}, and series and shunt resistances were all very similar. The implication is that UMG feedstock could be mixed with solar grade to obtain equivalent device performance at somewhat lower cost. Fig. 12 shows the efficiencies at 1 sun intensity for the five types of material and again shows near equivalence except for the 100% UMG. Since the 100% UMG wafers started out with much higher impurity densities, a greater degree of gettering would likely be beneficial for this material compared to the others.

The largest limitation to cell efficiency appears to be shunt conductance. Shunts represent leakage currents through the device which reduce the fill factor and can reduce the V_{oc} in severe cases. Fig. 13 shows I-V curves under 1 sun illumination for 10% and 20% UMG devices. The curves were picked to represent good, medium, and poor shunt resistance cells, illustrating the drop in efficiency with increased leakage current. There was a strong variation in shunt leakage between cells of all UMG blends as well as the solar-grade control. However, the series resistances did not vary significantly between UMG blends or different cells within a particular UMG blend.

> "The shunts themselves appear to arise when the bus bars and/or fingers cross high dislocation density patches."

To better understand the possible causes of shunt resistances as well as non-uniformities on the finished cells, maps of LBIC, luminescence, and DLIT were made on all of the cells and a consistent pattern was observed. Fig. 14 shows an LBIC map of a shunted 10% UMG cell where the lifetime varies by a factor of about 2 over the wafer. There are many red/orange-coloured patches at various positions which may represent areas of higher dislocation density. Similar patches to these were observed in nearly all wafers.

Fig. 15 shows a photoluminescence image of the same wafer as that shown in Fig. 14. In images such as these, bright areas usually represent higher lifetimes and darker areas represent lower lifetimes, localized areas where recombination centres are present in higher density. This is more likely to occur in high dislocation density areas. Comparison of Figs. 14 and 15 show a one-to-one correspondence

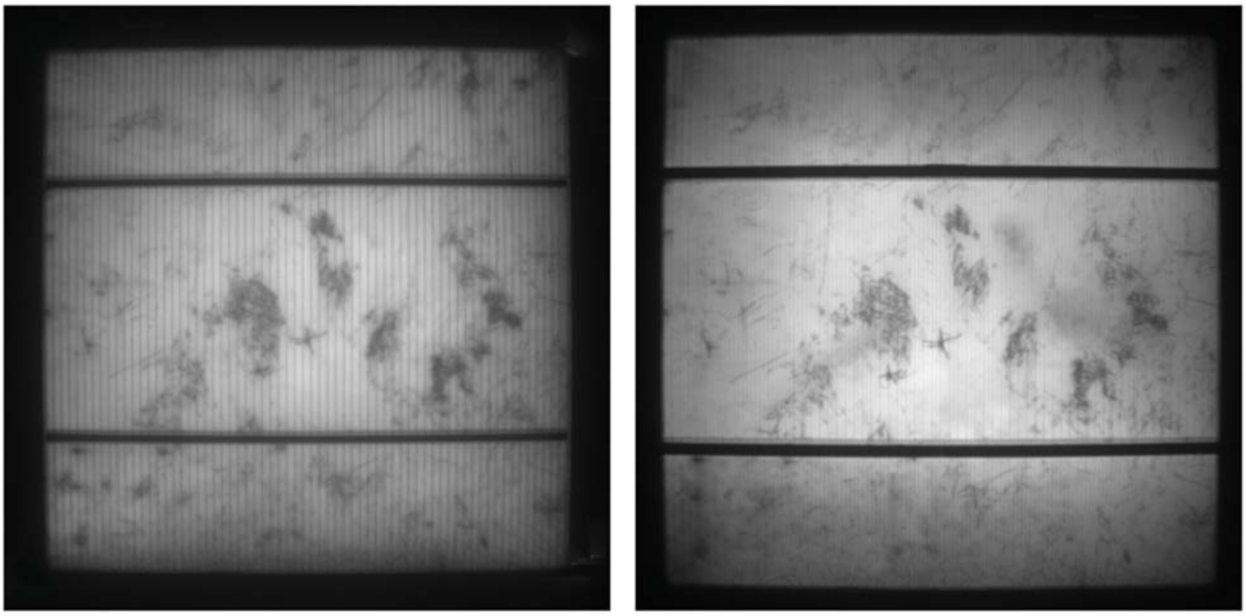


Figure 17. Photoluminescence (left) and electroluminescence (right) maps of a 15.4% efficient 10% UMG solar cell showing high lifetime and good uniformity.

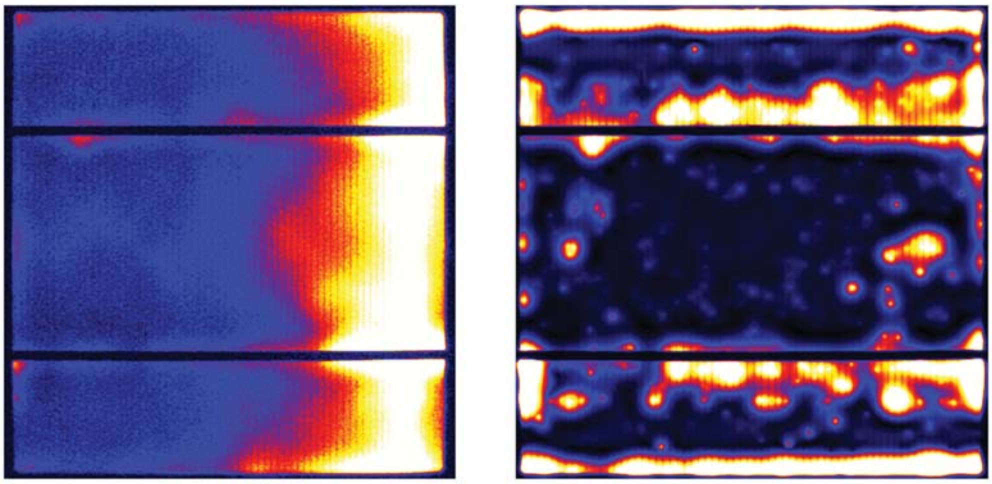


Figure 18. Forward bias (left) and reverse bias (right) DLIT images of the 10% UMG wafer in Figs. 8–11. Excess current is present where light spots appear.

between the low lifetime patches in the LBIC map and low intensity regions in the photoluminescence map.

Similar information can be gained from the electroluminescence map in Fig. 16. Generating such maps requires the application of a forward bias to result in forward bias currents of several amperes. High lifetime regions emit substantial luminescence and appear bright while poor lifetime regions appear dark. Shunted and poor lifetime wafers exhibit dark patches in both photo- and electroluminescence. This device can be contrasted with the luminescence maps of a much better cell shown in Fig. 17, which shows high brightness that is indicative of better minority carrier lifetimes. The uniformity of intensity indicates uniform lifetime and diffusion lengths.

On average, solar cells fabricated from UMG blends and non-UMG (solar-grade) material appear to exhibit the same degree of shunt leakage currents. These probably arise from grain boundaries and dislocation networks resulting from the casting process, which may then be decorated by impurities. The similar short circuit currents and efficiencies of the UMG blends and solar-grade material may be a result of similar background impurity densities as shown in Table 5. For the 100% UMG, the lower lifetimes and photocurrents may be due to higher impurity densities located at these dislocation areas. Iron and copper at were present higher densities in these starting wafers as were boron and phosphorus. Reducing these densities and/or incorporating more aggressive gettering techniques would be beneficial for this material.

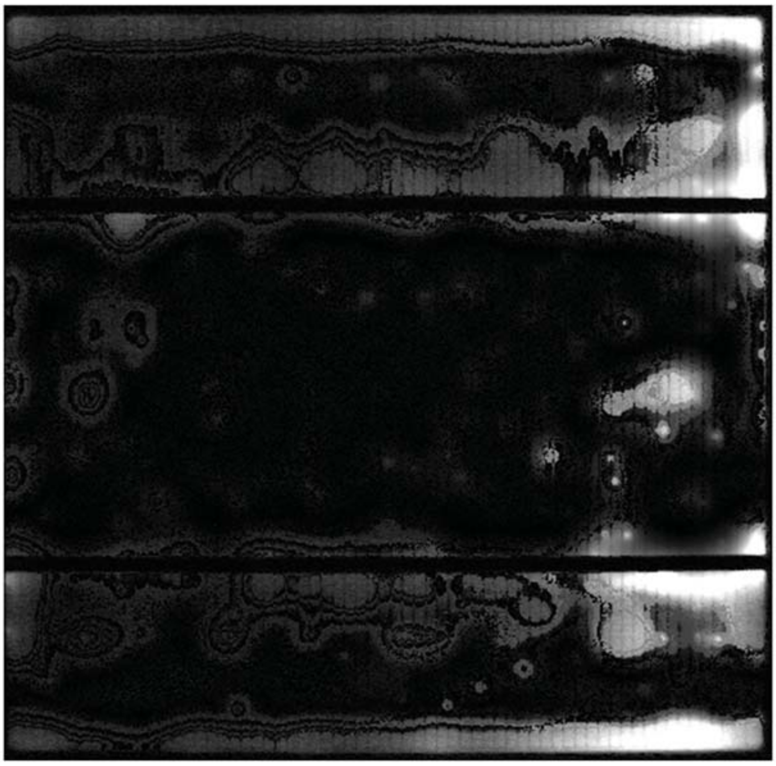


Figure 19. AND image of the forward and reverse DLIT images from Fig. 12 showing ohmic shunts along portions of the busbars and a portion of the edges.

Even in the small sample set available in this series of experiments (15 wafers of each variety), a considerable spread of device performance was observed. Though there were too few wafers to make any statistical conclusions, the shunt leakage was one factor involved in the efficiency variability. The shunts themselves appear to arise when the bus bars and/or fingers cross high dislocation density patches, but a large portion of the wafers also showed strong edge leakage, revealed in DLIT images. These images are made by biasing the cell in either forward or reverse bias and recording hot spots where excess current flows and the temperature rises [5,6]. The temperature is detected by infrared camera and lock-in techniques, resulting in excellent signal-to-noise ratios. Bright (hot) spots may indicate only a few degrees above the surroundings while more serious current channelling may result in spots up to a hundred degrees above. The same spots appearing in both forward and reverse bias are known as ohmic shunts and may be caused by the metal electrode penetrating through the emitter to the base region. Spots appearing in one bias only are diode-like and may be due to several causes [7].

Fig. 18 shows a DLIT image of a 10% UMG cell and indicates the areas where shunts occur (i.e. where excess current is flowing). The probes were uniformly placed along both entire bus bars; therefore the image is caused by a wafer non-uniformity and not the measurement apparatus. In forward bias (left-hand image), current crowding occurs along the right edge and may be due to a lower sheet resistivity in this region. In reverse bias (right-hand image), many shunts are seen to be covering a significant portion of the cell. Current leakage is prominent along both edges and at various positions along the busbars. Individual shunt areas are also located within the wafer at several individual spots.

By superimposing forward and reverse bias images in logic AND mode, ohmic and diode shunts can be separated. Ohmic shunts appear in both images and therefore in the AND map, while diode shunts disappear. Fig. 19 shows an AND image from the DLIT maps in Fig. 18. Comparing Figs. 18 and 19, only a fraction of the shunt leakages are due to ohmic shunts, where the metal electrodes may penetrate to the base or where doping may be high enough for tunnelling currents to appear. The bulk of the shunts are diode-like and may be associated in some way with grain boundaries or defects at the cell edges.

Summary

This UMG study clearly shows that the use of this material, compared to solar grade, can have significant cost advantages, demonstrated by the economics study comparing both materials. To be competitive, the UMG material must result in similar efficiencies as regular solar grade, i.e., the minority carrier lifetimes must be comparable. Lifetimes in UMG can benefit strongly from gettering, and UMG-based cells processed appropriately result in similar performances compared to solar-grade cells.

Additional follow-on studies would further quantify the potential advantage of UMG material measured in cost/Wp compared to solar-grade material. While manufacturing solar efficiencies are now around 15-16% for the UMG/solar-grade blends, they can be enhanced using selective emitters, improved contacts, and localized back surface fields. The same can be said of solar-grade material, indicating that incremental improvements in a cell manufacturing line does not preclude running UMG, UMG blend, or solar-grade starting materials.

In summary, solar cells made from UMG-based material have the same features as any multicrystalline-based cells except for somewhat higher impurity levels in the 100% UMG. These higher impurities appear to be diluted sufficiently in UMG/solar-grade blends to result in similar efficiencies with the reference solar grade. Quantum efficiencies, short circuit currents and open circuit voltages, and device performance are nearly independent of the UMG blend at least up to 30% UMG. Forensic analysis such as LBIC, photo- and electroluminescence, and DLIT are highly valuable in examining the detailed device behaviour and diagnosing problem areas for future solution. These same techniques are equally valuable in non-UMG solar cells.

Acknowledgment

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Disclaimer

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About the Authors

Rainer Krause has a Ph.D. in electrical engineering and physics. He has worked at IBM in Mainz, Germany for the past 13 years in positions such as engineering manager for automation, test engineering and lithography. He is manager of the ISC (Integrated Supply Chain) technology centre to support IBM WW semiconductor and server activities, and also holds roles such as master inventor, innovation champion and member of the technical expert council and patent review board. He is also a member of the WW solar council within IBM where he coordinates technology-related issues.

Dr. Harold Hovel received his B.S., M.S., and Ph.D. degrees from Carnegie Institute of Technology in 1964, '65, and '68, respectively. He joined the IBM Watson Research Laboratory in 1968 and has been involved in solar cell research for nearly 45 years and authored the first reference book on solar cells, *Solar Cells: Vol. 11 of Semiconductors and Semimetals*, in 1973, and has written many contributed and review papers on various aspects of photovoltaics, including crystalline silicon, gallium arsenide, amorphous Si, heterojunction, multijunctions, organic solar cells and concentrator cells. He is a National Associate of the National Academy of Sciences.

Dr. Eric Marshall performs solar cell research at the IBM TJ Watson Research Center. He received his degrees in applied physics from the University of California–San Diego and has worked as a Research Staff Member at IBM and as Vice President, Strategic Partnerships and Innovation at New York Hall of Science. Topics covered by his publications and presentations (>100) include the correlation of electronic materials and device properties in multicomponent systems. His research applies complementary fabrication and analysis techniques to explore materials and device processing of semiconductor-based systems (IV, III-V, and II-VI).

Gerd Pfeiffer is working in procurement engineering at IBM East Fishkill, NY, and has been involved in PV since 2006. Prior to joining IBM in 2000, he worked as an application engineer at MEMC Electronic Materials. From 1994-98, he was employed by SiBond, L.L.C. in the area of silicon-on-insulator characterization. He received a Ph.D. in physics from North Carolina State University in 1991 and spent three years working as a research associate at the Max-Planck-Institute for Solid State Research in Stuttgart, Germany.

Zhengwen Li has been working for the IBM Semiconductor Research and Development Center for three years, specializing in process development for thin films and metals, using CVD and ALD techniques to make high-dielectrics and metal films for embedded DRAM applications, middle-of-line contact metals, copper interconnect developments, and solar related activities. Zhengwen holds a Ph.D. degree from the chemistry department at Harvard University in 2007, majoring in atomic layer depositions from precursor synthesis and characterizations, to thin-film nucleation and growth.

Dr. Larry Clevenger is a Senior Technical Staff Member at IBM working in the area of Advanced BEOL Integration. He is a noted expert and leader for the innovation, development, and qualification of IBM semiconductor contact and BEOL technologies, and received a B.S. in material engineering from UCLA and a Ph.D. in electronic materials from MIT. He holds 132 issued patents, has co-authored more than 35 technical publications and has two IBM Corporate Technology Awards.

Kevin Petrarca has 19 years' experience in semiconductor development and fabrication through IBM's 200mm Advanced Silicon Technology Center and 300mm fab at the Hudson Valley Research Park in East Fishkill and the IBM T.J. Watson Research Center in NY. Currently working in 3D integration development, he has worked in areas such as manufacturing management, lithography, chemical mechanical polish and materials integration for low-k dielectrics. Kevin has co-authored several technical papers and holds over 60 US patents.

Davood Shahrjerdi joined IBM T. J. Watson Research Center in 2009, where he is currently working on advanced solar cell structures and materials. Davood did his Ph.D. in electrical engineering at The University of Texas at Austin, where he explored various III-V channel materials for CMOS applications. Prior to that, he performed research on self-assembly of nanoparticles for nanocrystal flash memory applications as well as ultra-low temperature crystallization of a-Si and a-Ge for flexible display and sensor applications.

Kevin M. Prettyman has a B.S. in chemistry with minor in physics from Brigham Young University, M.E., a Ph.D. in materials science and engineering from the University of Utah, and an M.B.A. in finance and operations management from New York University's Stern School of Business. A holder of multiple patents, he has managed development groups and manufacturing engineering groups in IBM's multi-layer ceramic and semiconductor areasand drove IBM's efforts in Solid Oxide Fuel Cells, serving as technology leader in photovoltaic devices in various technologies and material sets for IBM's Microelectronic Division.

Dr. Steve Johnston is a research scientist on the Electro-Optical team of the Measurements & Characterization division of NREL. He received his B.S. in engineering from the Colorado School of Mines (CSM); M.S. from the University of Illinois, Urbana-Champaign in electrical engineering; and Ph.D. from CSM in materials science. He has worked for over two years at Texas Instruments and Cray Computers and has over 10 years of experience with NREL in minority-carrier lifetime, capacitance measurements, and most recently, solar cell imaging techniques.

Enquiries

IBM Corporation – Research and Integrated Supply Chain
Yorktown Heights
NY 10598
USA

Hechtheimerstrasse 2
55131 Mainz
Germany

Cost reduction and productivity improvement strategies for multicrystalline wafering processes

Mark Osborne, Senior News Editor, *Photovoltaics International*

ABSTRACT

Multicrystalline wafers are the workhorse of the PV industry, with approximately 60% of crystalline silicon solar cells made from the substrate. They offer cost advantages in the form of good conversion efficiencies, which should continue to improve as cell technology advances continue. However, wafer prices were acutely impacted by the fall in PV market demand in late 2008, which continued through most of 2009. With relatively high capital costs, continued pricing pressures and calls for greater quality and control, wafer producers are now set on a course that requires rigorous and sustainable production cost-reduction strategies to meet customer requirements. This paper focuses on strategies that can be adopted to address this need for tighter quality specifications that reduce manufacturing costs downstream and boost cell conversion efficiencies.

Introduction

Polysilicon, wafer and solar module prices all declined severely in 2009. According to a recent report from iSuppli Corp., average crystalline module prices dropped by 37.8%, solar wafer prices fell by 50%, and polysilicon prices declined by 80%.

The market research firm expects further price declines in 2010, though not at the steep levels seen last year. In 2010, iSuppli is forecasting price declines for crystalline modules of 20%, solar wafers to decline by 18.2%, and polysilicon prices falling by a further 56.3% (see Fig. 1). Many industry observers now believe that with the continued growth in polysilicon production by both major and new entrant producers, declining prices along the supply chain are now set in stone for the industry.

Of course, this is a key prerequisite for an industry chasing the elusive grid parity (and beyond), which will benefit the players in becoming increasingly competitive with other renewable energy forms.

"The erosion in pricing is bound to change the face of the solar industry," noted Henning Wicht, Senior Director and Principal Analyst for Photovoltaic Systems at iSuppli. "The freefall of PV prices represents a permanent ratcheting down of price structures that will transform the industry into a more competitive marketplace."

iSuppli expects PV manufacturers to continue to focus on cost reductions in order to keep up with the price declines and to repair compressed profit margins experienced in 2009. When the cost-down programs eventually catch up with the rate of price declines, an overall improvement in the profit picture can be expected, Wicht said.

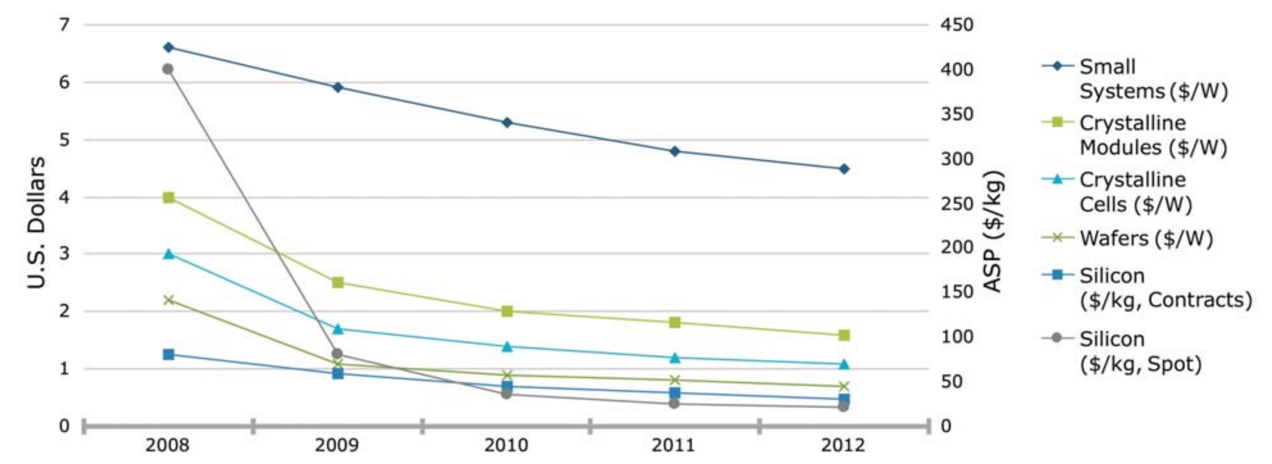
This is of particular importance to polysilicon and wafer producers, who have experienced the most aggressive price declines, yet have significantly higher capital costs compared to others downstream, such as pure-play module manufacturers.

Challenges also exist for wafer producers. With the strong wafer demand creating a very tight supply environment, further capital expenditures will be necessary to meet customer demand. Traditionally in periods of strong demand, equipment lead times extend to over nine months as key production equipment such as furnaces and wire saws are slowly churned out. These tools are large in size and/or complex in construction making them inherently difficult to manufacture in high quantities at the short lead times.

The role of polysilicon

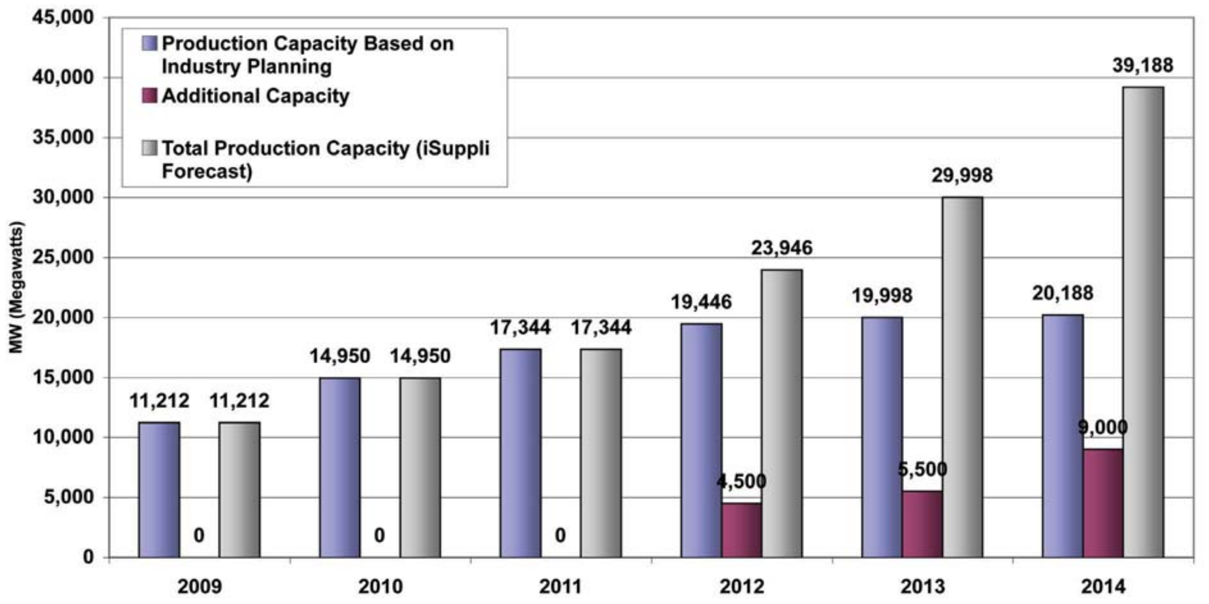
Disconnects between points in the supply chain as seen recently in polysilicon shortages are in danger of transferring to the wafering sector. This results in greater pressure to boost productivity while new capacity is planned and eventually implemented.

As can be seen in Fig. 2, iSuppli has surveyed wafer production expansion



Courtesy of iSuppli Corp.

Figure 1. Average selling price forecast 2008-2012 in US$/MW.



Courtesy of iSuppli Corp.

Figure 2. Global solar wafer production capacity plans (MW).

plans of producers that show only a gradual expansion (left column) in wafer capacity based on actual planned capacity additions. The middle column shows the potential additional plans that could be undertaken but have yet to materialize. Only in 2012 and beyond will we see those plans add meaningful production capacity.

It could be argued that such a forecast only reinforces the pressures on wafer producers to optimize current capacity throughput, yield and overall productivity. New capacity additions could also benefit from new technology introductions that also reduce production costs. Those that successfully tackle these challenges will not only benefit from lower costs and improved margins, but also attract more customers downstream requiring lower prices to remain competitive. They will also gain advantage in a continuing overall price decline environment.

There should be little doubt that polysilicon and solar wafers are intrinsically linked. Wafer price declines have primarily been a result of the even greater decline in virgin polysilicon prices since mid-2008. Numerous market research reports point to continuing capacity expansions that should lead to further price declines. A recent report from Bernreuter Research estimates that global polysilicon production will reach 250,000MT in 2012, with approximately 80,000MT produced in China alone, making up about one-third of global production.

Johannes Bernreuter, founder of the research firm, told *Photovoltaics International* that polysilicon supply/demand dynamics this year would translate into spot pricing in the range of US$45 to US$50/kg.

"Wafer producers have benefited from an overall improvement in material quality due to better availability of virgin polysilicon."

"In 2011, I expect that a significant volume in China will probably be produced at manufacturing costs below US$35/kg, and that the spot price will fall to this level – whether by the end of the year or earlier," commented Bernreuter.

Wafer prices will therefore continue to decline, but as seen in 2009, prices fell much more than manufacturing costs, leading to significant margin declines. However, wafer producers have actually benefited from the plentiful supply of polysilicon in a different way. According to Nick Sarno, the former VP of Manufacturing at LDK Solar and now currently consulting for the industry, wafer producers have benefited from an overall improvement in material quality due to better availability of virgin polysilicon and the declining dependence for some using scrap silicon to complement ingot production.

"This translates into cost reductions throughout the wafer manufacturing process," noted Sarno. "Less man hours on procurement of scrap silicon, sorting and storing has a small impact but better quality supply of virgin material produces better ingots, blocks and wafers, reducing scrap, consumables and delivering a better product all round."

Furnaces: is size the solution?

In an effort to reduce ingot costs, there has been a gradual but growing trend towards larger ingot sizes. The larger the ingot, the more blocks and consequently wafers can be produced, resulting in increased overall yield increases (see Table 1). This therefore requires larger ingot growth furnaces. Much of the current ingot production is performed using Directional Solidification System (DSS) furnaces that cast multicrystalline ingots using 450kg furnaces for volume production. Developments continue on charge sizes above 500kg and 800kg, and there are

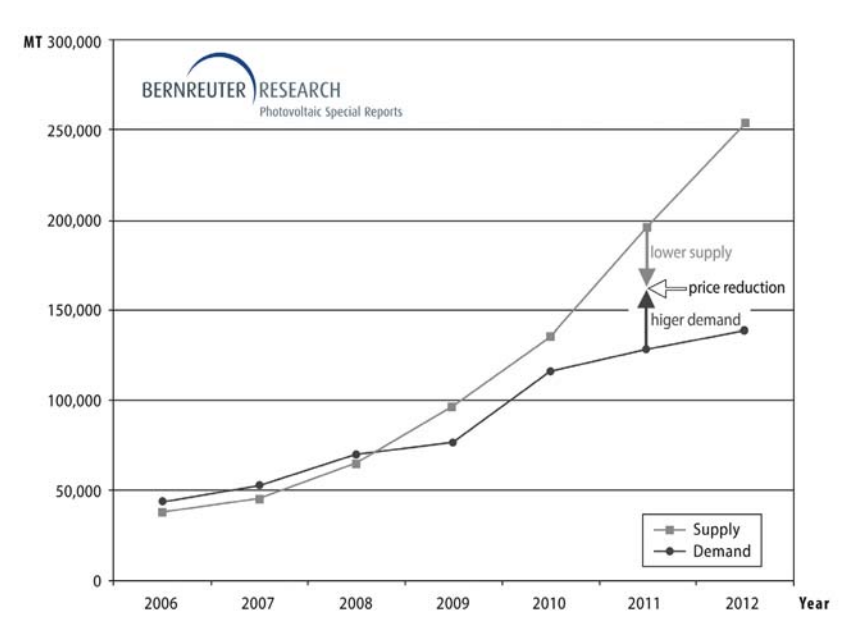


Figure 3. Bernreuter Research: polysilicon supply/demand pricing dynamics.

Figure 4. Crucibles at Ceradyne Tianjin Technical Ceramics.

Figure 5. GT Solar's DSS450HP ingot growth furnace.

Model Name		JZ-270	JZ-450	JZ-520	JZ-800
Initial Charge of Poly-silicon (kg)		270	450	520	800
Estimated Dimension of the Solidified Ingot (mm)	L & W	680	840	840	996
	Thickness	250	270	315	345
Estimated Dimension of Cropped Blocks (mm)	L & W	156	156	156	156
	Thickness	200	220	265	295
Estimated Weight of Cropped Ingot (kg)		181.4	311.8	375.7	602.2
Estimated Yield for Ingot (%)		67.2	69.3	72.3	75.3

Table 1. JYT large furnace benefit analysis.

efforts underway to increase ingot sizes to 1,000kg in the not-too-distant future.

In today's market, a key limitation is the technological capability to manufacture crucibles of ever-increasing size. Common industry practice has been to tackle this obstacle by adopting larger furnaces but using multiple crucibles at a time within the furnace for optimization and greater throughput.

"From a capital expenditure point of view this strategy is a plus," noted Sarno. "You are future-proofing investments in anticipation of the larger crucibles being available, while not having additional investments for going bigger just because of crucible size limitations."

Crucible manufacturers are attempting to address several challenges at once, answering increased demand for larger-sized crucibles – in particular 450kg products – while re-tooling for even bigger sizes in the future.

Ceradyne, a leading fused silica crucible manufacturer, is expanding manufacturing in the first half of 2010 in its existing facility, Ceradyne Tianjin Technical Ceramics (see Fig. 4), and has broken ground on a second facility, Ceradyne Tianjin Advanced Materials, which will be operational during early 2011, to meet growing demand.

A leading DSS furnace supplier is GT Solar, a company that has certainly seen the growing demand for larger systems in the last few years. During fiscal year 2009 and 2010, GT Solar sold approximately US$1 billion of capital equipment into the market to support the build-out of installed end-user capacity of approximately 8GW to 10GW.

Interestingly, the issue of larger furnace sizes was not the first point of conversation that Henry Chou, Product Marketing Manager, PV Equipment for GT Solar International wanted to mention. Rather, he noted that as the industry becomes more mature, GT Solar has brought to the table what he describes as the 'value metric.' Using simplified variables to highlight manufacturing costs, the company targets cost reductions via improved throughput of the tool coupled to higher yields and better overall ingot quality. This then translates into less wastage from the ingot to the wafer sawing steps, also lowering costs.

"Being able to get better quality wafers as a result does indeed enable cell producers to achieve higher conversion efficiencies," commented Chou. "What we look for is good kilograms produced per hour."

> "The two key metrics for cost reduction at the furnace are throughput and yield."

The two key metrics for cost reduction at the furnace are throughput and yield, according to Chou. With respect to throughput, this relates to the charge size divided by the process time.

"Interestingly, if you start to add more mass to the charge, your process time will start to increase. Based on the process time, the quality of the segregation of


Figure 6. CRS Reprocessing Services' typical slurry recycling system.

impurities and growth of the crystals changes the optimum balance. So if you grow bigger ingots it doesn't necessarily mean that you are going to get higher throughput, due to the growing cycle needing to be longer," added Chou.

He also believes that ingot sizes above 600kg could lead to other equipment changes that actually add to the cost of production. Consensus on whether charge sizes above 450kg are inevitable would seem to be premature. The company has recently been tapped for its 'DSS450' furnaces and ancillary equipment and services to the value of US$200 million. The orders come from a range of wafer producers, including Tianwei New Energy, Phoenix Photovoltaic Technology, Yingli Green Energy, JA Solar and Sino-American Silicon Products (SAS).

In early May 2010, the company launched the 'DSS450HP,' a high performance ingot growth furnace with a thermally optimized, second-generation hot zone that is said to improve throughput while delivering industry-leading crystal quality. Current users of the DSS450 and DSS240 models can migrate to the new DSS450HP with a field upgrade kit, which means that in the near term, wafer producers are regarding proven technology offerings as preferable to pushing the boundaries of even larger ingot/furnace sizes.

Slurry solutions

Slurry is at the heart of wafer manufacturing. It is used with wire saws to cut the wafers out of silicon ingots, normally comprising an abrasive mixture of silicon carbide and ethylene glycol that erodes, rather than cuts, the ingot. Generally, a conversation centring on where key costs are located across the various wafering processes will lead straight to the topic of slurry.

As the slurry is fed along a guide wire, the abrasive silicon carbide in the slurry (or 'grit') cuts through the ingots to produce the wafers. Slurry should be regularly replaced and reprocessed in order to keep the number and quality of the wafers high while maintaining acceptable unit cost.

Although slurry is vital to the process, it also represents a significant proportion of the wafer production cost; slurry costs are often second only to the cost of the polysilicon itself. Despite the relatively low price of US$3.50 per

Figure 7. In-house slurry recycling system at LDK Solar.

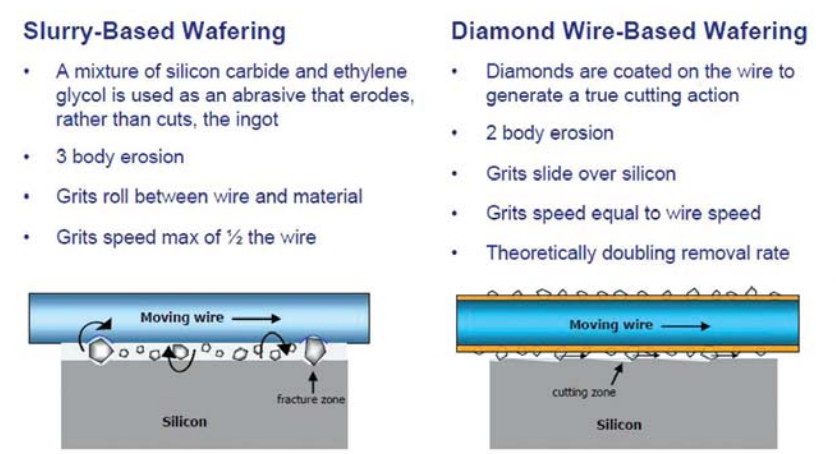


Figure 8. Meyer Berger's diamond wire comparison chart.

kilogram for new slurry, the overall cost can quickly escalate. In a scenario where 10 wire saws are being used in a process, the operating cost can be as high as US$16 million a year, not including disposal fees or labour charges.

> "A do-it-yourself scenario may impact quality control and productivity."

For the vast majority of manufacturers, slurry reprocessing ranks in the top five contributors to operating cost. Optimizing this aspect of the business can have dramatic and lasting effects on wafer production costs and overall quality.

According to CRS Reprocessing Services, a leading slurry recycling firm, wafer manufacturers that are planning a slurry reprocessing program or starting from scratch in a greenfield operation can benefit from significant margin-enhancing improvements. For a wafering operation running 10 wire saws with a volume of 385 metric tons per month, slurry reprocessing can result in a saving of anwhere in the region of US$8-10 million per year, net of recycling costs, utilities, and infrastructure investment.

Figure 9. Fewer Si losses are possible through the optimal positioning of the block within the cropping saw.

"At CRS Reprocessing Services we are able recover between 80% and 90% of both the grit and the carrier," noted Bill Lawrence, founder and president. "The actual amount of recovery is a function of the wafer size, wafer thickness, saw set-up and the silicon kerf loading in the used slurry. For oil-based slurries, the recovery of the cleaning solvents used to rinse wafers and equipment is typically greater than 90%. In short, the higher the recovery rate, the more material is effectively recovered and reused, and the less that must be spent on new material."

The benefits of slurry recycling were echoed by Nick Sarno, who recalled a huge move toward recovery strategies during his time at LDK Solar. Sarno noted that LDK has a 30,000MT recycling system designed in-house (see Fig. 7), with a similar system being installed as the company ramped wafer production beyond 2GW per annum. Sarno reiterated that cost avoidance was a key aspect as recycling significantly reduces the use of new material.

Perhaps not surprisingly, CRS's Lawrence cautioned against the tendency for wafer producers attempting to design in-house systems instead of using fully supplied and managed systems from expert third parties.

"The downside is that do-it-yourself options tend to have much lower recovery rates for both grit and for the carrier. These processes typically recover only a small portion, say, 20-30%, of the carrier. In addition, a do-it-yourself scenario may impact quality control and productivity resulting from lower specifications, limited lab verification tools and increased downtime.

"To put it in perspective, an optimal reprocessing solution that increased the recovery of both grit and carrier could easily decrease the overall costs for a 10-wire-saw operation by US$275,000 to US$375,000 a month. These factors, along with the need to fund resources that are not central to the business, reduce the potential savings that are expected by taking the process in-house."

In general, there are four options when it comes to reprocessing slurry: do-it-yourself, off-site reprocessing, on-site reprocessing, or do no reprocessing at all.

Lawrence went on to point out some of the cost issues associated with off-site reprocessing, which is popular in Europe. He noted that the service fee for off-site reprocessing can be competitive, perhaps even lower than the common alternative of on-site reprocessing. There are a number of other costs, however, that factor into an off-site processing scenario that should be considered.

Chief among these are freight costs – both trucking and shipping, which can vary depending on the amount of slurry and transportation distance. In some cases, the expense can be considerable. Rates range from US$0.03 per kilogram within a country to up to US$0.40 per kilogram around the world. For a customer processing 800MT per month, this could total over US$200,000 per month. Off-site reprocessing also requires that a manufacturer have large amounts of slurry 'in play.'

Many of these issues have long pervaded in parallel industries such as semiconductor manufacturing, where most of the required recycling is done on site, bringing with it other benefits.

From a quality control standpoint, on-site reprocessing brings full transparency to the manufacturer, who gains the advantage of immediate and verifiable slurry. Since the slurry does not leave the facility, it is reprocessed in a closed loop that eliminates the risk of outside contaminants entering the production stream. On-site testing, conducted by experts who can easily and quickly adjust levels to achieve consistent and optimized slurry, helps ensure wafer yields are high with minimal waste.

Once again, the issue of quality is a key factor that should not be overlooked in the pursuit of straightforward cost analysis. Optimized yield and high quality products are often greater cost saving pursuits.

Chemical contribution

Of course, slurry is not the only chemical used in wafer processing. Cleaning and texturizing steps use HF acids in baths. Simply shopping around for lower cost bulk chemicals may prove effective in the short term, but once again, using the right chemistries for yield and wafer quality considerations could prove to be a greater contribution to cost reduction and optimization strategies.

Frank Haunert, Product Manager at BASF, commented that 'solar-grade' bulk chemicals such as HF acids that are not specific to semiconductor purity levels have been developed, which means that they can therefore be offered at lower prices, while maintaining the quality and consistency requirements that optimize processes. With respect to BASF's 'Seluris' range of etching and texturizing chemicals, Haunert noted that they enable saw damage to be rectified and the wafer surfaces to be structured from 'drop-in' solutions, reducing quality inconsistencies and delivering a more homogenous wafer result.

> "A key bonus of diamond wires is that slurries are not required, therefore dispensing with the expensive material altogether."

With respect to slurry, Haunert noted they are developing slurries that have tackled issues such as wire pairing: "The typical wire saw can experience surface tensions that mean the wires cannot get through the slurry solution and start coming together creating one thin and one thicker wafer. This has a negative impact of yield and overall productivity."

Diamond wire solution

The new kid on the block for sawing bricks and wafers is diamond wire technology (DWT). A key bonus of diamond wires is that slurries are not required, therefore dispensing with the expensive material altogether. This of course means that there are no recycling costs nor any of the other costs associated with the use of slurry. DWT is also claimed to provide 2.5-3x the throughput compared to conventional wire/slurry combinations and is said to offer improved cutting accuracy, reducing kerf loss and providing stable processing partly due to its simplicity relative to slurry-based processing. Although still in its infancy from an adoption perspective, the technology has some potentially compelling aspects.

"We believe we can drive down the wafering costs by 10 to 15% initially with diamond wire technology and further improvements later," commented Peter Pauli, CEO of Meyer Burger Technology AG. "The important part of that is yield improvement. The industry as a whole only has an 80 to 90% total yield. If we only deliver a 5% yield gain this would be a dramatic improvement for the industry."

However, concerns have been raised over the use of DWT, not only because of the inherent cost of diamond wire, but due to the physical difference of the resulting wafers compared to conventional wire/slurry-produced wafers.

Nick Sarno cautioned that diamond wire leaves score marks on the surface of the wafer, making the wafers look physically different from non-DWT produced wafers. This has returned some negative feedback from customers, reporting that they are 'a little afraid of using' this type of wafer.

Meyer Burger's CEO was well versed on this issue: "The sub-surface damage is actually less than with slurry," Pauli pointed out. "The surface may look a little bit different, but changing to another technology takes time. We don't expect a dramatic uptake of the technology right now."

"Changing to another technology takes time" – the same can be said about changing perceptions regarding DWT. To that end, the company has made great strides in developing and importantly demonstrating the cost and yield benefits of DWT. Meyer Berger has invested positively in the complete system technology and infrastructure that would enable the industry to migrate to DWT at the high volume commercial level. Pauli noted that the actual diamond wire was only one aspect of the complete package needed to make adoption successful.

"The key is that DWT changes wafering, internally and dramatically," he added. "It gives us the opportunity to change and improve the whole line – simplifying and reducing steps and equipment needed in the value chain. With overall complexity of the wafering process reduced, we have the ability to improve the overall yield and bring the industry into the industrialization phase. This, to me, is the future."

Thinking thin

With the return of a plentiful supply of polysilicon, it would seem that there is less talk focused on migrating to thin wafers in order to reduce cost. Although companies like LDK Solar have continued to migrate gradually to thinner wafers, there is less emphasis on taking wafers thinner than 170 microns, due to concerns at the cell processing level regarding higher rates of wafer breakage. Although developments continue at the R&D level, production efforts remain focused on kerf loss.

Process optimization

However, conventional wire/slurry technology is not stagnant. Significant efforts are ongoing to provide the yield and cost reductions required for the industry across the complete wafering process flow.

Herbert Arnold GmbH & Co. KG is a leading manufacturer of production systems for processing mono- and multicrystalline silicon bricks that incorporate cutting, grinding and polishing.

> "Significant efforts are ongoing to provide the yield and cost reductions required for the industry across the complete wafering process flow."

Speaking with Wolfgang Schürgers, Sales Director at Herbert Arnold, it was apparent that there are significant opportunities in regard to the optimization of equipment and processes that not only shorten cycle times but also provide greater understanding of the overall processes that in return improve productivity, quality and yield. The introduction of advanced technology manufacturing systems improve process control and an integrated, process data analysis creates transparent and efficient production.

"What I can see is a lot of effort to optimize Gen5 ingots to produce 25 bricks of higher quality and improve the height of ingots by 300 to 400mm," noted Schürgers. "I don't see the trend towards the one-ton ingot. Kerf loss is still an important issue and we are able to provide a cut with the smallest kerf loss possible."

Schürgers highlighted that cropping with blade saws rather than wire saws provides accurate straight cutting and lower cost. The development of high precision (1.5mm) blades with the optimization of the thickness of the smallest of blades significantly reduces kerf loss and boosts machine uptime, increasing throughput.

With the move towards larger wafer production lines in excess of 500MW capacity, there will be a growing trend towards fully automated lines, according to Schürgers.

Herbert Arnold have calculated that automation of the entire process flow would generate at least a 10% overall productivity improvement. This is achieved by optimized 24-hour operations, reduced waiting times for tool availability and reduced machine idle time as a consequence. Importantly, highly optimized positioning of the brick and saw results in consistently improved yield.

Schürgers believes that high-volume facilities of 200MW and above that are still dependent on manual handling will have to deal with high error rates as a result of human operations, which have a considerable impact on the line's ability to be fully optimized.

Optimization of the complete line was repeated as a necessity by Greg Knight, Director of Process Engineering Turnkey Services for GT Solar.

"Equipment is one piece in operating a factory," remarked Knight. "How you utilize that facility is actually a bigger piece. We have done a lot of analysis on streamlining operations such as how we process material straight out of the furnace. There would seem to be a significant loss of revenue occurring in a lot of wafering facilities because they are making the decision to cut on the marked brick lifetime lines… while this is a useful metric, using metrology to determine what is good and bad enables only the bad material to be turned into dust."

According to Knight, better or less conventional cutting approaches can take yields to the 90% range when typically many wafer producers are operating in the sub-70% yield range.

Significant effort has been made with GT Solar's turnkey lines to enable the feedback of data from sawing to ingots. The multiple issues that can occur such as rejects and saw marks can be traced back to the specific furnace and correction procedures implemented in order to limit prolonged yield impacts. Detailed monitoring of the operations enables tighter process tolerances that reduce reactive changes and so boosts productivity and reduces cost.

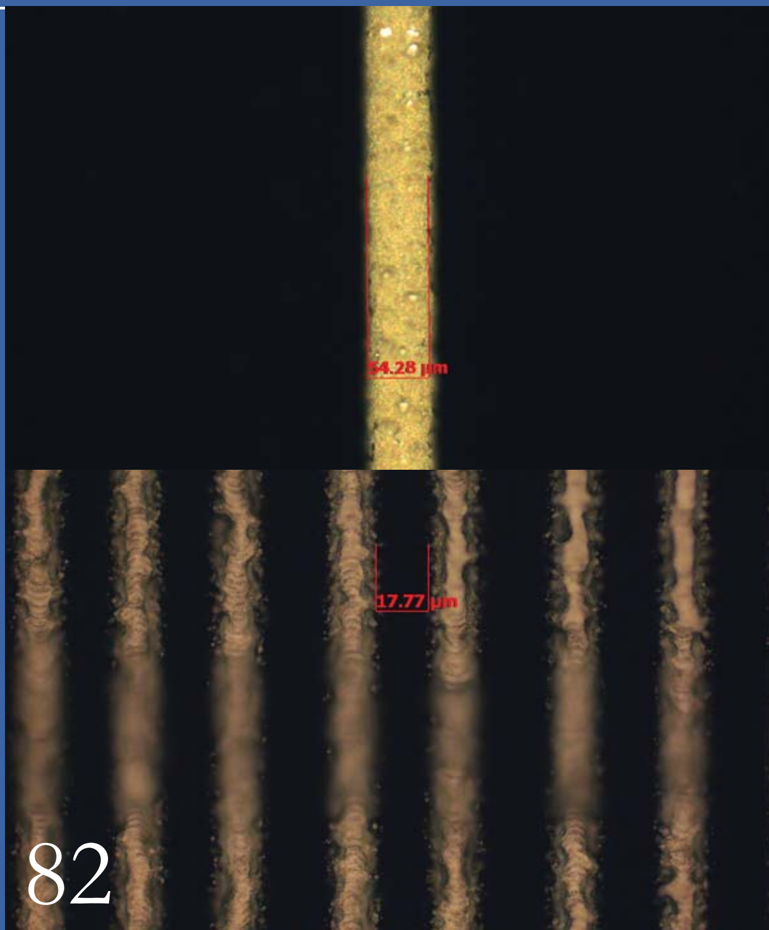
> "Better or less conventional cutting approaches can take yields to the 90% range."

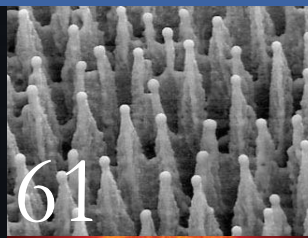
Chemical usage optimization was also a factor covered by BASF's Haunert. He noted that efforts are ongoing to maximize the use of a given amount of material for the highest possible number of wafers. Aspects such as bath temperatures and flow rates are fine-tuned to enhance the chemical characteristics for processes such as wafer cleaning.

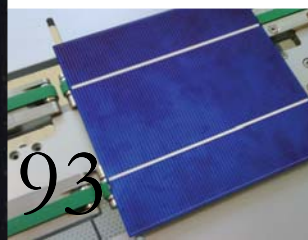
Conclusion

As wafer producers recover from rapidly declining prices in 2009 and focus on a new wave of capacity expansions to meet strong demand in 2010, cost reduction continues to be a core focus. The continuing abundance of polysilicon may well continue to place margin pressure on wafer prices, despite tight supply and a short-term recovery in wafer prices. Wafer producers that are vigilant in regard to cost and process optimization strategies will not only weather economic conditions better, but will likely flourish ahead of those competitors that fail to tackle these challenges in a coherent manner.

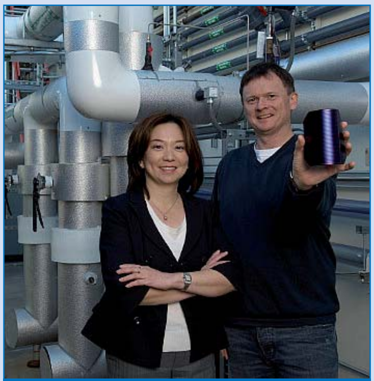
Cell Processing







PV cells processed with Innovalight silicon inks hit 19% efficiencies; 20% targeted by year's end



Innovalight's President/CEO Conrad Burke holds a silicon ink-based solar cell.

Innovalight has set a new record of 19% conversion efficiency for solar cells processed with the company's silicon ink. The Fraunhofer Institute for Solar Energy Systems measured the results on industry-standard size cells made by the materials and technology company at ISE's independent testing centre in Germany.

The company's proprietary Cougar platform offers what it calls a readily transferable process to crystalline-silicon PV cell manufacturers that allows them to improve solar cell performance, reduce cost, and boost output capacity by adding a simple step to already installed manufacturing lines.

"We continue to push toward our goal of delivering over 20% conversion efficiency to our customers," said Homer Antoniadis, Innovalight's CTO. "Our patented solar cell process with silicon ink is simple and optimized for use with silicon wafers and widely adopted industry printing tools."

Innovalight is working with JA Solar and several other cell-manufacturing companies and is ramping production of silicon ink in its Sunnyvale, CA, headquarters. The company, which was awarded a key cell manufacturing with silicon ink-related patent earlier this year, has filed for more than 60 patents in its specialized field.

President/CEO Conrad Burke told *PV-Tech* during a facility visit that the company expects to hit the 20% cell efficiency mark by the end of 2010. He also said that announcements with more specific details about Innovalight's partnership with other cell producers will be made in a few months.

Burke noted that Innovalight has developed and refined processes for screen-printing (the current market opportunity) and inkjet printing (a developing sector) in parallel, calling the matching of the ink with the printing system one of the keys to the Innovalight approach. The screenprint ink has a thicker, more viscous consistency, while the inkjet solution takes the liquid form associated with regular inks.

The Sunnyvale facility has a fully equipped ~10MW cell-manufacturing pilot line (standard equipment, both 125mm and 156mm) and analytical/metrology capabilities, where customers can come and learn about – and transfer – the processes, he explained. The chief executive added that the privately held firm plans to manufacture all the inks itself in a secretive production line capable of gigawatt-scale output at the Sunnyvale facility.

R&D News Focus

IMEC begins work on EU project Prima to improve solar cell efficiency through nanostructures

IMEC has started work on Prima, the project under the European Union's seventh framework program for ICT (FP7). The aim of the project is to improve the efficiency and cost of solar cells though the use of metallic nanostructures.

With IMEC as the project coordinator, Imperial College (London, UK), Chalmers University of Technology (Sweden), Photovoltech (Belgium), Quantasol (UK) and Australian National University (Australia) will work as project partners.

The aim of the project is to gain insight into the physical mechanisms of metallic nanostructures--in how they can improve the light absorption of the solar cell's material--while also providing an opportunity for the project's partners to study how these structures can best be integrated into the production of solar cells.

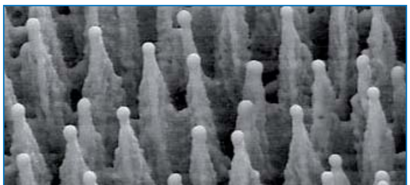
Metal nanostructures can improve the absorption in various types of cells, for example, crystalline Si cells, cells based on high-performance III-V semiconductors, or organic and dye-sensitized solar cells.

'Black Silicon' start-up SiOnyx partners with Coherent to demonstrate solar cell applications

Harvard University spin-off SiOnyx has entered into a joint development agreement with Coherent to evaluate and develop the start-up's light-absorbent material for solar cell fabrication applications. Fabrication of black silicon uses femtosecond laser processing of the target material to produce absorbent layers that better capture infrared light, potentially boost solar cell conversion efficiencies over conventional processes. Coherent has been active in developing laser-based techniques for both c-Si and thin film process technologies.

Little has been heard from SiOnyx since 2008, regarding its solar cell applications for its Black Silicon material. The company claims that the product can improve conversion efficiencies and manufacturing yields while reducing production costs.

The technology partners did not disclose how long the development program would last or whether a production ready solution would be available.

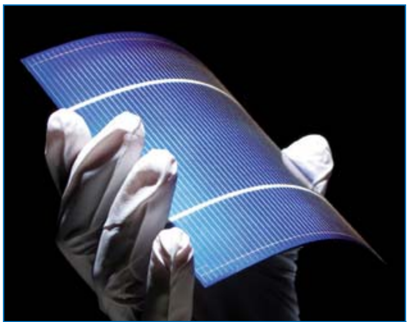


SiOnyx's black silicon technology.

Dow Corning partners with IMEC on ultra-thin solar wafer encapsulation

Intended to bring a range of new products to market for future advanced c-Si solar cell production and module assembly, Dow Corning has joined several of IMEC's industrial affiliation program (IIAP) on silicon solar cells. The collaboration includes development of novel silicone encapsulant processes for integrated cell and module processing using new cell structures that could be required when using ultra-thin and large wafers.

Dow Corning signed a three-year contract with IMEC to undertake joint research on advanced cell technology.



IMEC's 'i-PERC' (Passivated Emitter and Rear Cell).

Solterra to deliver high volume production methods for its tetrapod quantum dots

Solterra Renewable Technologies, Quantum Materials' wholly owned subsidiary, has entered into a process development agreement with a consortium of advanced chemistry companies in the Netherlands, to validate high volume production methods for its proprietary tetrapod quantum dots. The agreement follows the MOU that Solterra, FutureChemistry and Flowid signed in 2009.

FutureChemistry and Flowid will provide the expertise necessary to find optimal process conditions and scale the synthesis of the quantum dots to necessary levels. With larger quantities of quantum dots, Solterra will be enabled to pursue its goal of reaching 1GW of solar cell production. Solterra aims to increase available solar energy generation and to bring low cost quantum dots to the LED, display, broader optoelectronic and biomedical research markets.

Suntech Power, University of New South Wales and Silex Solar partner for research

For the duration of a three-year collaborative research project, Suntech Power, Silex Solar and the University of New South Wales will research advanced technology for the enhancement of power conversion efficiencies in crystalline silicon solar cells. AU$5 million was granted to the project from the Australian Solar Institute, making this the largest grant for any grant applicant in the ASI funding call.

Silex Solar and Suntech are committed to contributing an added AU$6 million in direct funding and in-kind resources over the three-year project. The project will focus on the development of advanced solar-cell device designs and high-volume cell manufacturing processes for advancements in performance and cost reduction.

Cell Production News Focus

Motech targets 1GW cell capacity in 2010, expects price declines to continue

The downward pricing trend throughout the solar industry supply chain is expected to continue throughout 2010, according to Motech Industries as the rapid expansion of low cost capacity continues, despite strong demand. Motech saw a revenue decline in the first quarter of 2010 of 2%, despite shipments increasing approximately 20% to 154MW as prices declined.

Motech noted that it was on track to reach a cell production capacity of 1GW by the end of the third quarter, up from 800MW today. Solar cell shipments for 2010 should reach 825MW, higher than its previous forecast of 750MW.

The company expects prices to continue decline in 2010 as they see the potentially rapid expansion of low cost capacity.

Motech Industries' solar cell capacity ramp plans.

PV3000 high throughput metallization solution

Combine SIX-SIGMA PRINT ACCURACY with patented parallel print processing and an extremely compact footprint. What do you get? A high-speed solar metallization line that drives throughput beyond expected levels for the industry's best yields. Backed up by an unparalleled global infrastructure and award-winning service & support,DEK's PV3000 sets new productivity standards in solar cell manufacturing.

think beyond equipment.

For more information: www.deksolar.com

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Schmid receives 1.5GW in equivalent orders for its selective emitter technology

Having launched its selective emitter processing technology at EU PVSEC last September, Schmid Group has said that it has received confirmed orders for related equipment, the equivalent of 1.5GW of solar cell production. The company claims that due to its simpler wet chemistry processes it has become the market leader of selective emitter technology.

Schmid said that order intake is exceeding all expectations with the majority of enquiries coming from Korea, India, China, Taiwan as well as many parts of Europe. The company reiterated that numerous trials carried out at their own technology centre together with additional tests and reports published by their research partner, the University of Constance, prove that the efficiency of multicrystalline wafers has been increased by 0.4 % and that of monocrystalline wafers by 0.8 %.

Its inline selective emitter cell technology, known as 'inSECT', is claimed to be easy to integrate in existing manufacturing lines, which is another reason for its high-interest levels. Throughput of the insect line is said to be 2,200/wph.

Ningbo Solar buys 50MW of PV cell metallization lines from DEK Solar

Ningbo Solar has bought another 50MW worth of photovoltaic cell metallization lines from DEK Solar, following the Chinese solar manufacturer's purchase of eight lines several months ago. Ningbo cited the PV1200 metallization line's ability to achieve six-sigma process capability at a resolution of ±12.5µm for maximum repeatability and accuracy, as well as DEK's customer service and support, among the reasons for the latest acquisition.

Financial terms of the transaction and delivery schedules for the purchased equipment were not disclosed. DEK announced earlier in 2010 that it had received further orders for its PV1200 solar cell metallization lines from Zhejiang Hongchen and other Chinese PV manufacturers.

Tempress receives US$15 million in new solar orders

Tempress Systems, a subsidiary of Amtech Systems, announced that since April 1, 2010, it has received around US$15 million in new solar orders for its diffusion processing systems from two new customers and one existing customer in Asia. These orders bring the fiscal 2010 order totals to approximately US$98 million.

Q-Cells Malaysian fab to reach 600MW cell capacity

The former dominant solar-cell manufacturer, Q-Cells has reported first-quarter revenue of €232 million, a decline of 8% compared to the previous quarter. EBIT adjusted loss was only €1 million. Production volumes reached 174MW, up sequentially from 161MW in the fourth quarter of 2009. Q-Cells said that it would be ramping solar cell capacity faster than previously guided.

Expansion phases three and four in Malaysia will be completed sooner than planned, adding 150MW of cell capacity to reach 600MW by year's end. The third production line is expected to ramp up by the end of the second quarter, followed by the fourth line by the end of the third quarter.

Total cell capacity is targeted to reach 1.1GW by the end of the third quarter, the company said, with cell production expected to reach 800MW.

JA Solar boosts 2010 PV cell shipments

JA Solar has published its first-quarter 2010 fiscal year results for the period ended on March 31. Revenue in the first quarter was $279.2 million, an increase from 2009's fourth-quarter result of $238.4 million. The company attributes an increase in gross margin, to 22.9%, from 20.5% in 2009, to a high utilization rate and manufacturing process improvements with cost control efforts.

Total shipments for this first quarter were 272MW, an increase from fourth-quarter 2009's 231MW. Operating income was $51.7 million over 2009's $36.0 million, with an operating margin of 18.5% from 2009's 15.1%. Operating cash flow for 2010's first quarter totaled $62.5 million with incurred capital expenditures of $48.7 million. Cash and cash equivalents were $281.6 million with a total working capital of $464.7 million.

JA Solar looks to increase its shipments in 2010 to over 1GW, with shipments in the second quarter expected around 275MW. Module capacity is anticipated to be over 500MW and wafer capacity over 300MW for the full 2010 year.

Heraeus to expand production capacity for PV products by 300% in 2010

Citing unprecedented global demand for its range of PV manufacturing related products, Heraeus is set to expand production capacity by 300% in 2010. Heraeus had recently completed a 30% capacity increase and expects another 30% expansion by the end of May. Overall, the company is adding additional production and technical personnel to meet demand.

Reis Robotics and centrotherm complete cooperation agreement

Reis Robotics and centrotherm will be coming together to develop solutions for turnkey production lines to manufacture crystalline solar cells and modules. The companies look to this new agreement in order to utilize each other's industry knowledge, improve manufacturing processes, lower production costs and help customers increase their added value.

Business News Focus

Samsung will invest $21bn in future growth drivers, including solar cells

Samsung has announced that it will invest US$21bn in renewable energy and healthcare over the next decade, identifying solar cells as one of its future growth drivers. The new investment plans will help Samsung challenge rival companies such as Philips Electronics,

The launch of Samsung's first cell line in 2009.

General Electric, and Sanyo Electric, reports the Financial Times.

Samsung expects that between its key growth developers, which include; solar cells, rechargeable batteries for hybrid cars, LED technology, biopharmaceuticals and medical equipment, it will generate US$44bn of annual sales by 2020. The group generated Won191,000bn in sales in 2008 and hopes to increase the current workforce of 276,000 employees by 45,000 over the same period.

Sanyo reveals three-year mid-term management plan

Japan's Sanyo Electric, majority owned by Panasonic, has announced plans to invest 170 billion yen ($1.8 billion) in capital spending for its rechargeable battery and solar cell operations for the next three years. The company wants to speed up the development of new technology to lower the cost of making rechargeable batteries and boost production focus to meet fast-growing demand for renewable energy sources.

Sanyo is aiming to achieve a 21% conversion efficiency for its HIT solar cells at mass-production level by March 2011. The company also plans to strengthen the cost competitiveness by production innovation and expand sales in the residential market in Japan and Europe.

The 170 billion yen accounts for approximately 60% of its total capital expenditure of 290 billion yen allocated for the three years to March 2013. Fifty billion yen will be set aside for the solar cell sector and 120 billion yen for rechargeable batteries.

The company plans to start solar cell production at Panasonic's panel plant by early 2013.

SunPower first-quarter results edge toward profitability; company guides at least $2B for FY2010

SunPower has come out with its first-quarter 2010 results, reporting revenues of $347 million for the period, which compares to $212 million and $548 million in Q1 and Q4 2009, respectively. The company's components segment accounted for 81% of the latest quarterly revenues, while the systems group pulled in 19% of the total.

On a GAAP basis, SunPower reported gross margin of 20.7%, an operating loss of $2.9 million, and net income per diluted share of $0.13 for the quarter, which compares to gross margin of 15.2%, an operating loss of $18 million, and a net loss per diluted share of $0.12 in Q109.

The company also expects capital expenditures of $375 million to $475 million, as Fab 3 in Malaysia ramps and enters initial production in the fourth quarter. Solar-cell production will reach approximately 550MW, with another 50-100MW of cells coming from third-party suppliers, according to the company.

SunPower said it will increase factory line productivity by 15% this year, through a combination of improvements in cell efficiencies, overall equipment effectiveness, and manufacturing yields. Panel costs will be reduced in line with its assumption of 20% lower module ASPs during the year.

It also announced that its Gen 3 cell technology, which will reportedly achieve minimum efficiencies of 23%, will debut in 2011.

Amtech Systems releases second-quarter results

Amtech Systems has released its financial results for its fiscal 2010 second quarter, which ended March 31. Net revenue totalled $16.1 million, a 4% increase from the previous $15.5 million. Solar revenue came in at $10.9 million, compared to $11.9 million sequentially. Operating income was reported as $422, 000 from $128,000 sequentially.

The second quarter bookings were $34 million, with $27.6 million in solar. Gross margin was 29% to a sequential 30% and net income was $206,000 compared to $80,000 sequentially. The ending cash balance was reported as $43.1 million as of March 31, an increase from $42.5 million on December 31, 2009.

Amtech expects revenue in the next two fiscal quarters to be between $35 and $37 million with GAAP operating margins at or above 10% in the second half of this fiscal year.

Product Briefings

Schiller Automation

Schiller Automation's TS 3600 claims new benchmarks for cell throughput, yield and reliability

Product Briefing Outline: Schiller Automation's TS 3600 high-performance tester and sorter is said to greatly increase cell throughput, yield and reliability. Processing up to 3,600 cells per hour, the system claims an assured good part yield of 97.3% and a guaranteed operational availability of 95%.

Problem: Production cost reduction strategies are required to remain competitive in a product price decline environment. At the end of cell production, the wafer cell has to be classified and sorted, which requires guaranteed precision and reliability. Obtaining higher throughput and improved results on fewer tools and lines are key goals for high volume PV producers.

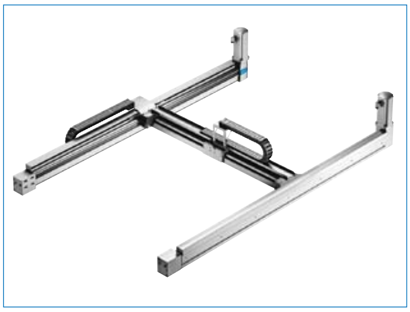
Solution: Manufacturers of solar cells using this tester and sorter will demonstrably increase their productivity and reduce the total cost of ownership. The TS 3600 is said to enable an annual output of 100MW on just one line for the first time. The high cell throughput, reliability, quality of results and lower costs per tested cell will increase the efficiency of production lines and permit more dependable planning.

Applications: Solar cell testing and sorting in high-volume manufacturing.

Platform: The line consists essentially of feed, tester and sorter modules. The innovative soft-handling concept and the high precision of the measurement systems used ensure the consistently high performance features, even in long-term daily use. The central conveyor system in the tester unit is based on a continuous conveyor chain. Once the cells are in position, they pass through all the test stations in a fixed, flat configuration. The performance measurements are carried out by means of a system of guided contacts applying minimum force, guaranteeing optimum measurement results.

Availability: Currently available.

Festo



H-Portal from Festo allows fast handling of solar wafers

Product Briefing Outline: Festo has introduced the high-speed H-Portal for the fast handling of solar wafers. Key features of the gantry with its recirculating toothed belts are the dynamic response of $50m/s^2$, a fast speed of 5m/s in the working space and a repeat accuracy of +/- 0.1mm. The high-speed handling is claimed to have the best delay response in a space-saving working area. The functional principle of the gantry is supported by reliable series components such as two stationary servo motors at the end of the axis. This lightweight composition is said to guarantee a long system service life.

Problem: Solar wafers have to be transported frequently and with high speed during their handling in the production area. Handling is a critical step that can often result in breakages due to the thinness and fragility of the wafers.

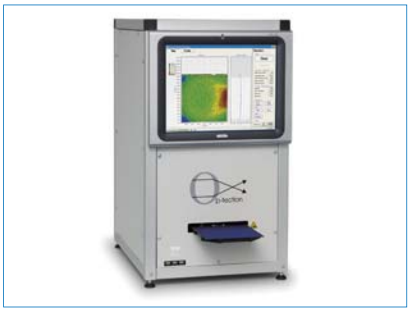
Solution: The planar surface gantry with an optional z-axis is designed to be extremely flat and, compared to other similar pickers, optimizes its working space use. The acceleration and delay values of the H-Portal provide a high level of dynamic response where other Cartesian Portal solutions fail, according to the company. The H-Portal is a cost-saving alternative to robot systems with delta kinematics.

Applications: Solar cell and wafer transport in the photovoltaics, flat panel and electronic industries.

Platform: The high-speed H-Portal consists of a lift-turn-unit (z-axis); a traverse, multi-axis controller CMXR; servo motors EMMS-100 and two tooth belt axes EGC 120. All components are from one source, including the axis mechanics, electric drive, vacuum solutions and controllers, the SBOx compact vision system and the basic steel frame.

Availability: Currently available on request.

Op-tection



Op-tection's 'OSIS Coating' system enables 100% inline measurement of SiN_x anti-reflective coating

Product Briefing Outline: Op-tection has introduced an advanced new technology family for the measurement of SiN_x anti-reflective coating for c-Si solar wafers. The 'OSIS Coating' system enables 100% inline measurement of the refractive index and thickness distribution on textured production wafers for consistent and high efficient wafer production. Its offline counterpart delivers detailed coating data of the complete surface topography at over 100,000 points within just one minute.

Problem: A highly stable silicon nitride deposition process is paramount for high cell efficiency as well as the consistent cosmetic appearance of the solar cells within modules. The 100% inline measurement of the SiN_x thickness and refractive index is necessary to provide engineers with essential capabilities to achieve the maximum from the coater and deposition process.

Solution: Inline measurement directly on textured wafers helps to avoid preparation of special polished wafers. Apart from lower labour expenses, measuring directly on the real production wafers has the additional benefit of rendering obsolete the indirect correlation between the measurement on polished reference wafers and the actual textured production wafers. Access to thickness and refractive index trends of every produced wafer enables the optimum use of plasma or sputtering targets. After periodic coater cleaning and maintenance, it is possible to return to the process window more quickly as the required control readings become available directly after the first coated wafer.

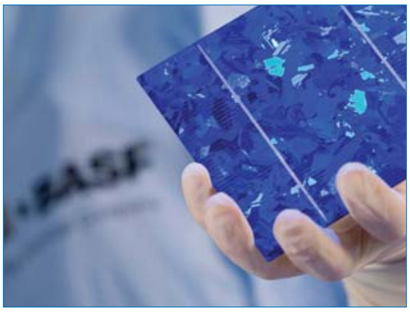
Applications: Measurement directly on textured wafers.

Platform: The standalone version of OSIS Coating is designed to complement its inline counterpart. Production wafers that need further investigation after the deposition process are measured, enabling the analysis of research coating behaviour in more detail.

Availability: Currently available.

Product Briefings

BASF



'SELURIS' Clean from BASF enables greater doping uniformity and passivation

Product Briefing Outline: BASF has extended its range of process chemicals for the manufacture of solar cells with a new, environmentally-friendly cleaning solution, 'SELURIS' Clean. It enables efficient hydrophilicity, i.e. the targeted modification of surface activity, as well as subsequent cleaning and passivation of the solar cell wafers. Additionally, SELURIS Clean can also be used at lower temperatures enabling lower processing costs.

Problem: Obtaining the correct wafer conditions before the doping process enables improved doping uniformity and cell performance. Post-doping cleaning also reduces the occurrence of undesired electrical errors, which would otherwise result in reduced solar cell performance.

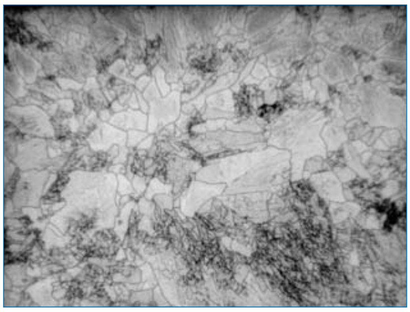
Solution: Before doping, the cut and texturized silicon wafers must be rendered hydrophilic. This allows improved surface wetting and therefore more homogenous distribution of the phosphoric acid on the wafer, and ultimately, optimum solar cell performance. After doping, SELURIS Clean primarily acts as an efficient cleaning agent. Any unwanted residual phosphorous remaining on the surface is removed quickly and easily.

Applications: The chemical is used twice in the manufacturing process for cleaning and passivation of solar cells – both before and after the phosphoric acid doping procedure.

Platform: The SELURIS range includes etching and texturizing chemicals, which enable saw damage to be rectified and the wafer surfaces to be structured. In addition, the portfolio also includes high-purity phosphorus oxychloride ($POCl_3$) for subsequent wafer doping.

Availability: Currently available.

BT Imaging Pty



QS-W1 luminescence-based inspection system from BT Imaging detects electrical material defects in wafers

Product Briefing Outline: BT Imaging Pty has launched what it claims to be a breakthrough product for qualifying the electrical quality of as-cut wafers in production. The QS-W1 is said to be the industry's first automated electrical wafer quality sorter, enabling the sort and rejection of as-cut wafers based on photovoltaic performance, which maximizes solar cell yield and efficiency.

Problem: In an ideal world, all solar cells would have maximum efficiency, and revenue would be predictable. Wafers are the largest cost element in solar cell manufacturing and faulty wafers can reduce absolute efficiency of a processed solar cell by as much as one percent. However, wafer electrical quality is not monitored today, and wafers are purchased at one price based on physical specifications, regardless of final cell efficiency. Electrical defects such as dislocations and impurities — which significantly impact cell electrical performance — are not seen by current inspection techniques.

Solution: The QS-W1 can take high-resolution (1 MP) photoluminescence (PL) images of as-cut wafers in one second. Automated algorithms classify and report the different electrical defect types seen in as-cut silicon wafers. Defects that reduce efficiency and yield — such as dislocations, impurities, and cracks — are automatically separated and reported. User-controlled binning is then used to grade the wafers appropriately based on defect density. The QS-W1 includes a crack and chip inspector, and an integrated thickness and resistivity measurement unit, which is used to normalize PL data to ensure accurate grading and sorting.

Applications: Electrical quality of as-cut multicrystalline wafers in production.

Platform: The QS-W1 is 10 times faster than previous generation systems, enabling inspection at production speeds for the first time.

Availability: The QS-W1 will start shipping to beta customers in Third quarter 2010.

StellarNet

StellarNet offers low-cost SpectroRadiometer to characterize and evaluate solar simulators

Product Briefing Outline: StellarNet has introduced a new SpectroRadiometer system designed to characterize and evaluate light emissions according to industry standards. The system is for use with solar simulators and has a variety of applications.

Problem: As solar cell manufacturers are driven to obtain higher production volumes and increased cell uniformity requirements, high performance solar simulation is a necessity. Many companies offer high performance solar simulator lamps that provide the cell manufacturer with measurement uniformity, comparability and traceability. Organizations such as IEC, JIS, and ASTM have developed standards that define solar simulator performance in three key performance areas: spectral match to the solar spectrum, spatial uniformity of irradiance, and temporal stability.

Solution: The complete NIST traceable system consists of a portable UV-VIS-NIR fibre optic spectrometer and fibre light receptor. The 'SpectraWiz' software now includes a new solar match panel that is part of the Light Monitor application, used to characterize and classify light emissions for solar simulators. The Solar Match Monitor application calculates spectral irradiance for each 100nm bin from 400-1100nm and compares the results to the ideal percent for each bin range per IEC/JIS/ASTM. The proximity of the measured data to the ideal values results in classification of the solar simulator lamp from A through D. The Light Monitor also measures UVabc regions below 400nm using both U.S. and European standards.

Applications: Characterization of solar simulator performance in three key performance areas.

Platform: SpectraWiz includes a multitude of radiometric and spectral analysis tools and calculations.

Availability: Currently available.

Methods of emitter formation for crystalline silicon solar cells

Jan Bultman, **Ilkay Cesar**, **Bart Geerligs**, **Yuji Komatsu** & **Wim Sinke**, ECN Solar Energy, Petten, The Netherlands

ABSTRACT
The emitter or p-n junction is the core of crystalline silicon solar cells. The vast majority of silicon cells are produced using a simple process of high temperature diffusion of dopants into the crystal lattice. This paper takes a closer look at the characteristics of this diffusion and possible variations in the process, and asks whether this step can lead to optimal emitters or whether emitters should be made with different processes in order to obtain the highest possible efficiency.

Basic properties of emitters and requirements for optimal performance

The ideal scenario

The operation of solar cells relies on light absorption generating electron-hole pairs. Electrons and holes then diffuse and/or drift to a charge-selective interface and are spatially separated as positive and negative charges at that interface (a process known as 'collection' – see Fig. 1). Collection leads to build-up of a potential difference between both sides of the interface, more commonly known as the cell voltage. The cell will generate a current when collected charges are allowed to flow through an external circuit.

The most important parameter for practical use is obviously the power output of the cell, which is equal to the product of voltage and current. Electron-hole pairs may be bound (excitons) or unbound, leading to distinctly different device design requirements. In the case of crystalline silicon, electron-hole pairs are normally unbound, which means that generated electrons and holes are able to move independently. The standard interface used for charge separation is the p-n homojunction. Here, 'p' and 'n' refer to p- and n-type doping, respectively, while 'homo' indicates that the doping is present in the same kind of semiconductor material which, in this case, is crystalline silicon. The resulting structure is a silicon bipolar diode. A well-known alternative for the selective interface is a heterojunction, where two different semiconductor materials are combined, e.g. crystalline and amorphous silicon.

The reverse process of generation of electron-hole pairs is recombination. When silicon is driven out of thermal equilibrium by light absorption and generation of extra electron-hole pairs, it will naturally respond by (net) recombination. This may prevent electrons and holes from being separated, since they may recombine before reaching the junction. Recombination may therefore lead to a reduced output current. Another effect of recombination is reduction of output voltage, as will be discussed later. Part of the art of solar cell processing and design is thus to minimize recombination and to maximize the probability for electrons and holes to be separated and collected.

The most commonly used solar cell device structure in crystalline silicon is a planar diode structure (see Fig. 2), where a thin layer of heavily doped silicon (n^+ or p^+) is present at the front surface of a moderately doped wafer of the opposite type (p or n). The heavily doped region is often called the emitter, while the moderately doped (wafer) material is referred to as the base. The term 'emitter' can be appreciated after a more detailed treatment of the p-n junction behaviour. The emitter area is the region that 'emits' (injects) most of the charge carriers under (dark) operation. It is also found in transistor terminology, where 'emitter,' 'base' and 'collector' are the device regions.

For the majority of commercial solar cells the wafer is p-type, but there is an increasing interest in n-type silicon. Reasons for the interest in n-type silicon are the absence of light-induced degradation due to boron-oxygen complex formation and the lower sensitivity to impurities of n-type silicon compared to p-type silicon. There is no fundamental reason why the p-n junction should be present at the front of the cell and neither is it essential to employ a planar structure. The most extreme and relevant illustration is the back-junction back-contact solar cell, where the collecting junction is present in the form of highly doped regions at the rear of the device. This cell is also referred to as the Interdigitated Back Contact (IBC) solar cell and has been developed and commercialized by SunPower Corp.

In the current standard process, the emitter is formed by in-diffusion at high temperatures of an n-type dopant (phosphorous, P) into the surface region of a p-type wafer doped with boron (B). By adding phosphorous at much higher concentrations than the background boron doping level, the surface region is inverted from p- into n-type silicon and a p-n junction is formed. This region thus consists of 'compensated' material. The point at which p- and n-type active doping concentrations are equal is called the metallurgical junction. On both sides of the metallurgical junction a depletion (also called space charge) region is found. This region is depleted of mobile charge carriers and thus only contains fixed charges at the ionized doping atoms, the

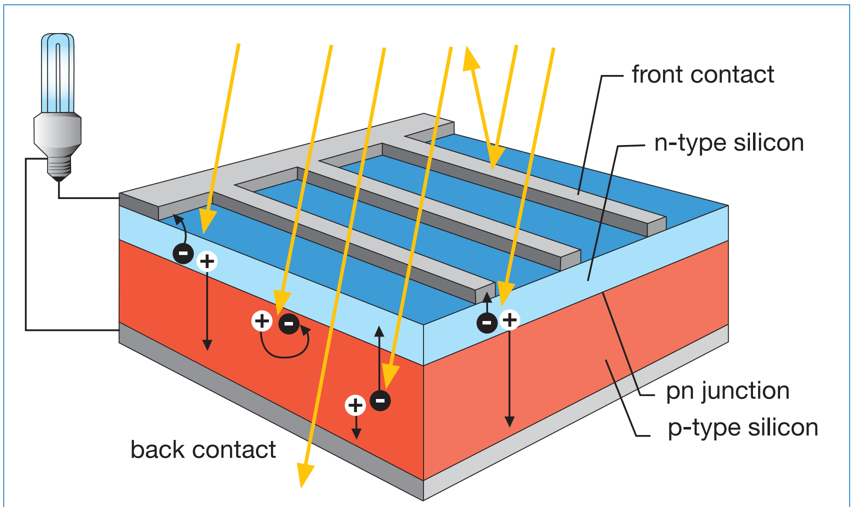


Figure 1. Schematic cross-section of a crystalline silicon solar cell under illumination.

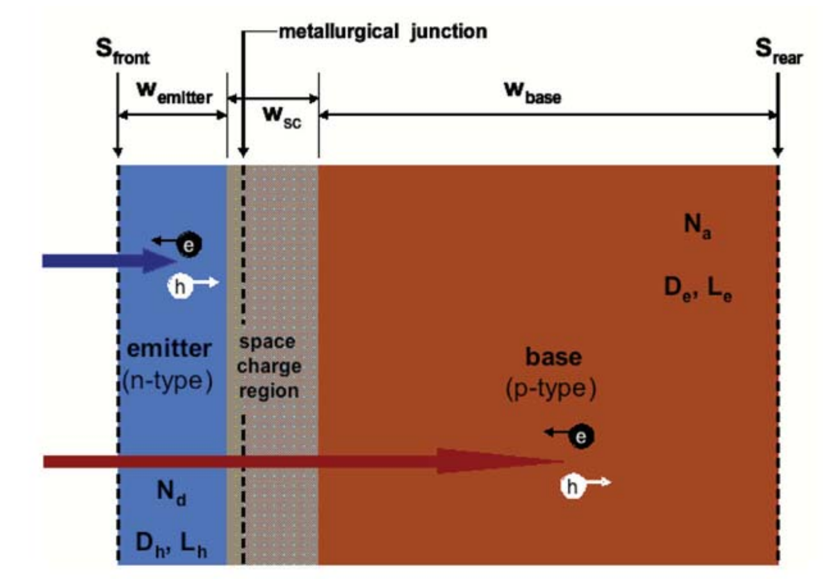


Figure 2. Schematic cross-section of a p-n junction solar cell, indicating the neutral emitter and base regions and the space-charge region around the metallurgical junction. It is shown schematically that red (long wavelength) light generates electron hole pairs deeper in the wafer than blue (short wavelength) light.

so-called space charge. At the n-type side of the junction the space charge is positive; at the p-type side it is negative. Note that the total space charge is zero: charge neutrality still holds on the device level. The widths of the space charge regions on both sides of the metallurgical junction therefore depend on the respective doping concentrations. For a heavily doped emitter (typically $10^{19}cm^{-3}$) on a moderately doped base (typically $10^{16}cm^{-3}$), almost the entire depletion region thickness of roughly 1µm is found on the base-side of the junction. An electric field is present within the space-charge region. This field counteracts the diffusive force on mobile charge carriers that results from the huge asymmetry in concentrations at both sides of the junction and allows establishment of an equilibrium situation. Note that the material outside the depletion region is field-free.

In order to understand the design and processing requirements for solar cell emitters, it is essential to consider the equation of an ideal solar cell under illumination [1]:

$$J(V) = J_o(\exp\frac{qV}{kT} - 1) - J_l \quad (1)$$

where J(V) is the solar cell output current density as a function of voltage, J_0 is the diode saturation current density (also called dark current density), q is the elementary charge, k is Boltzmann's constant, T is the absolute temperature and J_l the light-generated current density (normally equal to the short circuit current density J_{sc}).

The saturation current density J_0 of the p-n diode is given by:

$$J_0 = \frac{qD_e n_i^2}{L_e N_a} + \frac{qD_h n_i^2}{L_h N_d} = J_{o,base} + J_{o,emitter} \quad (2)$$

where D and L are the diffusion coefficient and diffusion length of minority electrons (e) in p-type silicon (usually the base) and holes (h) in n-type silicon (usually the emitter), respectively. The intrinsic carrier concentration, n_i, is constant at a given temperature, N_a is the acceptor doping concentration in p-type silicon, and N_d is the donor doping concentration in n-type silicon. Note that in thermal equilibrium $n_i^2 = [e]\cdot N_a = [h]\cdot N_d$. This relates the minority carrier concentrations to the majority carrier concentrations and thus to the doping concentrations for the case that all doping atoms are active and have donated an electron or a hole.

The diffusion length L (i.e. the average distance a generated minority carrier travels before it recombines) is determined by the diffusion coefficient D and the minority carrier lifetime τ, where $L = \sqrt{D\tau}$. L and τ are dependent on the strength of recombination. Materials and layers of high (electronic) quality are characterized by a long lifetime and a long diffusion length, although it should be noted that 'long' is a relative concept and must be defined in relation to device dimensions.

In general, three recombination mechanisms play a role: radiative recombination (the true inverse of generation by light absorption), defect-level-assisted recombination (also called Shockley-Read-Hall, SRH recombination) and Auger recombination. Defect levels may result from crystal imperfections in the bulk of the material and at the surfaces. Crystalline silicon has an indirect band gap [2], and both light absorption and radiative recombination are relatively weak processes because of the indirect nature of the band structure. Therefore defect-assisted and Auger recombination are the dominant mechanisms. As a rule of thumb, defect-assisted recombination limits the quality of industrially used moderately-doped silicon, while Auger recombination is dominant in heavily-doped silicon layers (and in very-high quality, high-purity, low-defect silicon). Surface recombination is determined by defects.

The quantitative values of $J_{o,base}$ and $J_{o,emitter}$ and thus also their relative importance may vary greatly with actual device and material parameters. For solar cell device optimization, both base and emitter components need to be taken into account.

From Equation 1 it follows that the open-circuit voltage V_{oc} of the cell (V @ J = 0) is given by:

$$V_{oc} \cong \frac{kT}{q}\ln(\frac{J_{sc}}{J_0}) \quad (3)$$

Maximizing V_{oc} thus implies minimizing J_0 and, as far as possible, maximizing the short-circuit current density J_{sc} (assumed equal to J_l).

In a very simple model, where material properties and the generation rate G are assumed to be constant, the short-circuit current density is given by:

$$J_{sc} = qG(L_e + W_{sc} + L_h) \quad (4)$$

in which W_{sc} represents the total thickness of the space-charge region. The current-contributing regions of the cell lie within one diffusion length from the junction.

The third parameter determining solar cell efficiency is the fill factor (FF):

$$FF \equiv \frac{J_{mp}V_{mp}}{J_{sc}V_{oc}} \quad (5)$$

where J_{mp} and V_{mp} represent the current and voltage at maximum power output, respectively. For ideal diodes the value of FF is an only function of V_{oc} [3], but in practical cases FF is limited by other effects, as outlined in the following section.

Non-ideal diode behaviour: surface and resistance effects

Equations 1, 2 and 6 hold for an ideal diode without surface effects, i.e. with infinite dimensions $W_{emitter}$ and W_{base}, as depicted in Fig. 2. In view of the importance of finite dimensions and surface recombination, a more general description that takes into account surface effects can be used [3]:

$$J_0 = \frac{qD_e n_i^2}{L_e N_a} * F_p + \frac{qD_h n_i^2}{L_h N_d} * F_n \quad (6)$$

where F_p and F_n are functions of the following parameters:

S – the surface recombination velocity (the product of S and the minority carrier concentration [e] or [h] yields the flux of carriers recombining at the surface).

$\frac{W}{L}$ – ratio of the layer thickness W to the diffusion length (L, the 'span of control' of the junction, represents the typical thickness of the region that is influenced by surface properties). If $\frac{W}{L}$ >> 1, surface quality is of minor importance; if $\frac{W}{L}$ << 1, device quality is dominated by surface properties.

$\frac{D}{L}$ – the 'diffusion velocity,' is the volume equivalent of surface recombination velocity. If an 'infinitely thick' base or emitter region of a solar cell, in which recombination is fully determined by volume recombination, is made thinner, recombination in the new structure is equal to that in the old structure if the surface recombination velocity is set at $\frac{D}{L}$. Thus, if one is able to make high-quality surfaces with $S << \frac{D}{L}$, device behaviour may be improved by using thinner or electronically more transparent (smaller $\frac{D}{L}$) wafers or (emitter or back surface field) layers, provided that light absorption can be sufficiently maintained.

Note that Equation 1 does not yet account for the effects of series (R_{se}) and shunt resistance (R_{sh}), nor does it include the effects of recombination in space-charge regions, which leads to non-ideal diode behaviour, expressed through the occurrence of a current term J_{on} with an ideality factor n ≈ 2. Note that lateral inhomogeneities in diode characteristics such as local variations in series resistance and minority carrier lifetime may also result in an (apparent) ideality factor n > 1 [2]. Taking these effects into account yields the current-voltage characteristic as shown in Equation 7 below).

$$J(V_a) = J_{o1}(\exp\frac{q(V_a - JR_{se})}{kT} - 1) + J_{0n}(\exp\frac{q(V_a - J_{se})}{nkT} - 1) + \frac{V_a - JR_{se}}{R_{sh}} - J_l$$

Equation 7.

R_{se} and R_{sh} are so-called lumped parameters, in which contributions from all parts of the device are taken together. This is obviously just an approximation of more accurate 2D and 3D device models. The expression shows that the voltage over the actual junction in the device, which governs the diode current, may be lower than the voltage over the device terminals (i.e. the applied voltage V_a). This leads to a loss in fill factor, and hence, in efficiency.

While the effects of shunt resistance may be negligible in well-processed practical devices, series resistance can usually only be optimized for maximum device performance. Series resistance is associated with current conduction in various parts of the device. The components related to the emitter are (see Fig. 1):

- lateral transport of collected carriers through the emitter to the contact (emitter 'sheet' resistance, which is the integral of emitter resistivity over depth);
- transport through the silicon-metal interface (contact resistance);
- transport through the front metal pattern.

Real emitters

As mentioned, emitters are usually formed by diffusion of dopant atoms into the silicon wafer surface. This does not yield a constant doping concentration throughout the layer as assumed so far. In the case of an infinite dopant source, diffusion ideally leads to a complementary error function doping profile; in the case of a finite source a Gaussian profile is obtained. As a result, the second term in Equation 2 has to be evaluated as a function of depth and Equation 6 takes a more complex form. Clearly, this can only be done using numerical simulation tools like PC-1D [3]. In addition to these rather trivial modifications, another effect needs to be considered. In the case of relatively high doping density gradients $\frac{dN_d}{dx}$ such as in the emitter, an electric field ε is formed even outside the depletion region [3]:

$$\varepsilon(x) = -\frac{kT}{q}\frac{1}{N_d}\frac{dN_d}{dx} \qquad (8)$$

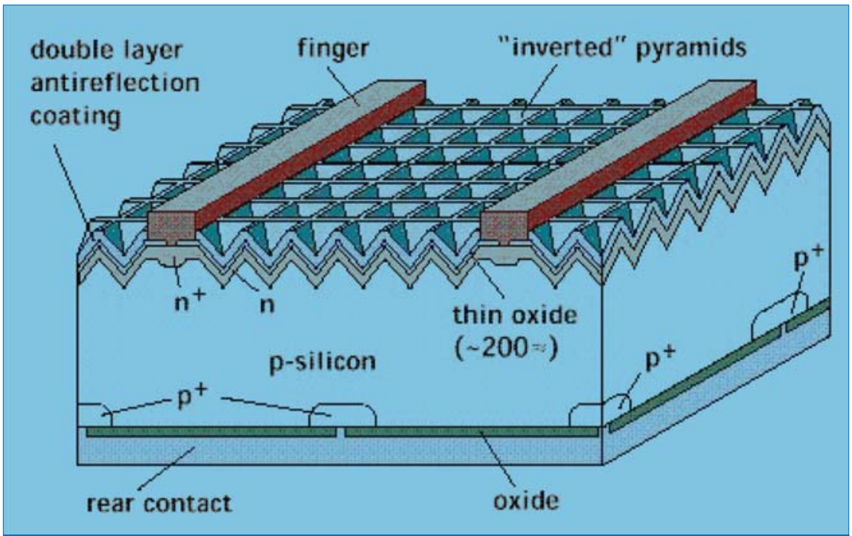


Figure 3. Passivated Emitter Rear Locally diffused (PERL) cell [8].

Although the strength of this field is much lower that that of the depletion region, it may assist diffusion of generated minority carriers to the junction (and thus prevent them from diffusing to the surface where they might recombine) by adding a small drift component.

The optimum doping profile (peak concentration, shape and depth) in the emitter can only be evaluated using a multi-parameter analysis. Moreover, the optimum is different for (shadowed) emitter regions under the front metallization and regions in between the metal fingers. This has led to the development of so-called selective emitters, where the doping profiles in both regions are different. Regions under the metallization do not have to absorb light and contribute to current generation, but they do need to provide a low-resistivity contact to the metallization (i.e., majority carriers can cross the interface without significant losses).

Furthermore, they need to prevent excessive recombination of minority carriers at the ohmic contact, which is characterized by a very high recombination velocity. This typically leads to a relatively deep doping profile with a very high surface concentration and a significant doping gradient. The high doping concentration at the surface guarantees the formation of low-resistivity tunnel contact [7], while the combination of concentration, depth and gradient reduces surface recombination. In terms of Equation 6, $\frac{W}{L_{eff}}>1$, in which L_{eff} is the 'effective' diffusion length in the emitter. It is noted that L decreases with doping concentration due to increasing Auger recombination.

Emitter regions in between the metal fingers need to be designed taking the following aspects into combined account:

- *efficient collection of the carriers* generated by light absorption in the emitter (determining the internal quantum efficiency for short-wavelength light);
- *low-loss lateral transport of (majority) carriers* from the location where they are collected to a nearby metallized area (this translates to an emitter sheet resistance in relation to the distance between metal fingers, which is in turn determined by the (minimum) width of fingers that can be made to avoid excessive shadow losses);
- *maximum output voltage* (see Equation 3). At first glance this seems to point towards maximizing the doping concentration, but when the decrease of diffusion length with doping concentration is considered, one finds an optimum rather than a maximum. This is strongly influenced by the possibility of providing a surface passivating coating on the emitter.

In practice, optimization of the parameters involved (taking into account the boundary conditions set by processing) leads to a doping profile that is distinctly different from that under the metallization. Under the condition that surface recombination can be effectively reduced by a well-passivating coating, it pays to reduce the overall doping concentration in the emitter to a minimum that is set by the requirement of low resistance losses for lateral current transport. In contrast to the region under the metallization, the active emitter regions are thus characterized by $\frac{W}{L_{eff}}<1$, allowing efficient collection of generated carriers, but also minimizing the right-hand term in Equation 6, and thus maximizing the output voltage (see Equation 3). The argument can even be enforced: for carrier collection, the best emitter is a very thin emitter. The collection efficiency achieved in the regions under the emitter (depletion region and moderately doped base) is normally better than that achieved in the highly doped emitter.

It is emphasised, however, that detailed design optimization for practical (industrial) cells should take into account the actual lowest value of the surface recombination velocity that can be achieved as a function of surface doping concentration (see the considerations about S vs. $\frac{D}{L}$ with Equation 6).

The concept of selective emitters has been applied very successfully in the 25% world-record cell made by Professor Martin Green and his team at the University of New South Wales [5] (see Fig. 3). This Passivated Emitter Rear Locally diffused (PERL) cell even employs a further refinement of the selective emitter design, by using emitter-contact areas that are narrower than the metal fingers on top. This sophistication allows a better trade-off between surface recombination at the silicon-metal interface and contact resistance losses.

Heavy doping, dead layers and impurity gettering

Standard diffusion processes can present an infinite source of impurities. These processes result in an impurity concentration in the emitter surface region equal to the solid solubility at the temperature involved. For phosphorous at a temperature range of 850-950°C, the solid solubility is ≈ $3{\cdot}10^{20}cm^{-3}$ (≈ ½ % of Si atoms is replaced by a P atom). Ideally, the active carrier (electron) concentration should be equal to the phosphorous concentration. At such extremely high carrier concentrations, Auger recombination is very effective and lifetime and diffusion lengths are very short. Moreover, P atoms may not be distributed homogeneously and (thus) phosphorous may be present at even higher concentrations, distorting the silicon lattice and leading to enhanced defect-assisted recombination. Under such conditions, not all dopant atoms are active and the chemical P-concentration may be higher than the electrically active concentration. Such surface layers are characterized by extremely short lifetimes and are called 'dead layers' accordingly. They may seriously deteriorate cell performance, particularly in active (unshaded) emitter areas. If dead layer formation cannot be avoided, it may be useful to remove it, either by chemical etching or by a drive-in diffusion during which the phosphorus impurities are redistributed over a thicker layer. Alternatively, dead layer formation may be prevented by reducing the dopant source strength or by diffusion through a barrier layer.

In specific cases the extremely high emitter dopant concentrations may be used to enhance cell performance. Highly doped (distorted) layers may act as sinks for impurities during gettering. At high temperatures (such as used in diffusion), lifetime-degrading impurities in the base of the cell become mobile. If the effective solubility in the highly doped emitter regions is higher than in the base of the solar cell, impurities may end up primarily in the emitter (they are 'gettered'). Provided that the negative effect they have in the emitter is smaller than the effect they had in the base, this will lead to enhanced cell performance. Given the fact that emitter recombination is normally determined by

Auger processes (as opposed to impurity- and defect-assisted processes) and taking into account that the emitter contribution to the saturation current density J_0 may be small compared to that of the base, this is not an unlikely situation.

Practical emitters formed by diffusion

Diffusion is the most common way of forming an emitter for c-Si solar cells. It does not require vacuum equipment and a large number of wafers (500) can be processed at once. The electricity consumption is small in spite of the high process temperature. Therefore, cost of ownership (CoO) of a diffused emitter is small compared to the overall CoO of a solar cell's manufacture. This technology was transferred from the semiconductor industry at the introduction of c-Si solar cells. In the meantime, the diffusion process is unpopular in the semiconductor (especially VLSI) industry because of its limited controllability of the doping profile.

For most solar cells, phosphorus is applied as an n-type dopant. Before phosphorus is diffused into the silicon, phosphorus has to be fixated on the silicon surface because the phosphorus diffusion temperature in silicon is above 800°C. At that temperature, most simple phosphorus compounds (e.g. P_4, P_8, P_2O_5, etc.) are at vapour phase.

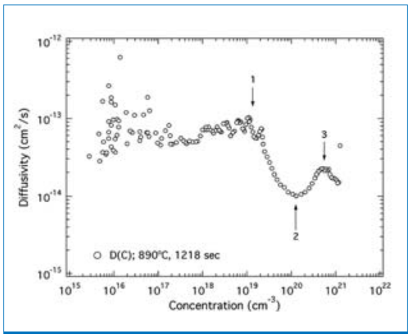


Figure 4. Phosphorus diffusivity as a function of phosphorus concentration [6].

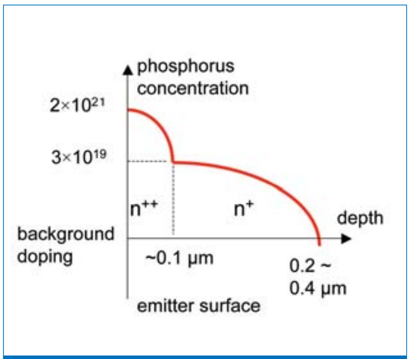


Figure 5. Schematic phosphorus dopant profile of a diffused emitter.

This is why a film of phosphosilicate glass (PSG), or $SiO_2:(P_2O_5)_x$ is required as a dopant source.

The amount of P_2O_5 in PSG is preferred to be 4%, which is the upper limit of incorporation. A stable and uniform formation of PSG is key to reproducible formation of the emitter layer. If the PSG concentration is not uniform, the doping profile will not be uniform either, reducing solar cell efficiency. Oversupplying phosphorus is an easy method to achieve uniform formation of PSG with saturated concentration of P_2O_5.

At the interface of PSG and silicon, P_2O_5 is reduced and phosphorus is

	J_{sc} (mA/cm²)	V_{oc}	FF (%)	Eff. (%)
Single plateau (conventional)	33.4	610	77.8	15.9
Multi plateau	33.7	613	77.8	16.1

Table 1. Results for 243cm² mc-Si cells as average values of 25 cells. Efficiency, J_{sc} and V_{oc} are improved, including a 0.2% absolute gain for the efficiency, while the fill factor is kept at the same level.

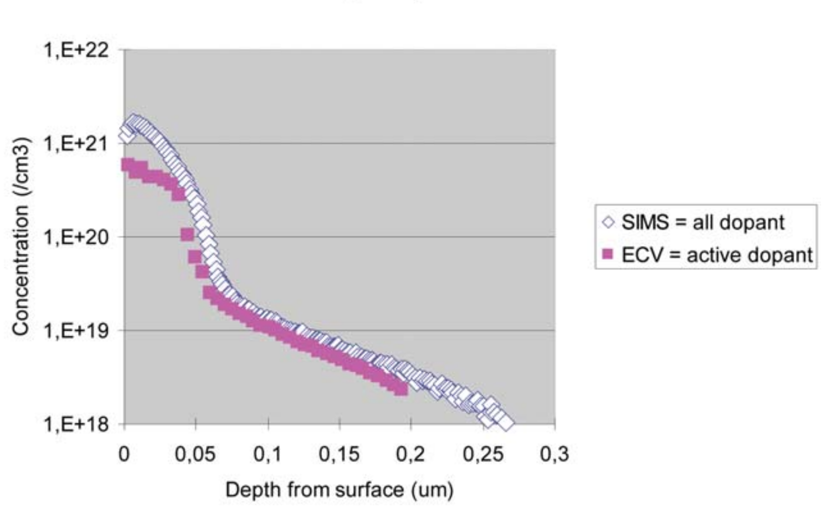


Figure 6. SIMS and ECV of a typical phosphorus dopant profile.

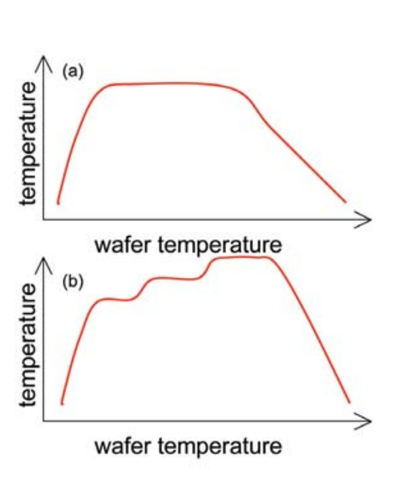


Figure 7. (a) Typical temperature time (T-t) curve with single temperature plateau carried out at the industrial production lines; (b) T-t curve example with multiple plateau.

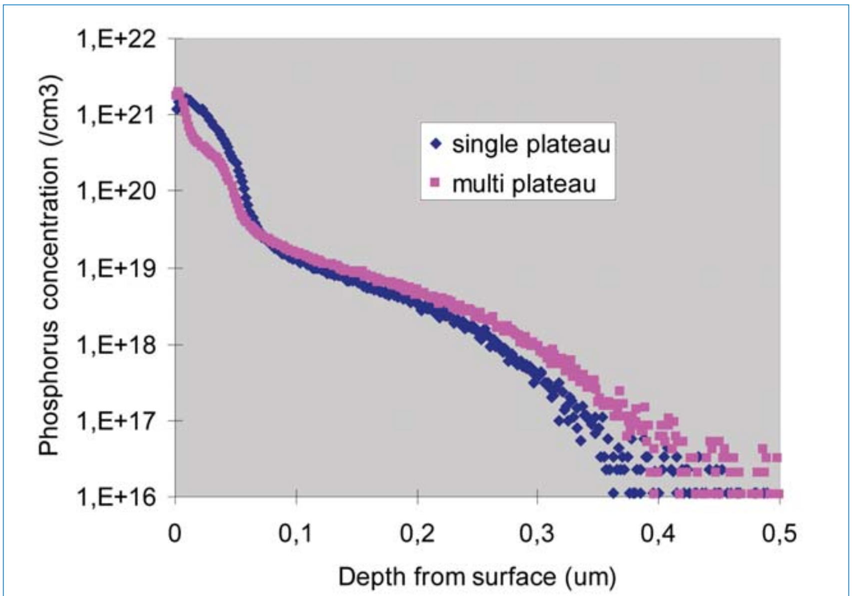


Figure 8. SIMS phosphorus dopant profiles for single- and multi-plateau temperature profiles.

supplied to silicon:

$$2\,P_2O_5 + 5\,Si \rightarrow 4\,P + 5\,SiO_2.$$

Although the solid solubility of phosphorus in silicon is known from literature to be less than 5~8 × $10^{20}cm^{-3}$, SIMS measurements indicate that phosphorus concentration near the PSG/Si interface (Si side) is about 2 × $10^{21}cm^{-3}$ which corresponds to about 4% the saturation value of P_2O_5 in SiO_2.

There are several methods of forming PSG. Most PSG is formed by decomposition of gaseous, phosphorus oxychloride ($POCl_3$). $POCl_3$ is a colourless liquid material with a boiling point of 106°C. It is normally introduced into a process chamber using bubbling by inert gas. After wafers in the process chamber are heated to 800~850°C, $POCl_3$ is introduced with a small amount of oxygen, resulting in $POCl_3$ being decomposed to P_2O_5 which is captured into the SiO_2 film growing on the surface by oxidation. This process requires a closed or semi-closed reaction chamber to isolate harmful and corrosive by-products (mainly Cl_2). Normally, a quartz tube furnace is used which can stand both high temperature and corrosive atmosphere. PSG formation and subsequent drive-in processes are carried out in one continuous (single) step.

A second method is deposition of a liquid phosphorus containing source, like a sol-gel or diluted phosphoric acid. A sol-gel consists of phosphorous doped silicate, i.e. a network of interchained SiO_2 and P_2O_5, dissolved in some solvent. Coating with sol-gel is normally performed using spinning of a few drops on a c-Si wafer. With a properly chosen solvent, it is possible to spray a sol-gel or phosphoric acid on a wafer. Baking after coating enables the formation of PSG. A subsequent drive-in step is performed separately or can be performed in the same furnace.

A subsequent phosphorus drive-in can be performed, which in essence is a simple annealing process. When $POCl_3$ or phosphoric acid is used for PSG formation, PSG formation and drive-in are performed in a single heating step. Since the temperature for PSG formation is normally high enough to drive phosphorus atoms into the silicon crystal, drive-in already starts at the beginning of the PSG formation.

Bentzen et al. investigated the dependence of phosphorus diffusivity on the phosphorus doping concentration [P] and observed three phase transitions in the diffusivity as shown in Fig. 4 [6].

Transition points are indicated with arrows 1, 2, and 3 in Fig. 4 at [P] = ~2×10^{19}, ~2×10^{20}, and ~$6\times10^{20}cm^{-3}$, respectively. These transition points cause different diffusion speeds at different doping concentrations, resulting in a doping profile which cannot be described with a simple Gaussian distribution model. Fig. 5 shows a schematic phosphorus emitter profile formed with the diffusion process.

Two Gaussian-like curves appear: one starts at the surface and the other starts at [P] ≈ $3\times10^{19}/cm^3$ due to the transition point 1 (arrow 1 in Fig. 4) where diffusion speed is several times higher at [P] < 2×10^{19} than at [P] = ~1×10^{20}. This causes the formation of two different layers with different [P], henceforth referred to as n^{++} and n^{+} layers.

The existence of the n^{++} layer has both positive and negative effects. The major positive effect is that it enables a good metal contact. One of the negative effects is that the heavily-doped phosphorus in the n^{++} layer results in an increased carrier recombination, yielding a lower operating voltage of the solar cell. Highly doped phosphorus causes both higher surface recombination and higher emitter bulk recombination. A higher voltage and a better contact are therefore contradictory requirements, and a compromise must be reached by optimizing the n^{++} layer.

Fig. 6 shows a typical phosphorus doping profile characterized by SIMS (secondary ion mass spectroscopy), and compares it with an active dopant profile by ECV (electrochemical capacitance voltage). The active dopant concentration levels off close to $3{\times}10^{20}$ as is expected from the solubility limit described earlier. The difference between these two curves suggests the existence of a large number of inactive phosphorus atoms, which are likely to contribute strongly to the surface and the bulk emitter recombination, related to the 'dead layer' effect that was described earlier.

In order to minimize the effect of the inactive high dopant region, we manipulated the doping profile [7] to optimize the phosphorus concentration to a 'moderate' level without increasing the total diffusion process time. This is achieved by introducing so-called 'multi-plateau' time temperature curves as shown in Fig. 7, resulting in the reduction of phosphorus atoms toward the active dopant levels in the n^{++} layer (see Fig. 8).

Recently, boron diffusion has been attracting much interest. The principle of boron diffusion is the same as phosphorus diffusion – like phosphorus, the diffusion source of boron should be fixated in a borosilicate glass (BSG) formed on a silicon surface; the boron oxide is reduced at the interface of the BSG and Si; the boron atoms are driven in into Si; and the emitter surface is exposed after BSG is removed by HF solution.

However, there are several differences:

1) A highly-boron-doped layer may have some gettering effect, but it does not have such a strong effect of preventing contamination from inside or outside the wafer [8] as phosphorus. A significant lifetime drop was observed using a BSG formation process with a metal conveyor furnace and sol-gel diffusion source [9]. Therefore, a quartz tube with BBr_3 (boron tribromide) as the source material should be used.
2) Boron oxide, the diffusion precursor of boron, is in the liquid phase at the temperature of BSG formation and drive-in, while phosphorus oxide, the phosphorus precursor, is in vapour phase. This is why it is more difficult to distribute the BSG precursor uniformly to the silicon wafers in the process chamber than the PSG precursor.
3) The temperature suitable for drive-in is 900~950°C, which is almost 100°C higher than that of phosphorus.
4) At the interface of the BSG and the boron emitter, boron atoms are precipitated as B-Si alloy. This makes it difficult to remove BSG with HF solution as it is therefore an oxidation of the B-Si alloy that is needed.
5) Peak boron doping concentrations as measured by ECV and the SIMS are almost identical at $1{\sim}2 \times 10^{20}$cm^2. This suggests that a diffused boron emitter does not include inactive boron atoms even in its heavily-doped region, unlike a phosphorus emitter.

ECN has recently overcome these aspects and published high efficiencies on n-type cells with a boron emitter [10].

Emitters formed by ion implantation and anneal

An alternative method to create a dopant profile for an emitter is to use ion implantation. In the 1980s, good laboratory solar cells were made with implanted emitters on single-crystalline substrates, either shallow and passivated [11] (V_{oc} exceeding 640mV) or deep and passivated [12].

Ion implantation is used in microelectronics because of its good process control and repeatability of amount and position of the doping [13]. Implantation is based on creation of a beam of dopant ions, which are accelerated by typically keVs and bombarded onto the silicon wafer. Conventional tools are of the beamline type (with a magnetic mass analyser to improve the purity of the ion beam). The ion source uses source gases such as PH_3 or BF_3. More recent developments are plasma-assisted doping, and plasma immersion ion implantation (acronym PIII or P3i) which were developed for high dosing requirements. However, these methods (PLAD, PIII) do not offer the mass filter capability of a beam line.

Cell Processing

As for conventional emitters, an implanted emitter will have to make a trade-off between the requirements for emitter recombination (low surface concentration) and contact (high surface concentration). Profiles have been published [14] with a concentration far exceeding the solid solubility at drive-in temperature in the first nanometres from the surface. This likely produces similar properties as the dead layer in classical diffusion: good contacting but high recombination.

Advantages of implantation are:

- excellent control over surface dose;
- potentially better control over the doping profile. Implantation allows the complete separation of the steps of deposition (for example, creating a delta-doped layer) and drive-in;
- the possibility of patterned implantation to create, e.g., selective emitter structures and interdigitated back contact cells. This could lead to very high efficiencies;
- the possible absence of a need for a separate edge isolation process step.

Implantation allows an elegant cell fabrication sequence by implanting front and rear of the wafer with opposite dopants, followed by a combined drive-in (what would nowadays be called 'co-diffusion'), where the drive-in is used to simultaneously form a passivating oxide layer [11].

Potential disadvantages are:

- the need to anneal to remove implant damage at the relatively high temperature of 900°C and higher (which can, however, be combined with the drive-in);
- possible absence of effective gettering by phosphosilicate glass;
- possible co-implantation of unwanted impurities; and
- possibly cost and throughput. To produce a 100Ω/square emitter sheet resistance, at least 7-8E14cm^{-2} phosphorous atoms will be required. It is within reach of the highest currents that can be produced in some tools (20-40mA) to realize this in 1 second. However, this dose excludes the formation of a highly doped surface area for metal contacting and the increase of doping required for a textured surface. Clearly, very high dose implant methods (10mA or more) will be required for PV.

Both high temperature anneal and potential absence of gettering may be a reason why implantation is unsuitable for multicrystalline silicon. In any case, there are no literature reports on high performance implantation doped mc-Si solar cells.

Emitters grown by epitaxy

Epitaxial growth can be a potential alternative for emitter formation. Its main advantage is the speed of emitter formation. When high temperature CVD is employed, it takes less than 1 minute to form a 1µm-thick emitter [15] while diffusion requires at least 20 minutes [16]. In addition, the epitaxial emitter can be varied in profile and a lowly doped high efficiency emitter can be easily realised [17]. No dopant deposition is necessary, as the emitter is grown in-situ by adding the dopant gas to the silicon precursor. Furthermore, no glass is formed, which is the case when using an oxygen-containing dopant. Therefore, less chemical etching is needed before and after the emitter formation.

Schmich carried out a wide range of studies on epitaxy of emitters grown by high temperature (1000°C-1170°C) CVD, including boron-doped p$^+$-emitter and phosphorus-doped n$^+$-emitter, in which the investigated cell size was as large as

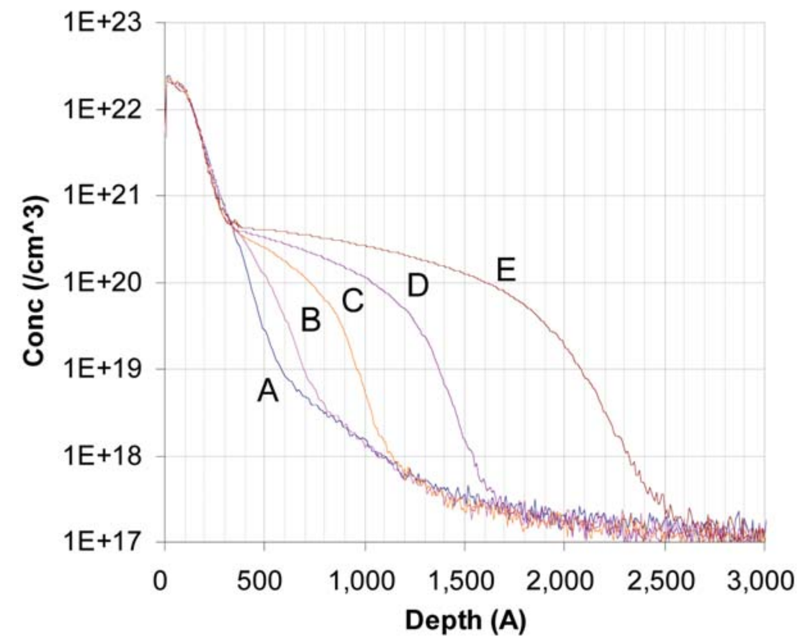


Figure 9. SIMS profiles of P3i B_2H_6 implants (8 sec., 8kV wafer bias, 3×1016/cm² dose) followed with 25 second anneals at (A) 900°C, (B) 950°C, (C) 1000°C, (D) 1050°C and (E) 1100°C (from [14], courtesy of Applied Materials).

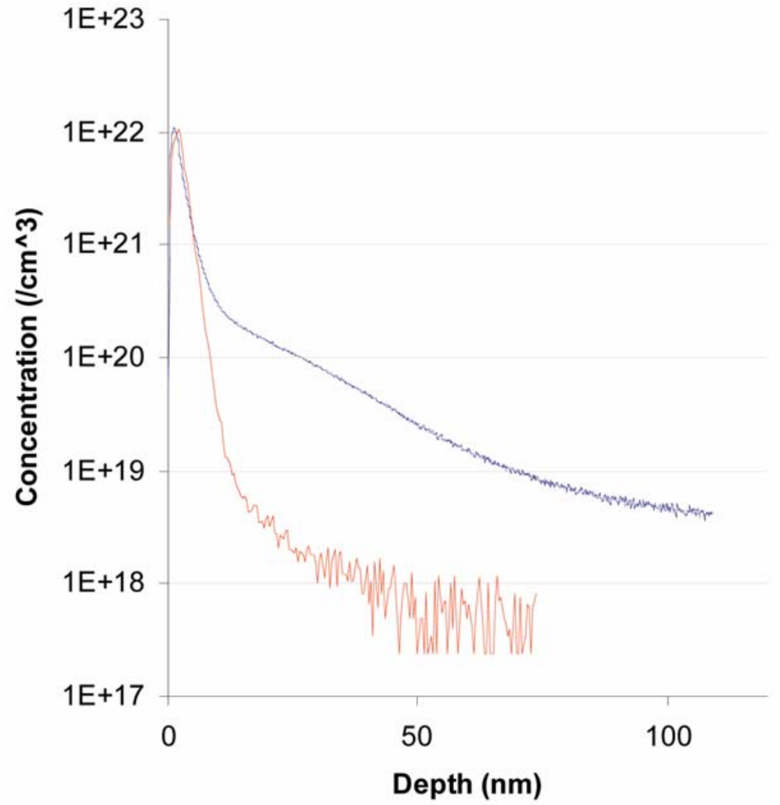


Figure 10. SIMS profiles for PH_3 implants at different energies (from [14], courtesy of Applied Materials).

$10 \times 10cm^2$ and both evaporated contact (Al/Ti/Pd/Ag for p^+ and Ti/Pd/Ag for n^+-emitter) and screen-printed paste of Ag [18]. The monocrystalline silicon solar cell with an epitaxiyally-grown n^+-type emitter in the best case showed the efficiency of 14.9% and a V_{oc} of 655mV, which was 7mV higher than that of the reference cell with a $POCl_3$-diffused emitter. The same V_{oc} difference of 7mV was shown for multicrystalline silicon, wherein the V_{oc} was 634mV and the efficiency was 13.4%. While evaporated contact was employed in this case, the best monocrystalline cell with screen-printed contact showed a V_{oc} of 618mV. The study implies that this value can still be improved upon. Since the principal motivation of this work is to develop the emitter for an epitaxially-grown base region of thin-film crystalline silicon, the emitters mentioned here were grown on some 20µm-thick epitaxially-grown base. Nevertheless, the epitaxial emitter also functions sufficiently for the case grown directly on a wafer as well as that grown on an epitaxial base.

Fig. 11 illustrates the doping concentration profiles of the epitaxial emitter with ca. 1µm deposition. To prevent the out-diffusion of phosphorus from the surface after the emitter growth – which causes a large contact resistance with the metal contact, PH_3 flow must be kept while cooling. Since the emitter depth of the best cell is 0.9µm with the sheet resistance of 85Ω/square, the optimal profile should look like a horizontally shrunk version of the curve with closed squares in the figure.

The doping profile is much deeper than that of a diffused emitter. Therefore, the recombination is much lower and the open circuit voltage is higher. It is questionable whether the surface concentration of an epi emitter is high enough to allow for a good screen-printed contact. One of the drawbacks of the epitaxial emitter is the inhomogeneous thickness of the emitter due to its high growing speed. However, the surface doping concentration can be almost uniform, enabling uniform contact resistance.

Another drawback of the epitaxial emitter is the implementation of texture surface. Schmich attempted the emitter growth on a pyramidary textured wafer [18]. The reproducible fabrication condition was not yet established, though one of the cells reached an efficiency of 16.5% with a V_{oc} of 607mV, J_{sc} of $34.4mA/cm^2$, and FF of 79.0%.

Van Nieuwenhuysen et al. took a different approach [19]. They used the method of plasma texturing of already epitaxially-grown emitter followed by additional epitaxial growth of thin and highly doped top layer. The solar cells using this epitaxial stack showed (on average) an efficiency of 16.0% with a J_{sc} of $33.0mA/cm^2$, a V_{oc} of 621mV, and FF of 78%.

Even though these applications of the epitaxial emitter to c-Si solar cell processes are still limited to laboratory scale, the intrinsic drawback against the diffusion emitter looks to have been solved already. This suggests that the epitaxial emitter can be a real alternative to the diffusion process in the future, because of the benefit of its much shorter process time and easier controllability of the doping profile. Since the epitaxial emitter process is compatible with the thin-film epitaxial base growth process, it will highly probably be employed when the concept of epitaxial thin-film Si solar cells is realized [20].

Inversion layer junctions as emitter

An alternative to the diffused p-n junction is the metal insulator semiconductor inversion layer. This junction is formed at the interface of SiN_x coating on a p-type wafer with moderate resistivity (1 – 1.5Ω/cm). Fixed positive charges in the dielectric layer increase the electron density close to the SiN_x/Si interface such that they become the majority carrier.

These junctions are characterized by a very small width depending on the surface charge's density and wafer resistivity. This is well illustrated in Fig. 12, where an n^+ region of the diffused emitter profile (R_{sheet} 60Ω/sqr) is compared to the profile of a surface charge induced emitter (Q_f =5e12cm^{-2} both on a 1.5Ω/cm p-type wafer). As a consequence of this shallow junction with peak electron densities in the order of 1e19 and 1e20cm^{-3}, the sheet resistance of surface charge induced emitters are typically in the range of 10,000 to 4,000Ω/sqr respectively [21], which is much

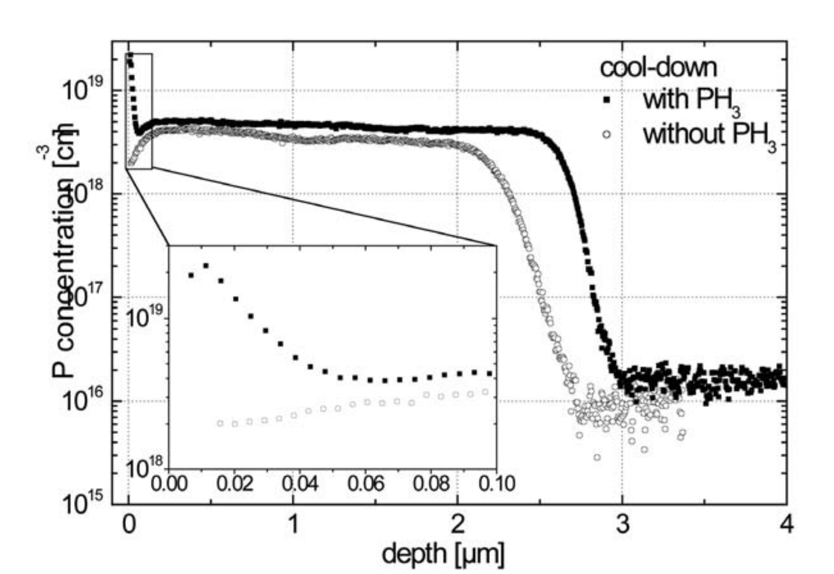


Figure 11. SIMS measurement of epitaxial emitters cooled with and without PH_3 [18].

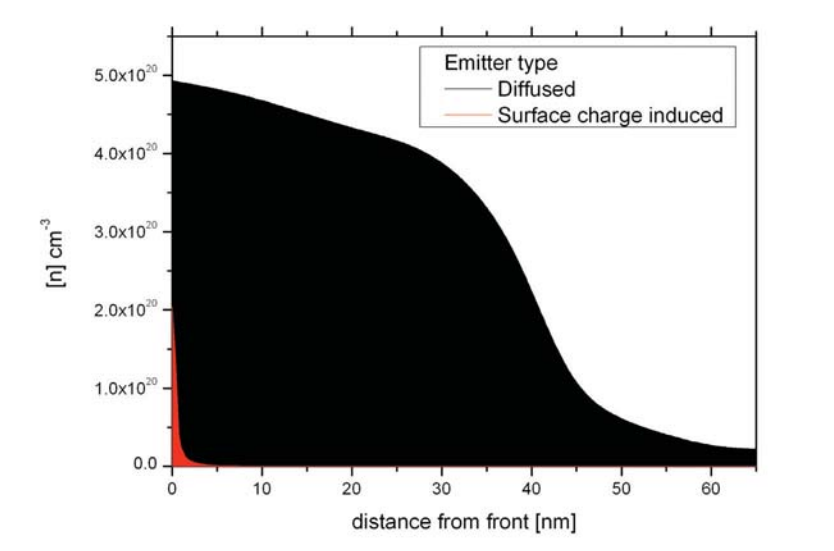


Figure 12. Electron density distribution of two emitter types: diffused phosphor emitter and surface charge-induced emitter.

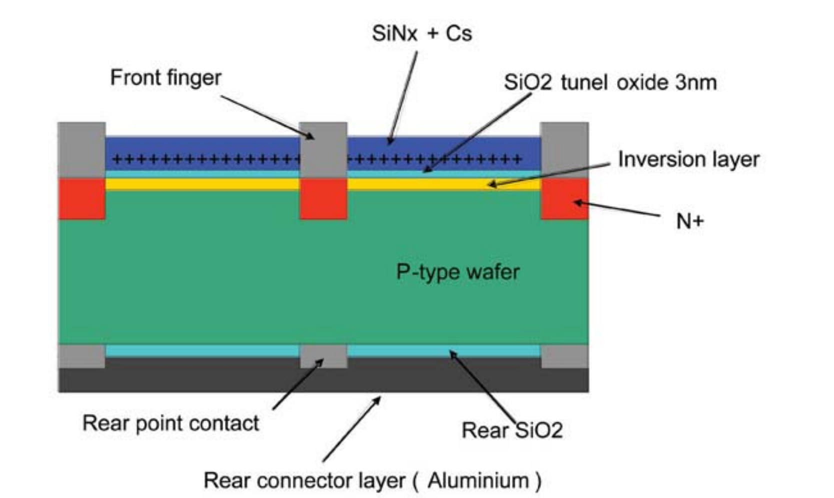


Figure 13. Structure of MIS-IL solar cells with oxide rear surface passivation and additional evaporated CsCl-layer. Front surface received random pyramid texture and a 4% metallization coverage, comprising of 300 micron pitched fingers.

higher than for diffused emitters (50 to 100Ω/sqr).

Another difference is the contacting scheme. As the emitter formation depends on the presence of the dielectric layer on the surface, it is necessary to find a way of extending the emitter below the front metal contacts. This has been achieved by local diffusion below the contact in analogy of selective emitters [22] but also by formation of a Schottky barrier. Careful selection of the metal work function of the leads allows formation of an inversion layer below the contacts (ϕ<4.5eV). One attractive candidate is aluminium for its low cost, its abundance and suitable work function (4.1 - 4.3eV). Thin films of CsCl (5nm) have been found to have even lower work function in the order of 2.1 eV, which increases the band banding even further and reduces contact recombination and J_o [23]. To further reduce contact recombination, a tunnelling oxide (d~1.5mn) is often used as it offers a selective tunnel path for majority carriers.

The MIS-IL solar cell has demonstrated cell efficiencies that reach 20% with very high V_{oc} values up to 693mV and J_0 values as low as 60fA/cm²) [22]. This demonstrates the potential for high efficiency concepts comparable to diffused junctions. The high efficiency cell concept is illustrated in Fig. 13.

This leads to the following advantages:

- no high temperature diffusion step is required;
- the inversion layer can be achieved with an SiN_x anti-reflection coating;
- no recombination effect due to diffused impurities and very low dark saturation currents.

and disadvantages:

- a new contacting scheme is required with related uncertainty in reliability;
- no impurity gettering effect exists, making it unsuitable for lower quality silicon wafers; and
- high sheet resistances lead to resistance losses.

Heterojunctions

A heterojunction emitter combines two different materials to create the charge-separating field. Both, but particularly the silicon heterojunction emitter, based on thin amorphous silicon films on a crystalline silicon wafer, are under intense R&D, as both have been proven by Sanyo to be very successful for creating high-efficiency solar cells [24].

The special properties of the silicon heterojunction emitter are that 1) they allow for excellent surface passivation, and 2) they provide reasonably effective selective contacts for majority carriers, reflecting minority carriers back into the wafer. This results in an emitter recombination current of about 25fA/cm², according to [25].

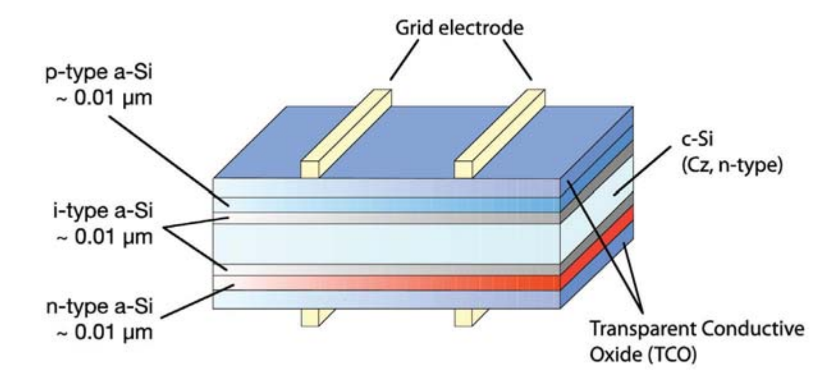


Figure 14. Structure of HIT cell.

The silicon heterojunction solar cell in principle requires only a doped amorphous silicon layer on the silicon wafer. Typically an n-type monocrystalline wafer will be used for its high lifetime to get the most from the high-efficiency capability of the cell structure. This means that the emitter will be based on a p-type amorphous silicon layer. Other layers, such as microcrystalline silicon and silicon carbide, have also been investigated for emitter layer. Sanyo has demonstrated that incorporation of an intrinsic (undoped) amorphous silicon buffer layer between the wafer and the p-type doped film is very beneficial in increasing the passivation, and thus the V_{oc} and cell efficiency. This approach named the heterojunction with intrinsic thin layer (HIT) technology.

As Sanyo's patent on the use of an intrinsic buffer layer will expire in a few years, several companies, such as Roth & Rau, are gearing up to provide silicon heterojunction solutions to the PV industry. Kaneka (in collaboration with IMEC), and Jusung (in collaboration with INES) are also active in the development of silicon heterojunction technology.

The structure of the HIT cell as developed by Sanyo is shown in Fig. 14. It consists of a textured n-type wafer, coated on the front with ultra-thin i/p amorphous silicon layers, and on the back with ultra-thin i/n amorphous silicon layers. The lateral conductance of the inversion layer (emitter) and accumulation layer (BSF) in the wafer is low (sheet resistance of order kOhm), therefore the device is coated with transparent conductive oxide films (TCOs) on front and rear to enable carrier conduction to the metal grid. The TCO also functions as anti-reflection coating. An H-pattern metal grid is printed on the front and rear of the cell, while the a-Si layers are normally deposited by PECVD.

Sanyo has demonstrated efficiency of 22.8% on 100µm-thin wafers and Swanson [26] has estimated that without optical shadowing and absorption losses, the efficiency generic to the device concept is about 25%. Due to the very good surface passivation, the V_{oc} is also very high (well over 700mV). Other advantages include:

- low temperature coefficient of voltage, meaning good module performance at high ambient temperature;
- bifacial cell design, minimizing stress on wafer and allowing bifacial modules;
- low temperature processing.

Some potential disadvantages are:

- proprietary technology – only Sanyo has been able to exceed 20% efficiency;
- the need to use excellent surface preparation;
- the need to use low-temperature metallization, resulting in the need for special printing techniques and a larger amount of Ag used per cell.

Process technology for silicon heterojunction cells differs drastically from normal cell process technology. For good performance, suitable wet chemical preparation of the wafer surface is very important. Amorphous silicon thin films do not survive temperatures higher than 200 or 300°C, which means that the cell process has to be a low-temperature one. Specifically, this means that gettering or hydrogenation is not possible (making mc-Si unattractive as a substrate), and that a printed metal grid cannot be sintered. The conductivity of the metallization is therefore low, and very high aspect ratio lines are required on the front.

The critical aspects for device performance have only recently become somewhat better understood, and are still subject to much fundamental and applied research. The extraction of majority carriers through the p-type amorphous silicon has to deal with a large semiconductor band offset, and therefore tunnelling plays an important role. As a result, the thickness of the amorphous silicon has to be kept very thin [27]. Additionally, the p-type amorphous silicon is usually contacted by n-type indium tin oxide, which means the p-type a-Si must be highly doped to create sufficient V_{oc} [28]. Limiting optical absorption losses is another reason for keeping the a-Si layers as thin as possible, but regardless of this, their passivating properties have to be very good.

Recently, results have been reported of back junction, back contact devices based on heterojunctions [29, 30]. This very interesting development potentially offers the advantages of silicon heterojunction cells (high V_{oc}, very good surface passivation), without the disadvantages (optical losses in a-Si and TCO, need for high aspect ratio metallization). An example of such a device is given in Fig. 15.

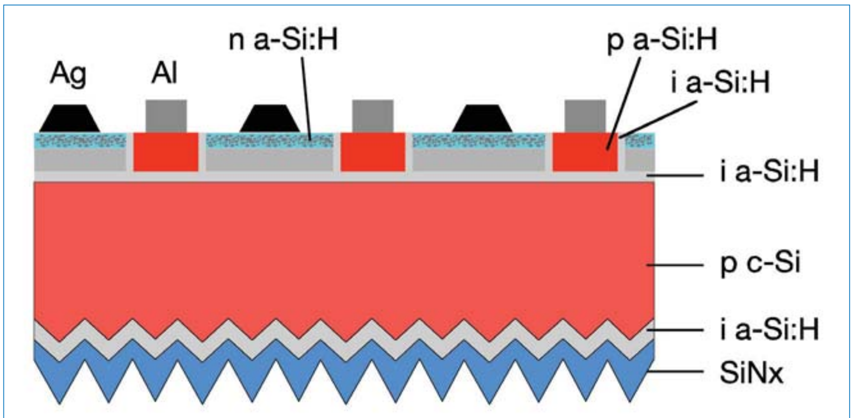


Figure 15. BEHIND cell, back junction, back contact heterojunction design [29].

Conclusions

Emitter quality to a large extent determines the efficiency potential of silicon solar cells. From a practical point of view, a high quality emitter is obtained when low recombination in the bulk of the emitter, a low-recombination interface with a coating, and a low contact resistance to the metal grid are combined.

Suitable and nearly ideal emitters can be made using the current industrial equipment – quartz tube diffusion furnaces, for example – but processes will have to be optimized more than is common in current industrial practice. However, for homojunction emitters, the requirement for low grid contact resistance will likely always mean a compromise with increased emitter recombination, whatever the method used to create the emitter.

For homojunction emitters, the metal contact requires a high surface dopant concentration. This is automatically provided during a standard emitter diffusion; alternative methods need special procedures to obtain this. This, of course, makes alternatives more complicated when applied to 'standard' cell concepts.

Because current emitter technology is already capable of near-ideal emitters, the benefit of alternative emitter processes, such as epitaxy, CVD, implantation, etc., will therefore have to be found to especially improve CoO or in practical advantages such as feasibility to make structured emitters.

For high efficiency concepts, there will be a need for interdigitated local emitters and local back surface field. This may favour new ways of providing dopants and alternative methods might also be introduced for these concepts.

The ultimate, ideal emitter will, apart from displaying very low bulk recombination, have a very well passivated interface to the contact, which contact should reflect minority carriers and extract majority carriers only. One of the closest known approximations to such an ideal emitter is the c-Si/a-Si/TCO heterojunction with intrinsic buffer layer.

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About the Authors

Jan Bultman is program manager for Silicon Photovoltaics with a team of 60 ECN researchers. He joined ECN Solar Energy in 1996, where he initiated the back-contact module development, culminating in ECN's recent world record module efficiency of 17%. A graduate of the Technical University at Delft, he studied physics and obtained his doctorate in nuclear engineering.

Ilkay Cesar is a researcher in the group of Device Architecture and Integration. He joined ECN Solar Energy in 2007, working on the industrialization of rear side passivated solar cells. He studied chemical engineering at the Technical University at Delft, and obtained his Doctorate in the field of photoelectrochemical hydrogen production at the EPFL.

Bart Geerligs is a staff member at ECN Solar Energy. He received a Ph.D. in technical sciences from Delft University of Technology for research on nanoscale quantum electronic devices and has been at ECN Solar since 2000. His current research activities are on the development of n-base silicon solar cells and silicon heterojunction technology.

Yuji Komatsu studied semiconductor engineering at Kyoto University where he received a Ph.D. degree on his study of tandem junction solar cells made of InGaP and Si. He joined Sharp Corporation in 1994, and worked on R&D of high efficiency c-Si solar cells until he left the company in 2005. Since then, he has been working at the Silicon Photovoltaics group of ECN Solar Energy, where he is now leading the R&D of both phosphorus and boron diffusion processes.

Wim Sinke is a physicist and works as a staff member at ECN Solar Energy and part-time professor at Utrecht University (Science & Applications of Sustainable Energy Systems). He was coordinator of the European Integrated Project CrystalClear, which was dedicated to wafer silicon PV technology. Currently, he holds the role of Chairman of the European Photovoltaic Technology Platform.

Enquiries

Jan Bultman
Energy Research Center of the Netherlands (ECN)
P.O. Box 1, 1755 ZG Petten
The Netherlands
Tel: +31(0)224 564786
Fax: +31(0)224 568214
Email: bultman@ecn.nl
Website: www.ecn.nl

Technology development of fine-line crystalline silicon solar cells

Zhichun (Jacky) Ni, **Jiebing Fang**, **Weifei Lian** & **Xiaolong Si**, China Sunergy, Nanjing, China

ABSTRACT
Development of fine-line crystalline silicon solar cells is a potential direction for application of high-efficiency and low-cost solar cells in the industry. Fine-line mask-free metallization offers huge potential to increase cell efficiency by reducing metal shadowing losses and surface recombination losses. At China Sunergy, three promising approaches for fine-line crystalline silicon solar cells are currently undergoing research, including processes such as laser doping selective emitter (LDSE) technology, inkjet or aerosol jet printing of metal paste and upgraded screen-printing technology. This paper presents the basic investigations of these three manufacturing technologies, singling out the technology that presents the most potential for further application.

Introduction

Reducing the cost per Wp is the industrial goal of solar cell manufacturers. Achieving this goal requires increasing the solar cells' efficiency while lowering the cost of production [1]. Metallization technology, commonly regarded as the technology with the most potential to satisfy these requirements, can be used to increase the cells' efficiency during the cell processing stage. Cell efficiency can be greatly improved by reducing the metallized area and implementing surface recombination [2]. As a result, fine-line printing has, along with sheet resistance, become one of the main research directions in standard industrial solar cell production. This process is very easily carried out in the lab [3], but due to complex processing and ultra-high cost, it is not suitable for industrial mass production.

"Cell efficiency can be greatly improved by reducing the metallized area and implementing surface recombination."

Based on lab development of solar cells, the two-step metallization concept seems to hold most promise [4]. In this process, the first step sees the creation of a narrow metallization line named the *seed layer* on the silicon surface. This seed layer should have a good mechanical and electrical contact to the silicon surface. Three techniques currently in use for seed layer formation include normal screen-printing of silver paste (NSP) [2], inkjet or aerosol jet printing of metal paste [5,6], and laser doping selective emitter (LDSE) combined with subsequent self-aligned nickel electroless plating [7]. NSP is the simplest and most cost-effective method of seed layer formation, using conventional silver paste and fine-line screen to achieve fine-line printing with a width greater than 40µm.

Compared to NSP, the LDSE technology requires more complicated processing steps. A phosphorous dopant source (phosphoric acid) is applied to the substrate before laser treatment. The heavy diffusion area is formed for selective emitter solar cells via local melting of silicon beneath the antireflection coating (ARC). During the laser doping process, the high-power laser removes the ARC and exposes silicon for nickel seed layer formation. The formation of the seed layer for LDSE is through plating Ni after laser doping

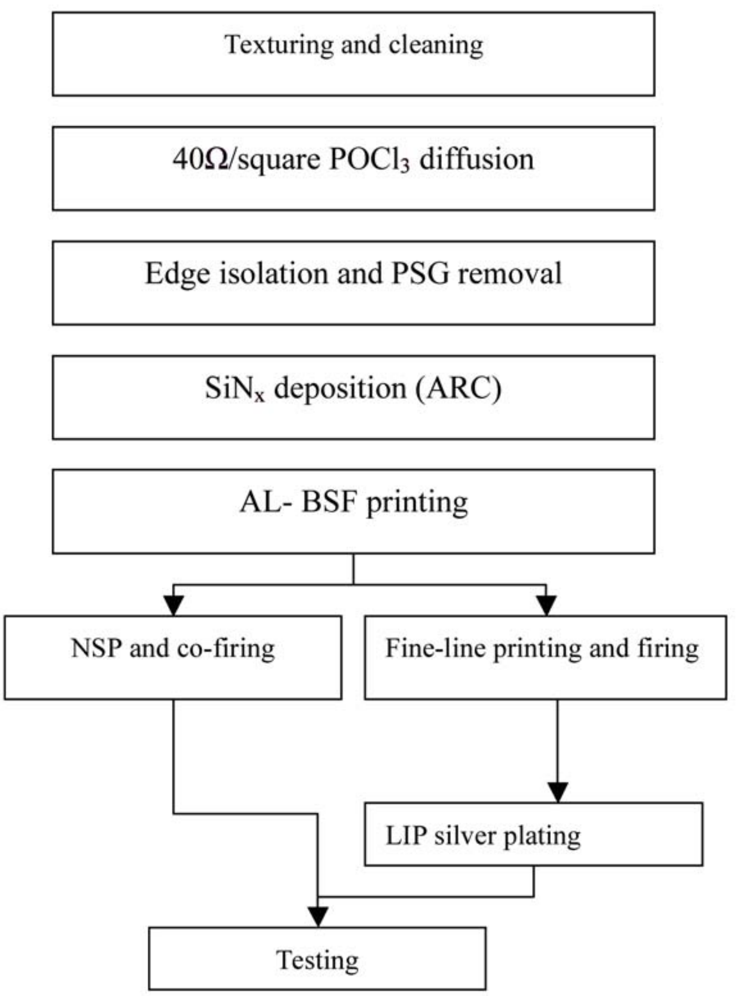

Figure 1. Typical processing flowchart of industrial crystalline silicon solar cells.

Sample	V_{oc} (V)	I_{sc} (A)	R_s (Ω)	R_{sh} (Ω)	FF	Eff	I_{rev2} (A)
A	0.624	5.60	0.0171	85	68.5	0.1554	0.289
B	0.625	5.52	0.0042	55	78.1	0.1740	0.971
C	0.625	5.65	0.0045	95	79.1	0.1804	0.263

* All measurements performed in-house on reference cells provided by the Fraunhofer Institute.

Table 1. I-V performance of screen-printed cells with: 40µm finger design before (A) and after (B) Ag plating, and cells with a 100µm finger design (C).

Group	SHR (Ω/square)	Number of fingers	Thickness of finger (µm)	Finger width before LIP (µm)*
A	80	82	6.6	50
B	60	82	6.6	50
C	60	96	7.8	50
D	60	110	5.4	50
E	60	69	6.6	50

*Average increased width after LIP is about 20µm.

Table 2. Experimental parameters of all samples before LIP treatment.

[8,9]. The line width of Ni plating depends on the laser power and wavelength, among other factors, but is normally greater than 15µm. Inkjet and aerosol jet printing offer a non-contact printing of the seed layer via deposition of nano-sized silver ink directly onto the substrate using a nozzle. The finest line width is smaller than 15µm. After sintering, the contact is thickened by light-induced electroplating (LIP) of silver, similar to the LDSE process.

After formation of the seed layer, the line is thickened by silver electroplating to increase the line conductivity, a process known as the *growth* step. The LIP process, one approach to plating, was used in recent tests to increase the conductivity of screen-printed solar cells, resulting in impressive efficiency increments [10].

Experiments conducted for this paper used this same technique for thickening seed layers. Furthermore, the contacts of different fine lines were investigated in detail. Optimized sheet resistance and finger numbers were also applied according to different formation processes of seed layers.

Experimental details

Typical Cz-silicon wafers with a base resistivity of 1-3Ωcm and about 200µm thickness were used in these experiments. For reference purposes, a standard industrial process was chosen for the fine-line screen-printing of the cells as shown in Fig. 1. Detailed processing steps include $POCl_3$ source diffusion in a tube furnace with uniform sheet resistances (SHR) of about 40Ω/square, followed by PSG removal by HF etching prior to SiN_x deposition. Frontal silver contact was formed using a 100μm finger-width standard screen following the AL-BSF metallization process step. A seed layer is conducted by reducing the fingers' width down to 50μm and increasing the amount of fingers to 80.

During the LDSE process, the seed layer was formed by laser doping of phosphoric acid and self-aligned nickel plating. In this paper, however, different surface morphologies and cell parameters are compared according to different laser parameters from several laser suppliers.

In the case of inkjet batches, most of the processing steps are the same as those used within the processing of typical industrial crystalline silicon solar cells. After AL-BSF printing and drying, the seed layer is applied by inkjet printing, yielding an average finger width of about 50μm. The thickness can be adjusted by applying various different printing conditions, but the typical thickness of a single layer is about 0.6μm. The I-V

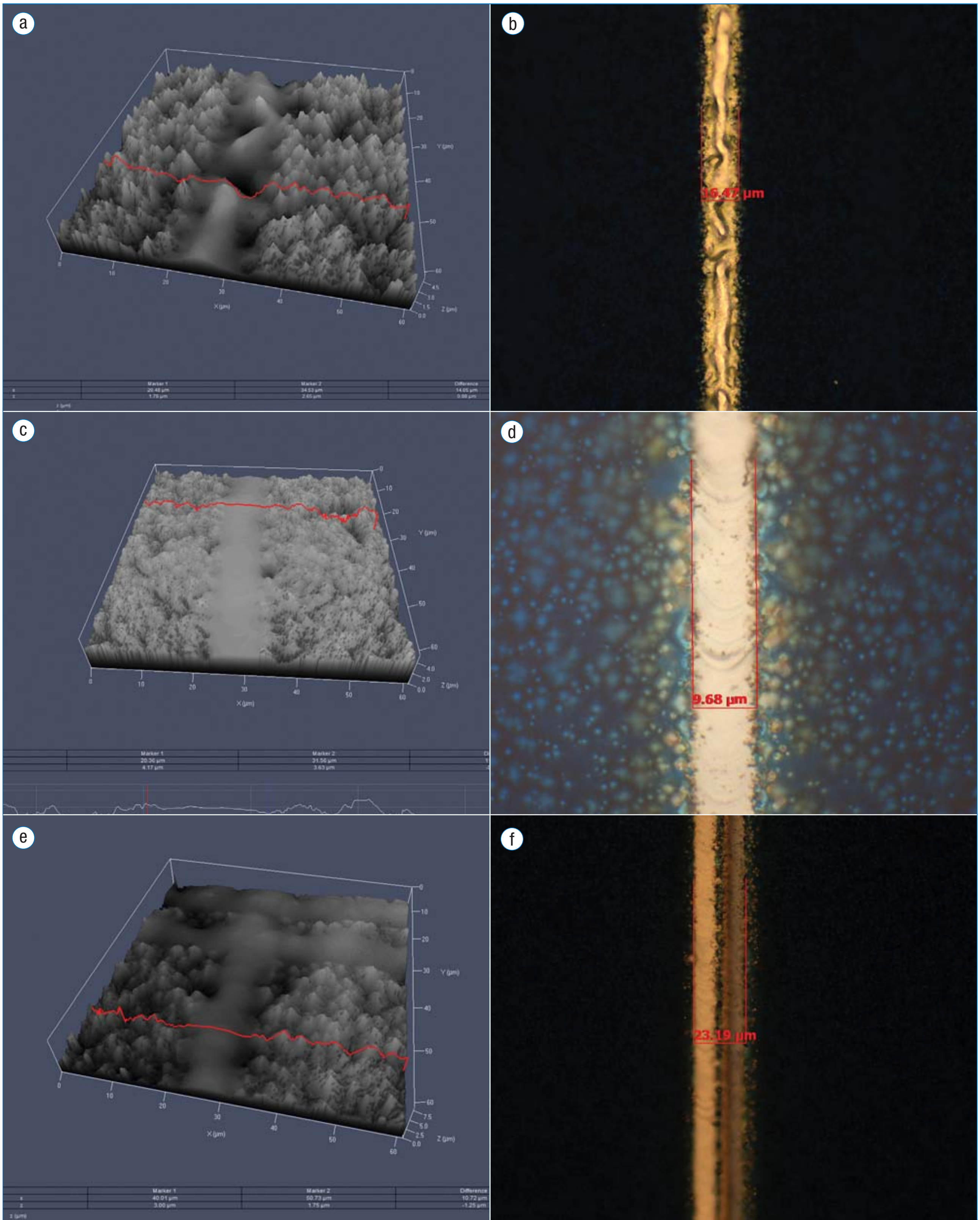

Figure 2. Laser-scanning microscopy images of fingers after laser scribing. A green laser (wavelength 532nm) was used for a and b; images c, d, e and f were created using a UV laser (wavelength 355nm).

performance of cells with different sheet resistance, finger numbers and finger thickness are investigated in the following section.

Results and discussion

Fine-line screen-printing

Screen-printing has already established itself as one of the most important processing steps in mass production of silicon solar cells today. The apparent contradiction between decreasing shading loss and achieving higher conductivity becomes obvious when manufacturing higher efficiency silicon solar cells. We attempted to use narrower finger design to realize fine-line printing, and continued to investigate the feasibility of 'normal' printing with 100μm finger width. Table 1 shows the I-V results for three samples: the fine-line pattern before plating (40μm finger width); the same fine-line pattern after plating (40μm finger width); and the reference pattern (100μm finger width). The V_{oc} remains constant for fine-line samples before and after plating (sample A and sample B). The decreased I_{sc} is a result of the increase in finger width from about 55μm to 75μm, while a higher fill factor (FF) arises from the increased conductivity brought about by decreasing R_s from 17.1mΩ to 4.2mΩ. Although an efficiency gain of about 2% was obtained through plating, the rate of finger breakage increased as a result of the narrowed fine-line design. Compared to the normal screen-printed sample C, a lag of 0.5% in the cell's efficiency is encountered. Optimized patterning, including finger numbers and finger width, need be redesigned to remedy this issue, for which further investigations are underway.

LDSE and nickel plating

Laser technology is widely used in the manufacture of PV solar cells. Most of the research carried out on this topic focuses on laser doping, cutting, ablation, and so on [11-13]. Combining selective emitter technology with lasers is proving to be potentially one of most promising directions for attaining the goal of higher efficiency solar cells. Lasers are often used to heavily dope below metal-contacted areas to form selective emitter structures. Typical processes involve adding the laser treatment directly after the ARC deposition.

> "Combining selective emitter technology with lasers is proving to be potentially one of most promising directions for attaining the goal of higher efficiency solar cells."

There are three types of lasers used in mass production: the IR laser, the UV laser and the green laser, which have wavelengths of 1064nm, 355nm and 532nm respectively. Different laser parameters will affect the laser doping profile and surfaces can be damaged by the laser's heating effect [14]. For LDSE samples, wafers with a resistivity of 1-3Ωcm were used. A 60Ω/square emitter was formed after diffusion in a tube furnace at a temperature of about 850˚C. The heavy diffusion area was formed using 5% phosphoric acid under the metal-contacted area.

The laser-doped area of the wafers processed using the green laser yielded a coarse surface, depicted in Fig. 2a. The finger width of the wafers was 16μm (Fig. 2b). In contrast, the laser-doped area of wafers using a UV laser shows a much smoother surface (Figs. 2c, 2d, 2e & 2f). Furthermore, the finger width of the LDSE area depends on the spot size of the beam and the laser's wavelength. Applying different laser parameters when using the UV laser results in a different surface morphology and finger width as shown in Figs. 2c and 2e. The morphology of the latter shows smoother grooves, while a narrower finger width, brought about by use of different laser parameters, is visible in Fig. 2c. The optimized parameters of UV lasers show a narrower finger width of 9μm in Figs. 2e and 2f.

Another use of these lasers is doping of the busbar. The surface conditions of laser-doped busbars following plating with nickel and silver are shown in Fig. 3. The busbar consists of many interconnected fingers, each of which

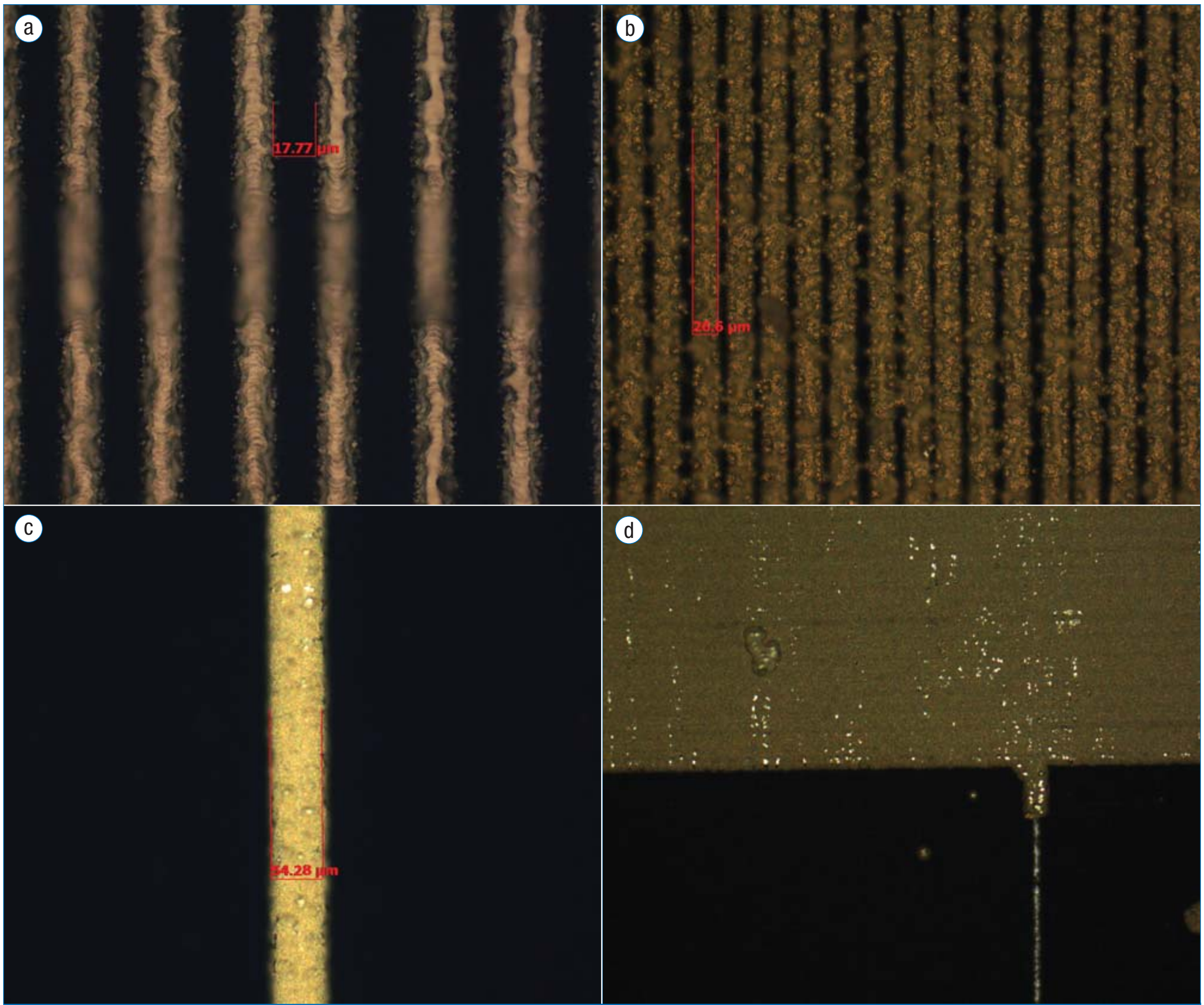

Figure 3. Laser-scanning microscopy images showing: laser-doped busbar after Ni plating (a); LIP Ag (b); prolonged LIP Ag time (c); and contact area between busbar and finger (d).

is about 17µm in width after Ni plating and 24µm after Ag plating (Figs. 3a and 3b). The surfaces are smoothed by the Ag plating (Fig. 3b). As the finger width approaches approximately 54µm, the grooves become a whole and continuous finger in the busbar. Ag is also present on non-metal areas, a result of deposition of silver on the top of pyramids (Fig. 3d).

At present, the performance of LDSE cells is not wholly satisfactory, which could be for a variety of non-optimized process reasons, including: laser-doping profile; nickel and silver plating; sintering condition, etc. Further research into all parameters and cell structure optimization are ongoing at China Sunergy.

Inkjet technology is one of most promising technologies used in the pattern formation of front metallization [4-6]. Table 2 shows the detailed parameters of processes for different samples. Average emitter sheet resistances are 80Ω/square for group A; the others are 60Ω/square. The average finger thickness is 6.6µm for groups A, B and E and the thicknesses of the seed layers are 7.8µm and 5.4µm for groups C and D, respectively. The width of all samples after printing is about 50µm, which increases to 70µm after silver LIP treatment.

The short circuit current and FF of group B is larger than that of group A, which could be a result of optimized firing conditions for group B. On a similar note, group A's low efficiency could be because of lower-than-optimal diffusion. The root cause of these results will be investigated further in future studies.

Table 3 illustrates the obvious efficiency improvements gained by increasing the finger thickness, especially in the case of groups C, D, and E, despite the fact that they have similar series resistance (R_s). Group C yielded the highest efficiency, thanks in part to the optimized finger sizes, SHR, optimized contact resistance, shading loss and combination. Higher I_{sc} loss is linked to the greater amount of fingers used in groups C, D, and E. It is probable that with further optimization

Sample	V_{oc} (V)	I_{sc} (A)	R_s (Ω)	R_{sh} (Ω)	FF	Eff
A	0.632	5.47	0.006	25	75.0	0.1731
B	0.630	5.84	0.007	56	76.4	0.1814
C	0.638	5.65	0.005	108	78.7	0.1830
D	0.627	5.59	0.005	44	77.7	0.1758
E	0.621	5.74	0.005	93	77.3	0.1779

Table 3. Typical I-V performance of cells from different group samples.

of the samples in the groups, efficiencies above 18.5% can be easily achieved.

Based on these basic investigations, we can conclude that LDSE technology still needs further optimization in areas such as the doping process, pattern design and surface damage by lasers. Inkjet technology seems to show the most potential; however, the scope of this investigation is just the start of fine-line technology investigation. The ultimate winner will be determined by a variety of factors, including reliability of the tools and equipment used, material quality, etc.

Conclusions

This paper investigated three different technology approaches for the development of fine-line crystalline silicon solar cells, presenting some basic findings of the experiment. Based on the two-step metallization concept, fine-line technology can be realized quickly in the mass production of PV solar cells, as illustrated by the results of this experiment. While there are three different techniques for the formation of seed layers – conventional screen-printing with narrow finger openings, laser scribing and doping, and inkjet technology – inkjet technology-based approaches seem to hold most promise for the future.

Acknowledgement

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About the Author

Zhichun Ni is Director of R&D for China Sunergy, which he joined in 2007 as senior researcher. Following a role as process engineer at Wuxi Suntech Power Co., Ltd., he completed his Ph.D. at the Shanghai Institute of Applied Physics. He also has an M.Sc. from the Institute of Metal Research, and a B.Sc. in physics from the University of Inner Mongolia.

Enquiries

China Sunergy (Nanjing) Co., Ltd.
123 Focheng West Road
Nanjing 211100
Jiangsu Province
China

Tel: +86 25 5276 6775
Email: zhichun.ni@chinasunergy.com

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Final testing: a secure release gate towards module manufacturing

Nico Ackermann, Volker Gutewort, Michael Quinque, Marcel Kühne, Elard Stein von Kamienski, Achim Schulze & **Ralph Wichtendahl**, Q-Cells SE, Bitterfeld-Wolfen, Germany

ABSTRACT

Among all of the tests performed in the production chain of solar cells, each with the scope of production control and the aim of driving engineering improvements, the electrical final test is certainly the most important. The final test defines the gate to module manufacturing and has a direct impact on finances and customer satisfaction. The test procedure itself is well known and continues to undergo constant further development, but that shall not be the scope of this article. This paper will elucidate on the issues faced by bringing these tests into high volume production, highlighting some issues on measurement accuracy and degradation of the internal calibration standards. In addition to pure electrical testing, the paper will discuss the Q-Cells approach to identifying hot spots and subsequent binning of the affected cells without adding process time to the test procedure, and will show their straightforward correlation to heat generation of these hot spots in real-life condition-encapsulated module tests.

Final test procedure

The test usually focuses on the parameters used to describe the cell according to standard test conditions (STC), namely P_{mpp} and the derived conversion efficiency (η), V_{oc}, I_{sc}, and the fill factor (FF). Beyond these measurements, other factors are recorded such as a better prediction of the behaviour of the cell in the module and field conditions, shunt resistances and dark operating curve parameters as reverse bias currents at voltages that might occur when a module is partially shaded.

Nevertheless, these parameters have not proven sufficient for protection of modules from losses and securing stable efficiency over the complete lifetime of the module. It is also essential to sort out cells that are suffering from local defects. Unfortunately, the influence of these defects would hardly be measureable during the integral electrical assessment of the cell at its first exposure to both light and current flow. Finally, modules should look uniform in colour and cells have to be sorted accordingly, even if electrical parameters are unchanged by these differences in the anti-reflection coating.

For those engineers dedicated to constantly improving line performance, process stability and cell technology, the final test results come to full power only if they can be correlated on an individual wafer basis against all the factors that influence the conversion efficiency η. Fig. 1 illustrates how sharp the usually very broad distribution of η becomes if it is plotted against the wafers' original position in the ingot or brick. Any smaller

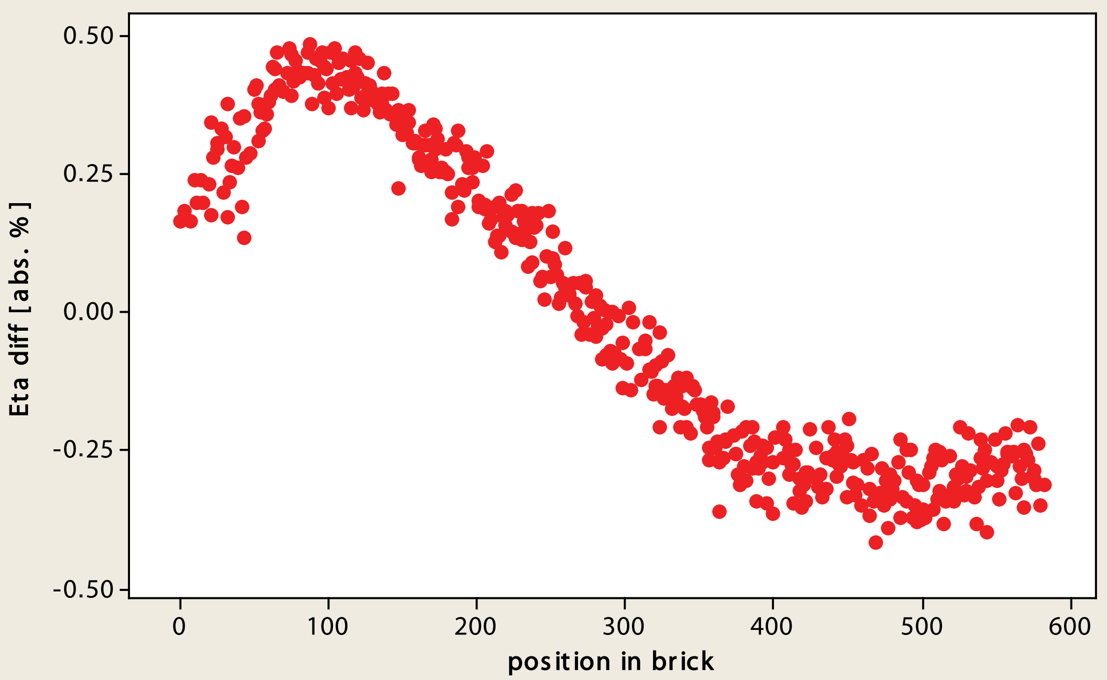

Figure 1. The usually rather broad distribution of cell efficiencies measured at the cell tester becomes much sharper if correlated against their major predictors, i.e. the ingot or brick position. MES systems maintain the data relation throughout the entire line. Exploiting this, incremental improvements and small deviations of less than one-tenth % can quickly and unambiguously be identified and levered.

deviation can now be detected and incremental improvement potentials levered. The issue with these correlations is less the knowledge of their existence than the precise tracking of the material all the way down into modules.

Finally and most importantly, cells are binned into boxes of different classes. Each class of box comes into module manufacturing with a commitment to minimal performance of the cells it contains. Confirming the importance of proper tester calibration, we will discuss the robustness of module yield manufactured out of these boxes.

As a prerequisite to the discussion later, we need to briefly revisit the testing procedure itself. After identification of the cell, it is fed into the dark test chamber where it is properly aligned and lifted onto rear contacts, which in turn hold the wafers against multiple contact beams over the bus bars. In order to yield good contacts and a rigid construction, the bars are a little wider than the bus bars, also precisely defining the shaded area subtracted from the active area for efficiency calculation, tolerating a certain misalignment. Then, operating curves are recorded, both under dark, low light and full STC conditions. Test temperature is actively maintained and monitored values are used to correct the data in voltage and current due to small remaining temperature offsets to the standard temperature. Light is provided by a distant, homogeneous and high-power flasher system providing proper illumination conditions during a period of some milliseconds long enough to acquire the complete operating curve. Any remaining flash intensity fluctuations during curve measurement are again recorded by a monitor cell and both currents and voltages are corrected accordingly. If the spectrum of this light is not perfectly similar to the STC AM1.5g, care must be taken to ensure that spectral mismatch can be minimized by setting a spectrally matched calibration standard at the centre of the current production window for each significant cell type.

As reported earlier in the sixth edition of *Photovoltaics International* [1], advances in cell design and even smaller improvements usually lever the thus-far less exploited violet and infrared ends' potentials in the quantum efficiency characteristic of the cell. The cell's convolution with the standard spectrum and the flasher spectrum, respectively, leads to changes in the mismatch factor that must be rolled out to production test with process changes of this category.

A frequent source of misunderstanding is the repeatability of a single measurement against the precision that can be obtained once sufficient statistics are used. Fig. 2 illustrates this problem showing the differences between five subsequent measurements of a batch of 100 cells on a production test system. Each measurement is compared against the same cell's result in the first batch run. The comparison reveals a superimposed noise added to the mean result, which is perfectly Gaussian distributed and independent from the test sequence or wafer properties. Positively speaking, we superimpose random noise with the measurement and are thus able to eliminate its influence sufficiently by applying some statistics to all calibration routines perfectly reproducing mean values. Secondly, as distribution width is rather small and constant, proper guard bands in testing secure test bins from containing significantly deviating low-flyers.

Calibration

A sophisticated task on its own is the calibration of the testers against the WPVS primary standards provided by the national institutes of standardization (e.g. the PTB, Physikalisch-technische Bundesanstalt in Germany), as the spectrum cannot be as easily materialized and transported as for other physical properties like length or electrical resistance. Q-Cells SE aims to very conservatively distribute the standard across all flashers at all production sites with the procedure outlined in the following section.

Standard encapsulated cells are delivered by PTB and re-circulated for calibration bi-annually to PTB. Several standards are used concurrently to ensure stability over time and alert on any incompatible finding. Using this verified standard, a solar simulator AM1.5g Grade A illumination source is checked every

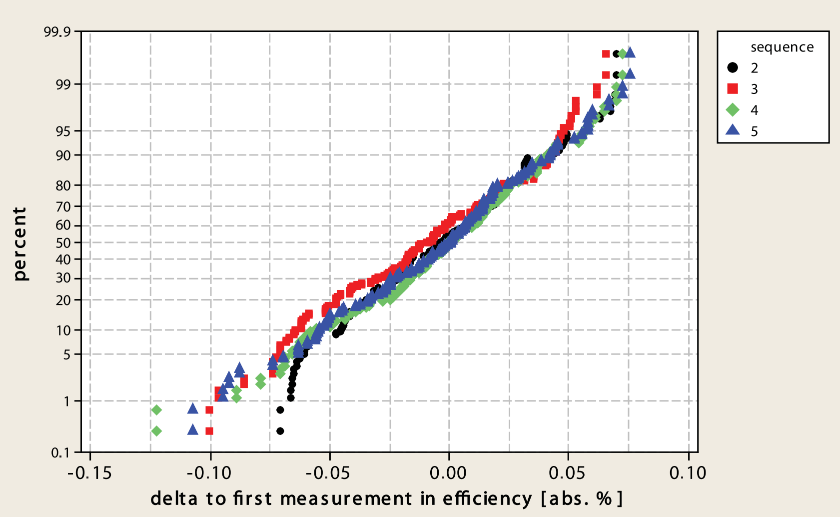

Figure 2. Reproducibility of a standard production flasher test. Cells are tracked individually through the five batch runs, and the differences to the first measurement are plotted against a normal distribution scale. They show independent normal distribution of similar width and very reproducible position.

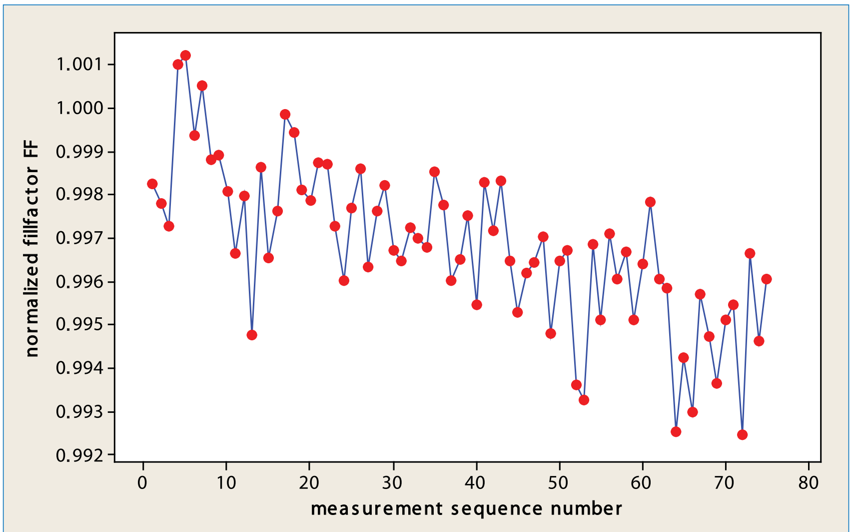

Figure 3. Degradation in fill factor of a 150-wafer batch contacted and measured repeatedly.

morning, and before calibration of internal secondary standards, to precisely deliver a standard 1 sun flux and spectrum at homogeneity across a 6" wafer. Here, a first re-confirmation loop is established by checking results with full-width wafers from ISE CalLab. Using this internal calibration standard, working and reference batches are measured using carefully optically degraded cells representing the centre of the production. Reference batches will be tested as few times as possible as they are designated to give reference against working batches to be produced for the future calibration runs over time. The working batch is used to calibrate all testers at the beginning of the calibration period.

The other testers are checked daily to ensure they still give similar results, with production batches produced on a certain predefined master-tester that has been checked with the previous reference batch. Degraded cells are stored in the tester and fed into the measurement position every hour to additionally contain any deviation that might occur in between. As and when suspicious test results occur in either of the verification runs, the tester is immediately re-calibrated using the working batch. After the end of their duty cycle, both the working and reference batches are returned to the lab to confirm their proper settings closing the second verification loop.

The predominant wear-out mechanism of reference or working batches is the frequent contacting which leads to a loss in fill factor (Fig. 3). As calibration is made to adjust on a point close to mpp (in addition to I_{sc} and V_{oc}) , leaving this batch for calibration a little longer is tempting as it would shift production to better efficiencies. Insufficiently pre-degraded batches would have the same effect.

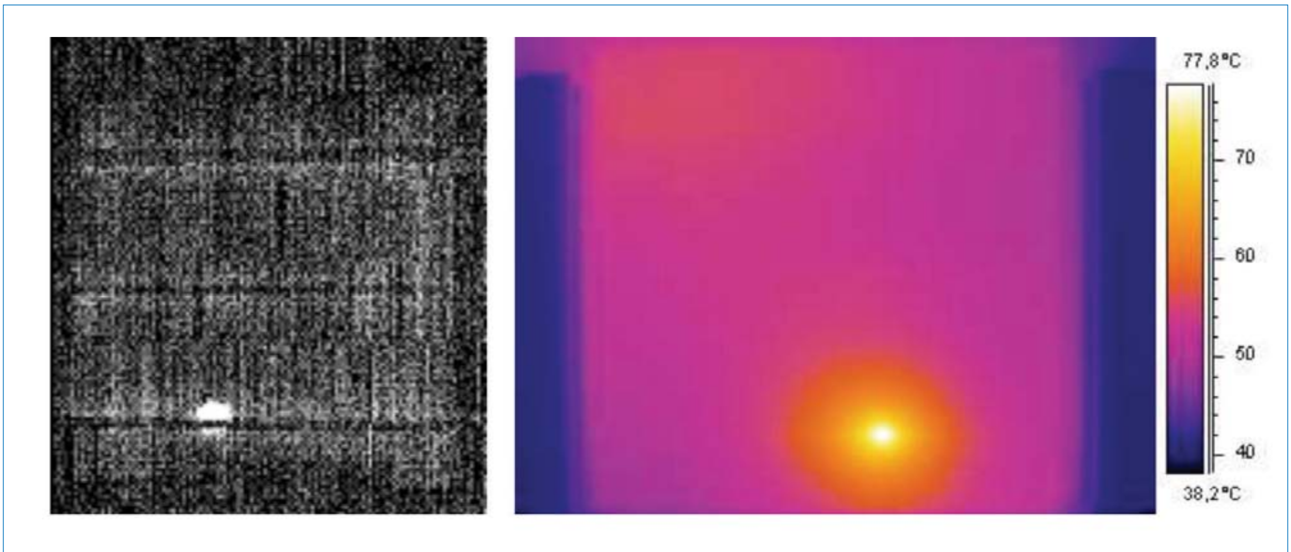

Figure 4. Diffential IR image of a cell under test, taken within fractions of a second. This image correlates well to a hot-spot that developed after assembly of that cell into a module and exposing it to field conditions for some time. Note that the cell is seen from the sunny side in the cell tester and inspected from the rear side during module operation.

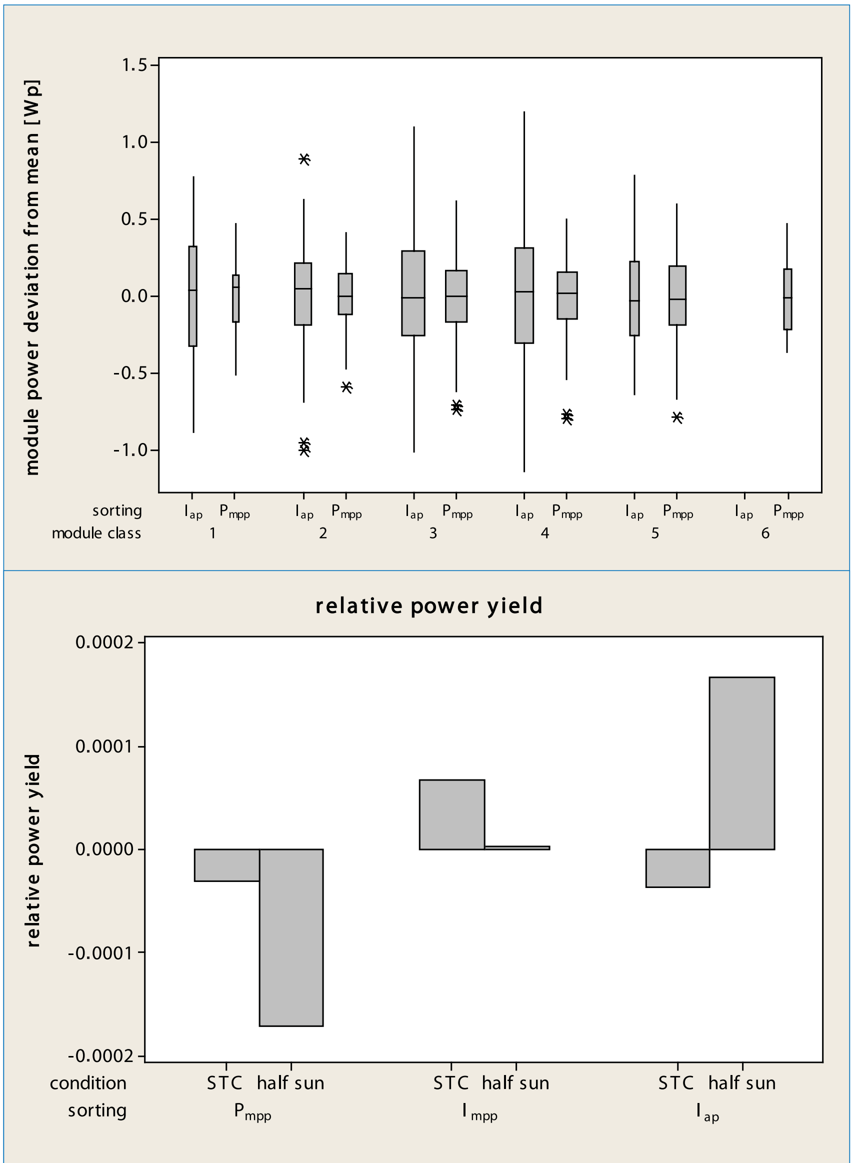

Figure 5. Simulation results of artificially assembled modules by combining 47,500 real measured cell operation curves to 3 × 20-cell-modules. The box plot shows that sorting according to the power at the maximum power point (P_{mpp}) leads to the best prediction for the power of the modules assembled of the sorted cells. In turn, the bar graph displays a slight advantage in total module power output for sorting according to the current at a fixed voltage (500mV, I_{ap}) for full- (1000W/m², STC) and half-sun (500W/m²) irradiation, yet differences are in the one-ten-thousandths range.

Hot-spot inspection and binning

As pointed out before, local defects such as shunts are hardly visible in the integral measurement of the entire cell. However, local heating and unfavourable operating conditions might lead to a self-amplification of that defect resulting in hot-spot temperatures that will irreversibly destroy the encapsulation of the module at that spot. On the other hand, the test must not decrease throughput at the final test insertion allowing the hot-spot enough time to go into the self-amplification regime. Our test engineers have developed a method to quickly detect and discriminate small local temperature increases that correlate well to failure seen in long-term module tests. Fig. 4 illustrates an example.

This method benefits from the fact that the sample is contacted anyway inside the tester, which means that in the same step as testing, power can be dissipated electrically into the cell under test. The resulting lateral distribution of temperature increase is measured with a differential IR-camera image. Test modules have been built from specially sorted cells covering all ranges of hot-spot patterns and intensities as well as increased reverse-bias currents. Accelerated real-life condition tests are then used to determine thresholds for the IR-camera patterns detected during final test. In addition, spatially resolved assessment of the patterns helps to classify the hot-spots and trace them down to process issues to be eliminated.

After being sorted by the IR camera tests and other quality criteria into the top category, the cells need to be binned. The ultimate goal of the binning is to not jeopardize any power generation capability of the cell to mismatches of the cells stringed together to a module. In this step, all the caution and effort spent on the accurate calibration of the cell tester pays off. Only using this procedure can it be guaranteed that all boxes labelled the same actually contain equivalently matching cells.

> “Total power achievable with the given collection of cells only changes by far less than one-thousandth of the total power for the proposed sorting schemes.”

Other manufacturers take different approaches to this sorting step. We have performed simulations testing different binning schemes of 47,500 measured real operating curves, and subsequently randomly combining these cells to modules (see Fig. 5). Ignoring other influences of module manufacturing itself, the module operating curves and individual P_{mpps} were calculated from the superposition of the individual cell curves, not just by adding the cell's P_{mpps}. I_{mpp} distribution does not broaden, regardless of whether or not it is binned according to the current at a fixed voltage (500mV, I_{ap}) or by P_{mpp}. Total power achievable with the given collection of cells only changes by far less than one-thousandth of the total power for the proposed sorting schemes. This is far below the uncertainty one has due to the slightly different early light-induced degradation which is not yet accessible to cell test, and impacts of the module assembly itself.

Outlook

Looking forward, a new challenge arises with improving cell efficiencies further by using material excelling in longer lifetime. With the longer lifetime of the minority charge carriers, it takes the cell longer to go back to equilibrium when the operation condition is changed. Standard measurement times are already in that regime when entering high efficiency classes. The effect of staying in non-equilibrium shows up in the hysteresis when running through the operation curve in both directions, as shown in Fig. 5. Only longer settle time per measurement point can overcome this pitfall, and clever segmenting of the test range helps to keep test times short enough to fit into the stable plateau of a flash, extending the current test methodology to the next generation of cells.

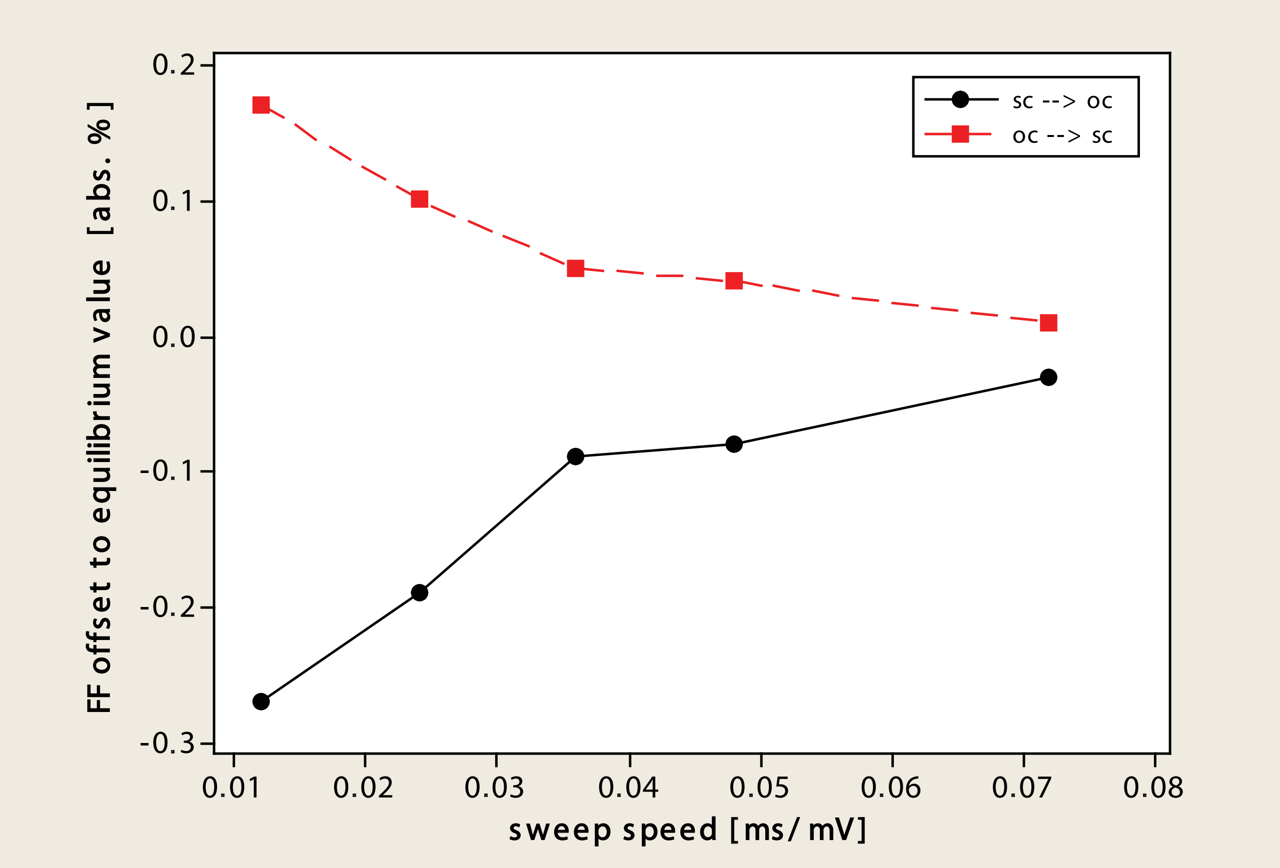

Figure 6. This graph shows the offset due to fast sweeping through the operating curve converging to the equilibrium value for slower sweep rates. Using measurements that are too fast poses the risk of over- or underestimation of the performance of the cell, respectively.

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About the Authors

Nico Ackermann received his diploma degree in technical physics from the University of Duisburg-Essen. While studying he gained experience in photovoltaics at the Fraunhofer ISE. He joined Q-Cells in 2005 and has responsibility in the field of characterization and physical analysis.

Volker Gutewort joined Q-Cells in 2005 and holds responsibility for overall process optimization and data analysis. He received his diploma degree in physics from University of Leipzig in 2002. From 2002-2005 he worked as software developer for a leading company in the smart card industry.

Michael Quinque started his career as an electrician with Siemens, continuing to study electrical engineering at the University of Applied Science in Leipzig. Since 2004, he has been team leader in the Metrology department at Q-Cells SE.

Marcel Kühne completed his Dipl.-Ing. at the Martin-Luther University Halle/Wittenberg in chemical engineering in 1998. He then worked at the Dow Chemical company in several production positions, joining Q-Cells SE in 2007. He has held responsibility for the IR-Camera System since 2009.

Dr. Elard G. Stein von Kamienski did his Ph.D. research in the field of MOS-technology on SiC at the Semiconductor Institute of the RWTH Aachen in 1996. He developed devices for embedded flash processes at Infineon and managed semiconductor product engineering for charge trapping flash and floating gate flash products with Qimonda. He joined Q-Cells SE in 2008 and is currently head of measurement technology and process analysis.

Dr. Achim Schulze studied mathematics at the University of Bayreuth. Working on stability problems in plasma- and astrophysics, he joined the analysis and modelling team of Q-Cells after receiving his Ph.D. in 2008.

Dr. Ralph Wichtendahl did his Ph.D. research in the field of chemical physics and synchrotron instrumentation at the Fritz-Haber Institute in Berlin in 1999. He joined Q-Cells SE as head of analysis and modelling in 2009, bringing experience in managing DRAM semiconductor product engineering at Infineon and Qimonda.

Enquiries

Q-Cells SE
Sonnenallee 17-21
06766 Bitterfeld-Wolfen OT Thalheim
Germany

Tel: +49 (0) 3494 6699 52117
Email: r.wichtendahl@q-cells.com
Web: www.q-cells.com

Examining cost of ownership for front- and back-side metallization of crystalline-silicon solar cells

Darren Brown, DEK Printing Machines, Weymouth, U.K. & **David Jimenez**, Wright Williams & Kelly, Pleasanton, California, USA

ABSTRACT

This paper, the third in a series covering cost of ownership (COO) studies for photovoltaics [1], examines the need for metallization of silicon-based solar cells and how it has evolved over the past few years. The technologies and techniques that are being developed for this part of cell manufacturing in the foreseeable future are also discussed. The paper will conclude with a COO case study using the DEK Solar PV3000 as an example.

Solar cell production outline

Metallization is the final step in the solar cell manufacturing process and, as such, its success depends very much on the steps that precede it. A discussion of metallization and its development must therefore take into consideration the entire solar cell production cycle. So before describing the process of cell metallization, it is worth first outlining the entire process through which the silicon wafer travels on its way to becoming a fully-fledged cell.

First, the silicon wafer is sliced from a monocrystalline or polycrystalline silicon ingot. This step can be carried out either directly at the silicon foundry or by the solar cell manufacturer. The sliced wafer then goes through four distinct manufacturing steps, finishing with metallization, after which it is ready for mounting into a solar panel.

The first step in the cell manufacturing cycle is wet etching, which is described in depth in the second paper in this series [2]. Here, the imperfections created in the sawing process are removed and the wafer's surface is texturized to create the microscopic pyramid structures that will enable it to trap and absorb sunlight rather than reflecting it.

As described in the first paper in this series [1], the second step is a thermal diffusion process whereby an n-type layer is diffused through the wafer's top layer and down into its structure. Typically made of phosphorous-rich material, this combines with the wafer's own n-type material to create the cell's p-n junction, a planar semiconductor device that will generate electrical current. During the diffusion process, a layer of glass is created on the surface of the cell that is removed in an additional etching and de-glassing process.

In a further print step, the cell's antireflective layer is laid down in a plasma-enhanced chemical vapour deposition (PECVD) process that gives the cell its blue colour, after which the cell is ready for metallization.

Metallization explained

The photovoltaic industry uses screen-printing as the method of choice for depositing silver and aluminium onto its solar cells. Inkjet printing, the only commercially available alternative to screen-printing, is little used, principally because its use calls for an additional plating process, which adds extra cost and which does not lend itself to the solar industry's inline production approach.

Today's metallization process typically consists of three separate print phases, two on the cell's back-side and one on the front-side. The order of the printing steps depends on the manufacturer's operations. In the first back-side print step, silver contacts are printed in the form of two bus bars or, less frequently, in the form of simple tabs. In the second print operation, a thin layer of aluminium is laid down across the entire back-side, creating the cell's back-side field, or contact (see Fig. 1). In a further print step, the front-side of the cell is printed with a silver conductor grid (see Fig. 2).

The aluminium and silver act as the terminals of a battery, routing the electricity off the cell. The electricity is generated by photons of sunlight hitting the cell's p-n junction and releasing electrons that migrate through the n-type silicon to the cell's front face. Here they are captured by the grid of silver conductor fingers and routed through the cell's electrical circuit to the back field, their movement creating an electrical current that generates the cell's electricity. In the meantime, the atoms at the p-n junction that are now without their electrons are in turn attracted by the aluminium back field, where they recombine with their electrons, and then migrate back into the wafer.

Clearly, the more electrons the silver conductor grid harvests, the more efficient the solar cell, so ideally, the conductor grid should be printed across the entire front surface of the cell. Unfortunately, this is not possible, as the same grid that collects electrons actually prevents their generation by putting the underlying silicon into shadow. Thus, there must be a trade-off between electricity generation and harvesting efficiencies. The solar industry has access to numerous mathematical formulae that calculate the best grid size and density for any cell design.

Typically, the wafers are presented to the metallization line either on a conveyor straight from the PECVD

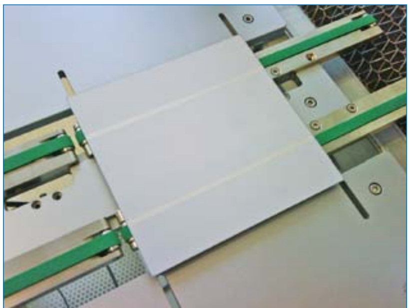

Figure 1. Back-side metallization of a solar cell.

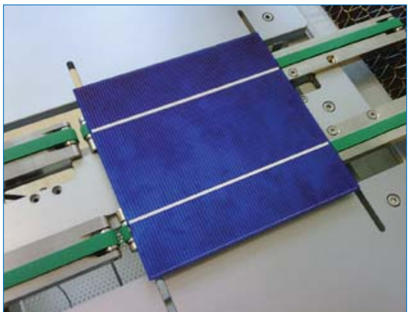

Figure 2. Front-side metallization of a solar cell.

process or in coin stack boxes or cassettes. The first piece of equipment in a metallization line is usually an unloading mechanism and possibly an inspection station that checks the wafers for damage from previous processes. At this point, they will go into the first screen printer, where they may be loaded singly into a completely flat nest that supports them and holds them down using a vacuum. A camera system is used to align the image on the printing screen with the edges of the wafer, or alignment features or fiducials on its surface, after which the wafer is presented to within approximately 1mm of the screen, depending on the print gap.

In some cases, an automatic paste-dispensing system will dose the print paste onto the screen prior to the print stroke but often, and especially in lower labour cost areas, this is achieved manually. DEK's equipment, for example, uses a print flood process whereby a floodbar, or doctor blade, first spreads a very thin layer of paste across the surface of the print screen, after which the squeegee sweeps across the screen, pushing the paste through the mesh onto the wafer. After the print stroke, the screen and the cell part company, and the cell is transferred to an inspection station that will check for print quality and accuracy, alignment, breaks, shorts, width violations, and, in the case of the aluminium, back-side contact and voids.

Unlike electronics manufacturing, solar cell production does not include rework as a standard process. A few breaks in a cell's printed features will, of course, affect its functionality, but not enough to warrant the time and expense of rework. Once the cell gets to the end of the line, it will be tested and graded according to its efficiency. Lower-efficiency cells will simply be less expensive and will be sold into less demanding applications.

After print inspection, the cell is loaded into a dryer, such as a hot-air convection oven, to drive the solvents out of the printing paste, and then it is transported on to the next printing station. Once all three print processes have been completed and the wafer dried, it goes through a sintering furnace that fires the front-side silver through the antireflective coating and into the silicon's n-type to create an electrical connection. Here it is essential that the silver is fired to a controlled depth and that it does not contact the p-n junction, since this would create a shunt, or short-circuit.

The industry standard beat rate is currently at around 3 seconds, and on a standard DEK printing line this three-print process takes around 4 to 5 minutes, including all handling and inspection operations. One cell at a time is printed on all DEK machines, to allow for individual alignment of each cell – a factor that is becoming increasingly important in the industry.

Developments in metallization

Over the past few years the front end of the solar manufacturing cycle – the etching and antireflective processes – have changed a great deal. Now, those changes are moving down the production line and metallization is up for some major developments, driven by a number of important factors. The following is a brief description of some of these factors and their effects on the metallization process.

Wafer handling

Until a few years ago, wafer thickness was typically in excess of 300-400µm. Then, as the solar industry started competing with the semiconductor industry for its limited supply of silicon, efficient ingot use became paramount and wafers came down to 200µm, then 180µm in 2009. Today's standard – 160µm – is even thinner, and some manufacturers are even considering wafers just 120µm thick. At the same time, wafer sizes have gone from being 100mm to 125mm square, and they are now at an industry standard 156mm square.

The general move away from monocrystalline silicon to the more fragile and less expensive polycrystalline silicon has brought with it several fundamental changes to the wafer handling process. Today, edge contacting is absolutely prohibited and, therefore, so are edge grippers and the practice of driving a cell into a hard stop for alignment. This means that only vision and sensors can be used, and the wafer is picked up from the underside or is moved on belts. Indeed, it is now the case that the only time the wafer is put under stress is during the print stroke – and development work is under way to address this issue as well.

Feature size and repeatable accuracy

When DEK started its involvement with the solar cell industry some 30 years ago, the widths of the features being printed were up to 300µm. Now, as a direct consequence of the need to reduce the shadows cast by the cell's front-side silver conductor fingers, print features have become progressively finer over the past few years. The industry has, accordingly, seen linewidths shrink from a standard of around 150µm three years ago to 120µm in 2010, with some manufacturers looking to achieve sub-100µm features. The inherent challenge in this degree of miniaturization is to ensure that the conductors lose none of their current carrying capacity, and so it is imperative that if they are to be printed narrower, they stand higher.

A whole new set of technologies is being developed that will allow high-aspect-ratio grid features, but these demand extreme precision from the printing process. Print-on-print, for example, allows manufacturers to print ultrafine silver conductor lines twice but calls for a highly accurate and repeatable printing process.

Selective emitter technology also resolves the problem of shadowing by depositing extra n-type dopant in a pattern mirroring that of the collection grid. Thus, like print-on-print, this requires a second front-side printing operation in the metallization line that will enable both print patterns to be aligned with each other to within a few microns. The added challenge here is that the dopant, the first pattern to be deposited, is invisible, and normal vision alignment systems cannot be used to align the subsequent silver collection grid pattern to it. Most manufacturers, therefore, use two small 0.5mm-diameter fiducials, printed at the outer extremes of the cell, to which both deposition processes must be precisely aligned.

As can be seen, in just a few short years the industry has gone from fairly wide features and noncritical alignment requirements to today's ultrafine features. This change must be accurately registered to either internal and invisible parameters or to previously printed patterns.

A further route to increased efficiencies is to move the relatively wide busbars from the front of the cell to the rear, connecting them to the collection grid by means of metal wrap-through holes, a more complex version of the electronics industry's plated-through holes. This process also relies on high print alignment accuracy and repeatability.

Print throughputs

Print throughputs have increased enormously, but so too have other demands that on first glance are incompatible with today's increased speeds. Five years ago, solar cell manufacturers mainly focused on throughput because they were dealing with thick, fairly stable wafers. As wafers became thinner and thinner, the focus changed to include yield and breakage, and now features have become so fine and technologies have changed so much that accuracy is paramount. Speed, yield, throughput, accuracy, and now equipment footprint are the parameters that guide equipment design and development. Concerned that increased print speeds could result in increased wafer damage and decreased accuracies, DEK has developed its PV3000 printing line (see Fig. 3) to increase throughputs threefold without increasing the speed at which the wafer is printed. It has achieved this by tripling the number of printing heads at any one printing station, allowing three cells to be printed at the same time and effectively reducing the line's beat rate from 3 to just 1 second per cell.

Printing pastes

Other areas where the metallization process is undergoing rapid transformation are in pastes and screens. Pastes are typically made of silver or aluminium together with the binder complexes and solvents that render them printable. In the case of front-side silver print pastes, the glass frit allows the silver to fuse down into the silicon during the co-firing process. Pastes for front-side printing are exclusively based on silver, while the back-field pastes are based on aluminium. The pastes used to put the silver contacts on the back-side, on the other hand, are often a mix of the two as the silver lends solderability while the aluminium creates an electrical contact. Considerable concern around the future availability and cost of silver compared to other conductors such as copper is fuelling development work around other, less expensive alternatives, but no viable alternative has yet been identified.

Transparent and semi-transparent conductor materials such as indium tin oxide (ITO) are also undergoing research, as they are potential remedies for the problem of shadowing. The problem is that in order to achieve the electrical properties required the material must be applied at a thickness that renders it opaque. Some manufacturers are studying the possibility of printing hybrid conductor grids using a thin layer of transparent conductor and a reduced number of silver conductors.

In the meantime, the standard off-the-shelf pastes of five years ago have been tuned for higher speed printing, faster drying, better rheology for higher aspect ratio features, better conductivity, and even for the way in which, and the depth to which, they fire into the wafer during the co-firing process. This has become particularly important for today's thinner wafers, where the p-n junction sits much closer to the wafer's surface.

Printing screens

Screen manufacturers have put a lot of work into improving paste transfer properties and, therefore, conductor grid structure and efficiencies by reducing the diameter of the wire used in print screen meshes to a current industry standard of 20-25µm. Apart from this, however, little has changed in the last decade in terms of the screens used for solar cell printing.

However, DEK's research has led to the development of an innovative hybrid screen design that combines the advantages of mesh-printing screens with those of two-layer electroformed stencils. This enables the repeatedly accurate printing of new, high-aspect- ratio features getting the industry closer to technologies such as print-on-print, selective etching, and selective emitter.

Case study

This case study will look at the COO of front- and back-side metallization using the DEK Solar PV3000 as an example. The base costs will be examined then contrasted with a single head system; sensitivity analyses also will be performed to find those areas for future cost improvements.

COO review

A more detailed discussion of COO can be found in the first paper in this series in the sixth edition of *Photovoltaics International* [1]. To review, the basic COO algorithm is described by [3]:

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

Where:

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

Figure 3. Integrated screen printer and drying equipment.

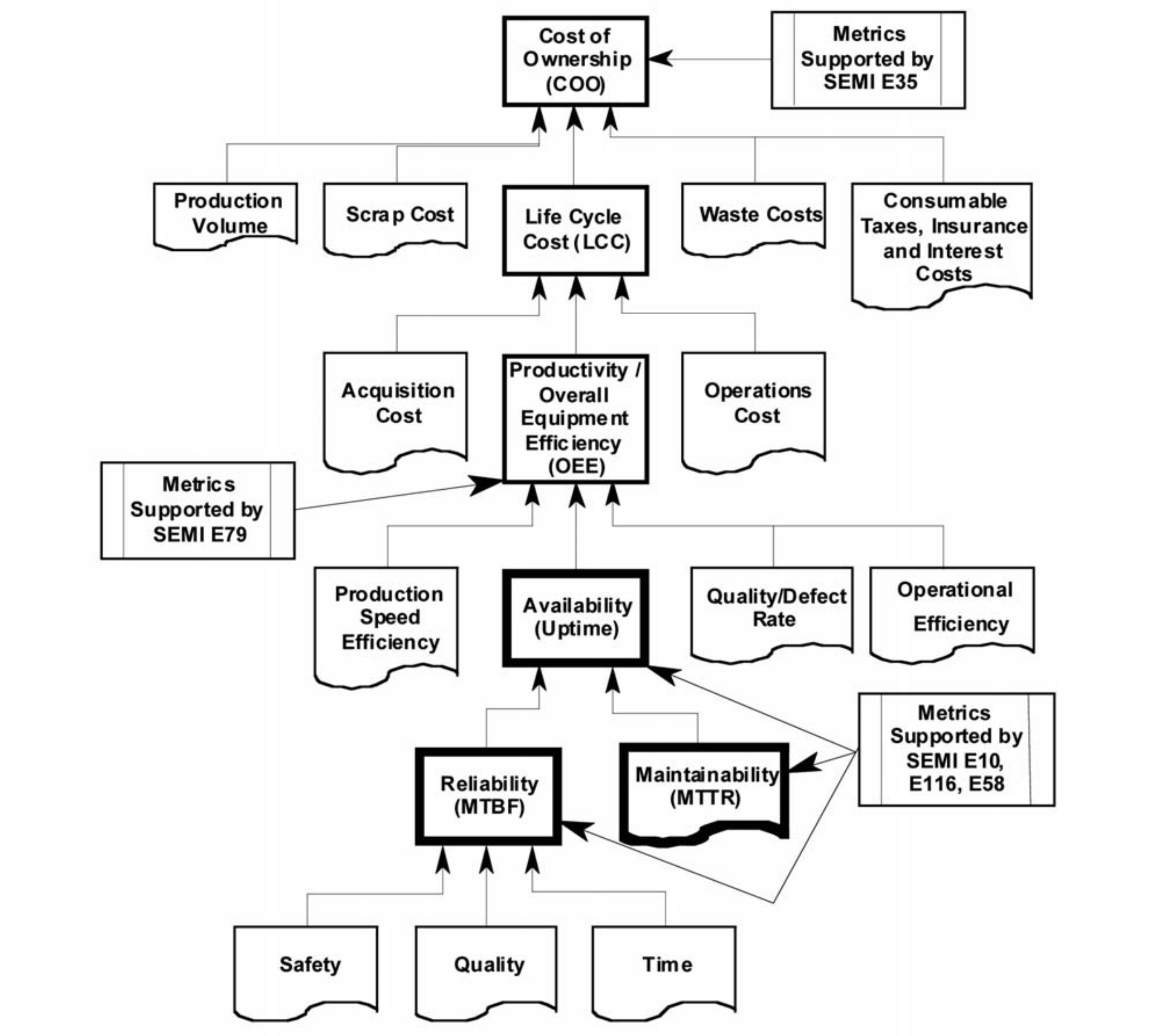

Figure 4. Hierarchy of equipment performance metrics [5].

C_F = Fixed cost

C_V = Variable cost

C_Y = Cost due to yield loss

L = Process life

TPT = Throughput

C_C = Composite yield

U = Utilization

Overall equipment efficiency (OEE) review

One of the most popular productivity metrics is OEE [4]. It is 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.

If the accuracy requirement is not a critical factor, use the following formula to calculate an approximate OEE value:

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

There are many equipment performance metrics at different levels, as depicted in the hierarchical tree in Fig. 4. As shown in the figure, when a time dimension is added to quality and safety, it becomes reliability. Reliability and maintainability jointly make up availability. When production speed efficiency and production defect rate are combined with availability, it becomes productivity (OEE). Acquisition and operational costs make up life cycle cost (LCC). When scrap, waste, consumables, tax, and insurance cost are added to LCC and the total is normalized by the production volume, it becomes COO.

Cost of ownership inputs

The following are the results of the COO analysis run on the PV3000 metallization line. Table 1 highlights the major input parameters.

In addition to the Table 1 parameters, where required, we used example values from SEMI E35 for administrative rates and overhead [3]. These values where provided by SEMI North American members and may not be applicable to other geographic regions. However, it is our experience that these example values do not impact the COO results on a relative basis.

Cost drivers

Examination of the detailed cost of ownership model in Table 2 highlights the main cost and productivity factors [6]. Recurring costs are approximately 30× initial capital costs over the life of the process, which are driven primarily the cost of aluminium paste used for back-side metallization. Next, the top cost drivers and opportunities for improvement will be closely examined.

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

The top three cost drivers account for 96% of the total COO, so attention will be focused on those areas as the cost sensitivities to input parameters that drive material/consumable costs, labour, and depreciation are scrutinized.

Cost driver sensitivities

The first factors to be examined are supplies and consumables. Table 4 shows the annual costs per system by supply item. One of the issues involved in defining a sensitivity analysis for some of these items is their interrelationship with other factors. Changing the price/quality of the screens could impact throughput, paste consumption, or yield; paste consumption changes could impact throughput and the conversion efficiency of the device. Since the aluminium paste is such an overriding cost for the entire process, there needs to be an examination of the cost benefits that could be achieved by reducing the consumption or cost per kilogram.

As can be seen from the chart in Fig. 5, the usage of aluminium paste has a significant impact on the total COO. A 50% reduction in usage provides a 33% reduction in the total COO for the process. While it may not be possible to achieve this level of reduction and maintain the cell efficiency, it certainly shows a significant opportunity for continued research in conducting materials.

Likewise, the price of aluminium paste has a similar impact on the total COO. A 50% reduction in price provides a 33% reduction in the total COO for the process (see Fig. 6). Based on information from a materials supplier, much of the cost of pastes is driven by polymer costs, not the cost of the metals. This is clear from a look at the pricing for both aluminium (US$85/kg) and silver (US$100/kg) pastes, even though silver is currently US$17.95 per ounce and aluminium is approximately US$0.07 per ounce. Again, given the dominant cost impact of aluminium paste, it would be well worth the effort to examine alternatives.

The industry is looking at transparent and semi-transparent conductor materials such as ITO as a replacement for silver. While working to achieve lower shadowing on the front-side to improve cell performance will help drive down the cost per watt, it appears that finding a replacement or reduced usage or price for aluminium would perhaps provide an even greater cost-per-watt improvement.

The next factor to be examined is labour content, which represents 4% 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

Parameter	PV3000
Throughput	3,000 wafers/hour
Wafer size	156mm
Wafer cost	$3
Mean time between failure (MTBF)	2,000 hours
Mean time to repair (MTTR)	2 hours
Equipment cost	$2.3 million
Equipment yield	99.7%
Utilities	$41,470/year/system
Consumables	$5,638,022/year/system
Maintenance	Owner provided

Table 1. Major COO inputs.

Cost per system	$2,300,000
Number of systems required	1
Total depreciable costs	$2,355,000
Equipment utilization capability	97.52%
Production utilization capability	97.52%
Composite yield	99.70%
Good wafer equivalents out per week	490,009.49
Good wafer equivalent cost	
With scrap	$0.30037
Without scrap	$0.29134
Average monthly cost	
With scrap	$639,544
Without scrap	$620,323
Process scrap allocation	
Equipment yield	100%
Defect limited yield	0.00%
Parametric limited yield	0.00%
Equipment costs (over life of equipment)	$2,541,145
Per good wafer equivalent	$0.00995
Per good cm^2 out	$0.00005
Recurring costs (over life of equipment)	$74,204,096
Per good wafer equivalent	$0.29042
Per good cm^2 out	$0.00152
Total costs (over life of equipment)	$76,745,241
Per good wafer equivalent (cost of ownership)	$0.30037
Per good cm^2 out	$0.00157
Per productive minute	$14.97

Table 2. COO results.

Cost drivers per good wafer equivalent	
Material/consumables	$0.26695
Labour	$0.01254
Depreciation	$0.00922
Scrap	$0.00903
Maintenance	$0.00133
Floor space costs	$0.00070
Support personnel	$0.00057
Training	$0.00001
System qualification costs	$0.00001
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.

Supply/consumable	Annual cost per system
Electricity	$28,470
Exhaust	$13,000
Screens	$768,821
Aluminium paste	$4,356,654
Silver paste	$512,547

Table 4. Annual supply/consumable costs.

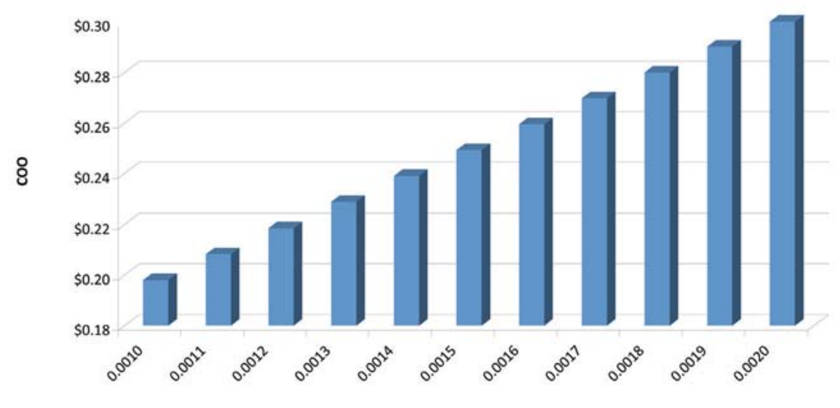

Figure 5. Sensitivity analysis of aluminium paste quantity vs. COO.

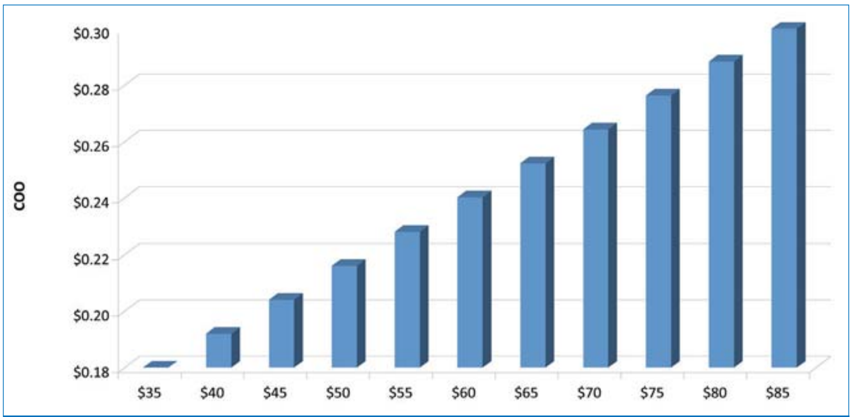

Figure 6. Sensitivity analysis of aluminium paste price vs. COO.

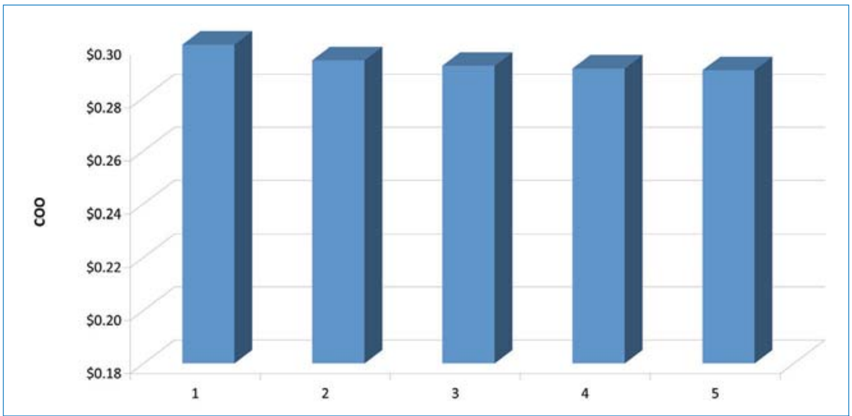

Figure 7. Sensitivity analysis of labour vs. COO.

sensitivity to labour content should such opportunities present themselves.

Lastly, we look at the factors impacting depreciation: purchase price and throughput (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 US$0.0047 (1.5%) per US$1.2 million (~50%) change in purchase price. This indicates that even if the purchase price were zero, the impact on COO would only be approximately 3%.

However, as Fig. 9 shows, improvements in throughput can have a significant impact on COO, depending on where on the curve the equipment is operating. In this case, the printing line is operating at an average throughput of 3,000 wafers per hour (wph), and ±200wph near the average only impacts COO by 0.6%.

Another question that arises from the previous discussion is whether the assumption that a three-printhead system is, in fact, a lower cost alternative to the traditional single-printhead systems. For this analysis, the model was modified from a throughput of 3,000wph to 1,200wph and from a capital cost of US$2.3 million to US$1.2 million. The design throughput of the PV3000 is 3,600wph, but a more conservative value of 3,000 was used in this study. The same assumption was not made for the single-printhead system, so the actual costs for that system may be higher. The consumables per wafer were also assumed to be the same since the end product should have the same specifications.

Even with the above assumptions, the COO value for the single-head system was found to be US$0.33 per good wafer compared to the US$0.30 for the PV3000. Therefore, the multiple-head system is estimated to have approximately a 10% cost advantage over traditional systems.

Overall equipment efficiency

Table 5 shows the OEE of the PV3000, which shows the OEE in excess of 81% based on a maximum throughput rate of 3,600wph. If that factor is eliminated, the OEE is over 97%, leaving little room for improvement.

Conclusion

The photovoltaics industry has gone through some immense changes over the past few years, yet it is still developing rapidly in many ways. This means that while this paper can offer a snapshot of the metallization process and its costs today, these will very likely look quite different even a year from now. The upstream processes in solar cell manufacturing have gone through a practical revolution in the past few years and this, combined with the pressures inherent within the metallization process itself, are now driving huge transformations within this part of the production cycle.

As the industry moves forward, it will continue to focus on faster throughputs, better yields, higher accuracies, and higher aspect ratios. There will also be higher levels of automation, right through to the end of the line, approaching the ultimate goal of having a hands-off, lights-out operation where the materials are automatically fed into a line which monitors and runs itself. The surface mount technology industry is almost there, so there is every possibility that the solar industry will achieve the same.

Each improvement in the process has its development costs and while, in

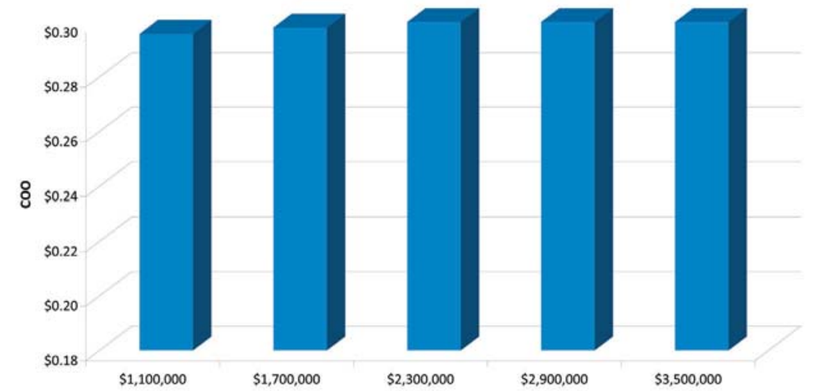

Figure 8. Sensitivity analysis of purchase price vs. COO.

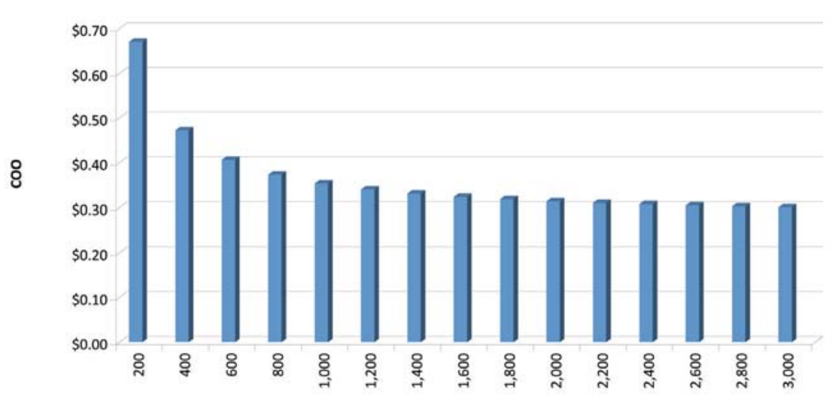

Figure 9. Sensitivity analysis of throughput vs. COO.

many cases, COO will be reduced as a result of their adoption, in other cases it may actually increase. While this seems counterproductive in a world of lean manufacturing and cost pressures, it should also be remembered that COO should be measured against changes in cell efficiency. For the solar industry, the combination of these factors gives the most crucial metric of cost per watt, and there is no doubt that the many developments mentioned here have brought or will bring significant improvements to the cost per watt of solar power and will continue to make solar energy a cheaper proposition for the future.

Overall equipment efficiency	81.02%
Availability efficiency	97.52%
Engineering usage	0.00 hr/week
Standby	0.00 hr/week
Hours available/system (productive time)	163.83 hr/week
Downtime	4.17 hr/week
Scheduled maintenance	4.00 hr/week
Unscheduled maintenance	0.17 hr/week
Test	0.00 hr/week
Assist	0.00 hr/week
Non-scheduled time	0.00 hr/week
Equipment uptime	163.83 hr/week
Total time	168 hr/week
Performance efficiency	83.33%
Throughput at capacity/system	3000 layers/hr
Theoretical throughput	3600 layers/hr
Operational efficiency	100%
Rate efficiency	83.33%
Quality efficiency	99.70%
Equipment yield	99.70%
Redo rate	0.00%

Table 5. OEE results.

Acknowledgement

The authors would like to thank DEK's senior process development specialist, Tom Falcon, for his contributions to this work.

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[6] TWO COOL® is a commercial software package from Wright Williams & Kelly, Inc.

About the Authors

Darren Brown is the global business manager of DEK's alternative energy group, responsible for maintaining the company focus on solar PV and hydrogen fuel cells and developing processes and equipment for these new and emerging technologies, including the PV1200 metallization line and the next-generation PV3000. Since joining DEK in 1995, Brown has held positions as a support engineer, global applied process engineer, and U.K. sales manager before heading up the alternative energy business unit. He has contributed articles and conference presentations on both fuel cells and solar throughout Europe, Asia, and the United States.

David Jimenez is president and cofounder of Wright Williams & Kelly, the largest privately held operational cost management software and consulting services company. He has approximately 30 years of industry experience, including management positions with NV Philips and Ultratech Stepper. He is also the author of numerous articles in the fields of productivity and cost management. Jimenez holds a B.S. in chemical engineering from the University of California, Berkeley and an M.B.A. in finance.

Enquiries

Darren Brown
Tel: +44 (0)1305 208435
Email: dwbrown@dek.com

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

Thin Film


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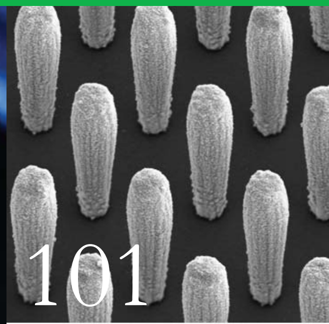
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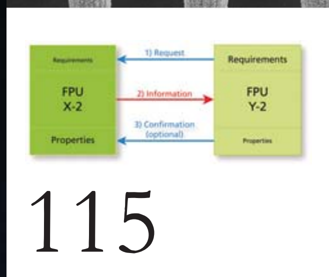
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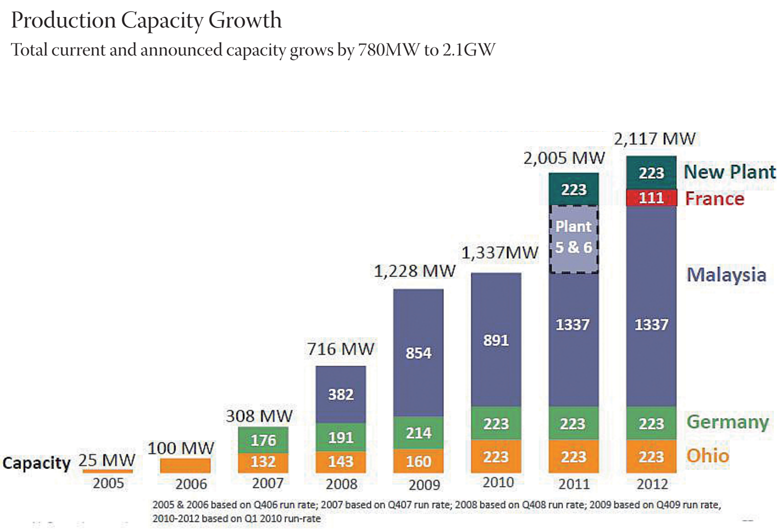
First Solar to add four new production lines; sold out through 2010

Although quarterly net sales were down US$73.3 million from the previous quarter due to a shift from turnkey system sales to module sales, demand for First Solar's thin-film modules remains strong and the company is adding a further four production lines with a capacity of 220MW. The location of the new lines will be disclosed as soon as legal procedures have been completed. The plant is expected to begin production in the fourth quarter of 2011. Production for the first quarter reached 322MW, up slightly from 311MW in the previous quarter. Quarterly net sales for the first quarter of 2010 were reported as US$568.0 million. For 2010, First Solar forecasts net sales of between US$2.6 and US$2.7 billion, up from US$2.06 billion in 2009.



First Solar's CdTe thin-film capacity ramp (2010-2012).

Annualized capacity per line continued to increase as the company is running at full capacity at existing production lines. In the first quarter, each line was able to reach an output of 55.7MW, up from 53.4MW in the previous quarter. This is another new record output level for the company.

Interestingly, the company is shifting module supply to meet demand from distributors and other customers primarily from Germany, and is having to move some utility-scale projects into 2011 to accommodate.

R&D News Focus

CIGS record of 20.1% efficiency reported by researchers at ZSW

The U.S. research institute NREL held the conversion efficiency record for copper, indium, gallium, and selenium (CIGS) solar cells for 16 years but has lost this accolade to scientists at the Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Germany (Centre for Solar Energy and Hydrogen Research, ZSW). ZSW, based in Stuttgart, has demonstrated CIGS cell efficiency of 20.1% on a 0.5-square-centimetre cell. The Fraunhofer ISE in Freiburg, Germany has confirmed the new results.

The solar cell consists of the semiconducting CIGS layer and contact layers. It has a total thickness of only four thousandths of a millimetre.

The new efficiency record shows the great potential of CIGS technology for lower-cost, efficient photovoltaic systems. Dr. Michael Powalla, member of the board and head of the photovoltaics division at ZSW, said that efficiency levels of up to 15% could also be achieved in commercial modules within the next few years.

CIGS Lab at the ZSW Centre for Solar Energy and Hydrogen Research.

Dyesol and Csiro to collaborate on higher performing dyes

Dyesol and Csiro are in the process of finalizing documents for a partnership to develop higher performing dyes in a two-year project funded by Csiro's Australian Growth Partnership (AGP) program.

Through the partnership, Dyesol will project manage a team of scientists from Csiro to work with the company on an agreed development program leveraging Dyesol's knowledge of ruthenium-based dyes and Csiro's modelling and research capability.

The partnership will also involve the purchase of a Dyesol laboratory solution by Csiro, a direct investment into Dyesol via the AGP program and contributions from both Csiro's Energy Transformed Flagship and Dyesol.

NREL confirms 11% conversion efficiency for SoloPower flexible CIGS PV modules

SoloPower's flexible CIGS PV module.

NREL has confirmed that flexible CIGS solar panels manufactured on SoloPower's pilot production line have achieved aperture conversion efficiencies of 11% during tests at the lab's Golden, CO, facility—the highest efficiencies yet achieved by a full-size flex module. NREL had previously verified 13.4% efficiencies on the company's $11.8cm^2$ lab cells.

SoloPower uses a proprietary electroplating-based process to manufacture its CIGS cells on flexible metal foil. The devices are then processed in a moduling line and laminated in an encapsulation system that provides a moisture barrier and environmental integrity.

The company expects the low-cost, high-efficiency module to address the commercial and industrial rooftop and distributed solar power generation markets. UL tests on the SoloPower batch of modules should be completed by early summer.

Once certification occurs, the CIGS firm will build out and ramp volume manufacturing on a new 75-100MW production line in its facility in Edendale Technology Park in southern San Jose. Tools for the first high-volume R2R line, which will run a metre-wide foil web, were scheduled to be ordered in May.

In the meantime, shipments from the company's 10MW pilot line (which runs a one-third-metre wide web) continue to be sent to customers, with several supply deals to be announced soon.

Ascent Solar, Cambrios partner on U.S. Army contract to research transparent conductive PV films

Ascent Solar Technologies and Cambrios Technologies have joined forces as research partners to investigate how Cambrios' liquid, transparent conductive films can be applied to lightweight, flexible CIGS photovoltaics. The joint research is the topic of a recently awarded 12-month U.S. Army contract and marks the first time that Cambrios has publicly disclosed the nanomaterial's possible feasibility for use as a PV cell electrode.

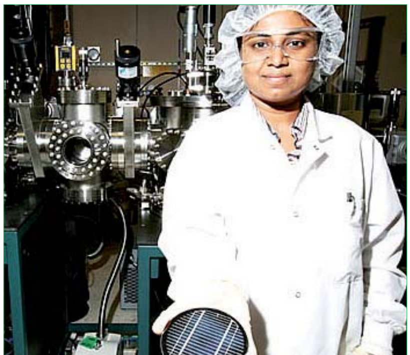
As part of the program, which will be undertaken on behalf of the U.S. Army Natick Soldier Research, Development and Engineering Center, Cambrios will deliver flexible solar cells that incorporate its ClearOhm electrode layer. Because of the material's improved transparency and light handling capability, the cells are expected to be 1-3% more efficient than the equivalent cells made with the conventional transparent electrode material, according to the company.

CIGS PV developer AQT scores US$10M in funding, signs equipment deal with Intevac

In a major step toward commercialization, CIGS thin-film photovoltaics developer Applied Quantum Technology has landed US$10 million in funding and also signed a production equipment deal with Intevac. The funds, which come from the company's original investors as well as some new backers, will be used to build out AQT's initial 15MW solar-cell production line in Silicon Valley and expand its staff. The new funding brings the total investment in the company to almost US$15 million.

The company said that the first Intevac processing system will be delivered to its new Silicon Valley development and manufacturing centre in the second quarter, in order to ramp production in time to fulfil current customer orders due by the end of 2010.

AQT seeks to leverage Intevac's manufacturing technologies and platforms that have been field-proven in the hard disk-drive industry. The company says that its technology allows for continuous in-line manufacturing, which simplifies and streamlines the CIGS manufacturing process, resulting in the highest projected capital utilization efficiency in the industry, while minimizing costs.



Applied Quantum Technology's CIGS process lab.

The CIGS company claims that its highly scalable architecture allows it to produce very-low-cost drop-in replacements for conventional crystalline-silicon cells. Intevac is also collaborating with another CIGS developer, XsunX, to develop that company's TFPV production scheme.

Production News Focus

Q-Cells highlights CIGS thin-film ramp

On the heels of the sale of its portion of Sovello and the insolvency of Sunfilm (another investment company), Q-Cells also announced that as part of its "ongoing focusing of the company's investment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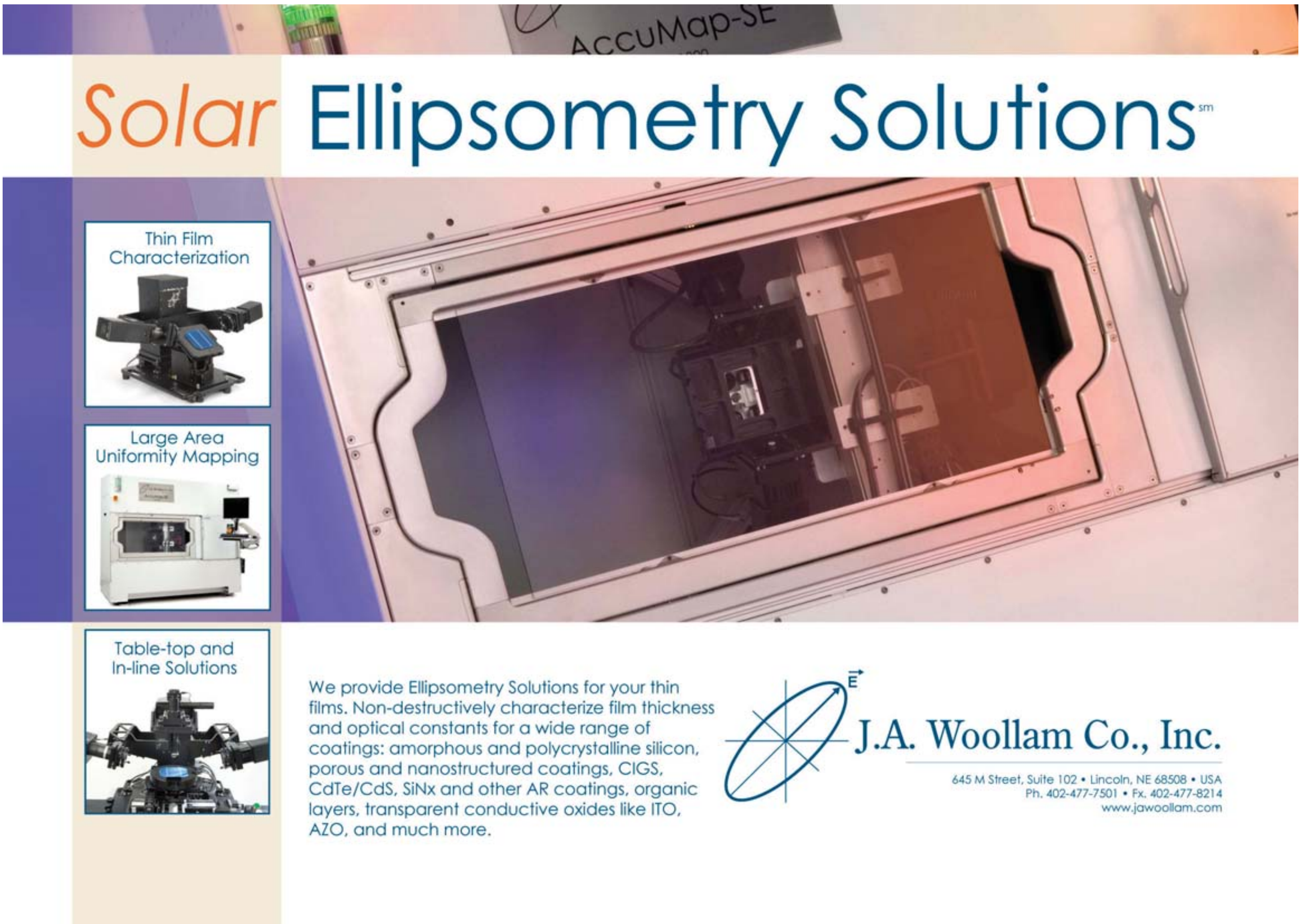
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portfolio," it was pulling the plug on its Calyxo (CdTe) and VHF Technologies/ Flexcell new technology companies, at least until new funding can be found.

Both units will be classified as "discontinued operations" as of Q1, and a total impairment of €36.8 million will be incurred, according to documents.

The company said that it continues to look for potential investors to keep the two units afloat, with the search for a financing partner for Calyxo (which has a remaining book value of €18 million) in the "due diligence phase." As a result of shutting down the pair of subsidiaries, 273 employees have been laid off, according to Q-Cells' full quarterly report.

The move leaves Solibro as the sole remaining operating company in Q-Cells' new technology segment. Additional information about the CIGS subsidiary revealed in the quarterly report notes that it did not sell all of the 8.8MW of modules that it produced in the first quarter, with Solibro garnering only €5.9 million in revenues for the quarter.

The unit has reportedly de-bottlenecked its first production line, and expects to ramp that facility from 15MW to its full 45MW capacity during the first half of the year, concurrent with the ongoing ramp of its second line to its full 90MW capacity by the end of 2010.

Inventux boosts tandem junction module efficiency to 9.2% as production reaches full capacity

Continually rising module efficiencies are finally making an impact in demand for Inventux Technologies tandem (a-Si/μc-Si) junction 'micromorph' thin-film modules, as the start-up says it is at full capacity in its 33MW plant near Berlin, Germany. Coupled to its professional sales network with direct customer access, Inventux says that it is producing a 132W module with 9.2%-plus stabilized efficiency, up from 8.9% in April 2009, and is currently sold out of modules during the winter months.

Inventux says that demand and order book have remained strong and expects a good year for sales. With the proposed feed-in tariff changes in Germany, Inventux is strengthening its international market in 2010 and expects further gains in conversion efficiencies.

Founded in 2007, the thin-film silicon producer is a customer of Oerlikon Solar's 'micromorph' technology and currently employs around 200 people.

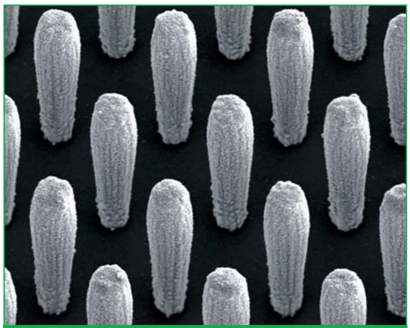
Ascent Solar begins initial production from its Fab 2 production plant in Colorado

Ascent Solar has successfully begun initial production of monolithically integrated flexible CIGS modules from its Fab 2 production plant located in Thornton, Colorado.

Farhad Moghadam, president and CEO of Ascent Solar, said, "Ascent Solar is the first company to commence regular production of monolithically integrated lightweight thin-film CIGS modules using a plastic substrate. This milestone marks the initiation of our regular production capability and our factory ramp-up based on market demand. Initial production from Fab 2 is producing 10.5% efficient modules with peak module aperture efficiency as high as 11.9%, which gives Ascent a very competitive product across our target market opportunities."

Bloo Solar selects CVD for 'Solar Brush' development

Startup company Bloo Solar has selected CVD Equipment Corp. (CVD) as its development and manufacturing partner for the advancement of its "Solar Brush" thin-film solar module range. The company has now began its nanoscale Solar Brush wafer development production run, which it plans to bring to market with initial commercial modules in 2012.



Bloo Solar's 'Solar Brush' technology consists of three-dimensional needle-like structures (nanocables) that are coated with ultrathin films.

Bloo Solar's Solar Brush features three-dimensional, single-junction architecture, which the company claims provides more surface area, light trapping, and minimum recombination to provide higher efficiency and a total power output up to three times higher than current technologies.

By selecting CVD as its partner, Bloo Solar will develop a key process for transparent conductive oxide (TCO) coating. CVD Equipment provides offline and online CVDgCoat APCVD for fluorine-doped SnO_2 (SnO_2:F) coating and offline LPCVD for ZnO coating.

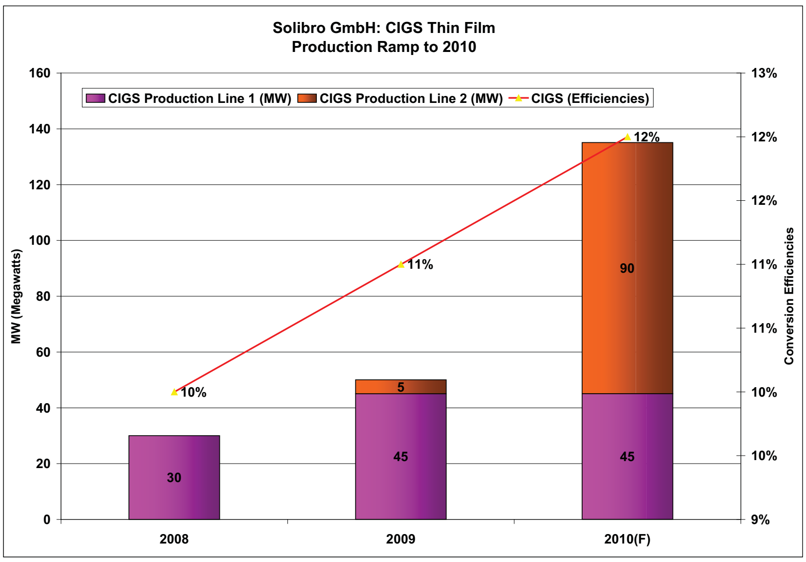
Solterra to deliver high volume production methods for its tetrapod quantum dots

Solterra Renewable Technologies, Quantum Materials' wholly owned subsidiary, has entered into a process development agreement with a consortium of advanced chemistry companies in the Netherlands, to validate high volume production methods for its proprietary tetrapod quantum dots. The agreement follows the MOU that Solterra, FutureChemistry and Flowid signed in 2009.

Dyesol and Singapore Aerospace Manufacturing sign MOU

Dyesol has signed a memorandum of understanding with Singapore Aerospace Manufacturing (SAM) for an alliance in the design, development, and building of an automated pilot manufacturing facility for DSC products. This MOU stems from the current relationship between Dyesol and LKT Industrial, a subsidiary of SAM, which manufactures a range of Dyesol test and process equipment under contract.

The two companies will design and cost a pilot manufacturing facility with an excess of 20,000m² in annual production capacity. They will also cultivate the business case and build the facility.



Solibro's CIGS thin-film production ramp (2008-2010).

MCP Group forms combined operations for thin-film metals production

MCP Group, a specialty chemicals producer of thin-film metals such as indium, gallium, selenium, and tellurium, is combining manufacturing operations into Atlumin Energy to streamline operations and meet growing demand, especially from the thin-film PV industry. Copy-exact processes at its U.K. operations in Wellingborough are to be expanded to its Sunnyvale, CA, facilities.

"The complementary synergies will substantially increase our business scale and expand our customer base," commented Laurent Raskin, CEO of MCP Group "This is another step in our strategy to compress the material supply chain and offer increased system level efficiency to our customers, thereby helping them to be more competitive."

Atlumin Energy's recycling and reprocessing plant.

Atlumin also offers advanced recycling and reclaim programs. Atlumin is headquartered in New Hartford, NY, and manufactures in Germany, the United Kingdom, and the United States.

NexPower to build 35MW a-Si thin-film PV module factory in Shandong, China

NexPower Energy plans to build a 35MWp amorphous silicon (a-Si) thin-film PV module plant in Shandong Province, China. The initial investment in the factory will be US$90 million, with construction of the facility set to commence in 2011.

The UMC solar subsidiary has been running at full capacity since the beginning of the year, with an estimated annual production of 60MWp. The Taiwanese company is said to expect yearly capacity to reach 100MWp by the end of 2010, with just under 50% of its capacity dedicated to micromorphous tandem-junction PV modules.

NexPower Energy's micromorphous tandem-junction PV module line.

NexPower's production lines are outfitted with three CVD and the company plans to add two more later this year, according to the news outlet.

NexPower is believed to have received orders to supply 70MWp of PV modules for three power plants in Shandong, with shipments to the sites starting in March 2010.

Thin-Film Business News Focus

Gartner highlights its 'Cool Vendor' solar start-ups

In its 'Cool Vendors in Solar Energy, 2010' report, Gartner highlights some of the solar energy start-ups to keep an eye on that it believes are developing technologies and innovations that will likely have a strong impact on the adoption of solar energy. Companies included in the review include, Applied Quantum Technology, BrightView Systems, Confluence Solar, Innovalight and Solexant.

Gartner noted that innovation remains strong in the PV industry, although venture funding is somewhat limited in comparison with two or three years ago.

A key hurdle for start-ups is to overcome the lack of project finance for solar installation projects as finance requirements have turned to the 'bankability' of projects, which dictate the use of previously used and known vendors and products.

According to the market research firm, vendors in the Cool Vendors report are developing innovations that have the potential to dramatically lower the cost of PV solar energy, if they can surmount the bankability barrier. This has become a key focus of start-ups since the collapse in average selling prices that occurred during 2009.

Pasan sells first sun simulator in Japan

Mitsubishi Chemical has selected and successfully installed a sun simulator from Pasan, a division of Meyer Berger. This is the first sale to a Japanese customer for the company, which will use the equipment for testing of very large a-Si thin-film solar modules and is part of MCC's move into the BIPV market. Pasan said that it had successfully commissioned the PV performance measurement equipment for MCC in its Yokkaichi plant in early January.

Jusung to supply US$138.8 million turnkey lines for a-Si and c-Si production

Chinese power generation company G Group has selected turnkey cell lines from Korea-based equipment supplier Jusung Engineering worth an initial US$138.8 million. Both thin-film a-Si equipment and c-Si equipment have been ordered, with deliveries scheduled for October 2010. Jusung said that it won the current contract after competitive bidding with other equipment suppliers from the U.S. and Europe.

Jusung's equipment and transparent conductive oxide (TCO) technology allow a "higher a-Si energy conversion rate (7.56% for single junction and 10.2% for tandem junction) and lower manufacturing costs than those of competitors," commented Chul-joo Hwang, CEO of Jusung Engineering.

MVS receives cluster tool system order from Tian Wei Solar Films

MVSystems (MVS) has received a cluster tool system order from Tian Wei Solar Films. The system will be used for development of solar cells using amorphous and nanocrystalline silicon materials.

MVS has recently installed cluster tools systems for the University of Toledo and the University of Stuttgart and for rigid substrates at Solar Energy Research Institute in Singapore. The company is also conducting R&D in Si thin-film solar cells and solar to hydrogen conversion using a-Si sponsored by the U.S. Department of Energy, National Science Foundation, and industry.

Phoenix Solar, MiaSolé sign four-year deal for 4.5MW of CIGS modules

Photovoltaic integrator Phoenix Solar and CIGS solar module manufacturer MiaSolé have signed a framework agreement that will run through 2013. The deal calls for MiaSolé to fulfill a Phoenix Solar order for an initial 4.5MW of CIGS thin-film PV panels in the second quarter, with the remaining shipment amounts to be determined.

Financial terms of the agreement were not disclosed.

The current wattage rating of the metre-square MiaSolé modules is 111W ±2W, with a conversion efficiency of 10.5%. A higher efficiency product will be shipped by the end of 2010, the company said.

The framework agreement also includes a recycling warranty where required by regulation or financing; at the end of the module's lifetime, the customer can choose to have them taken away by MiaSolé and recycled, or reconditioned.

Calyxo selects 5N Plus CdTe supply and recycling

Leveraging its refining facility in Germany (5N PV GmbH), which was established to meet the needs of First Solar's thin-film production facility in the country, 5N Plus has been selected by First Solar rival, Calyxo, to supply high-purity metals and compounds for its CdTe thin-film products. Calyxo is a subsidiary of Q-Cells. The agreement also includes long-term PV module and production scrap recycling services. 5N Plus also recently secured a similar deal with another CdTe thin-film start-up, Abound Solar.

Applied Materials 'SunFab' thin-film customer files for bankruptcy

Sunfilm, the a-Si thin-film producer, filed for insolvency on March 26 in the district court in Dresden, Germany. A merger in May 2009 with another thin-film start-up, Sontor, gave the company a combined capacity of 145MW and tandem-junction cells with 8% claimed efficiencies and a healthy position as a competitor for crystalline solar technologies. However, dominance from CdTe thin-film global leader, First Solar, has squeezed many thin-film producers through 2009 and into 2010.

Approximately 300 employees at Sunfilm's two manufacturing plants were on shorter working hours since late 2009. The merged company had approximately 400 workers when the merger was announced.

However, the insolvency is hoped to enable a new investor to take control and undertake a restructuring of the company to reduce debts and re-enter the market. Sunfilm was initially backed by Q-Cells, Good Energies, and Norsun.

The production line in Grossroehrsdorf, Germany, uses the SunFab thin-film technology from Applied Materials. The turnkey equipment supplier has recently acknowledged that its hopes for the technology have been revised, and it expects to downscale activities while continuing to work with existing customers on next-generation technologies and potential capacity ramps.

Signet Solar backs out of US$840m manufacturing centre, denied DOE funding

Signet Solar has backed out of its plans to build a US$840 million manufacturing centre in the city of Belen, New Mexico. The amorphous-silicon thin-film solar company was unable to keep its commitment, as it could not secure funding for the project from the U.S. Department of Energy (DOE).

Back in January, DOE rejected the company's loan guarantee that was to back 80% of the US$220 million of the initial funding for the four-part expansion of the plant.

Jim Wood, VP of Coast Range Investments, told Belen city councillors on April 5 that the company received word of the withdrawal from Signet officials March 30, almost three months after DOE rejected the loan guarantee, according to news reports.

Masdar PV sacks both CEO and COO

In another sign of the difficult market conditions facing a-Si thin-film module manufacturers, Masdar PV has sacked both Rainer Gegenwart (left) and Joachim Nell (right) from their roles as CEO and COO/CMO, respectively. Michael Alexander will head Masdar PV in the interim. Masdar PV is a customer of Applied Materials turnkey thin-film technology and equipment under its 'SunFab' product line.

Many a-Si firms are now in a difficult position in which they cannot ramp to reduce the cost per watt. Demand is extremely low for this technology, and expected higher conversion efficiencies from tandem junction cells may not be competitive with First Solar's 11% efficiencies to spark demand and enable economies of scale to help reduce costs.

Former Masdar PV executives Rainer Gegenwart (left) and Joachim Nell (right).

Testing and Certification News Focus

Spire introduces new solar simulator

Spire has announced its new 6m × 1.3m solar simulator, the 6013, which was developed off of the company's Single Long Pulse series. The first unit will be delivered to SoloPower in San Jose, California for use in CIGS modules.

Spire's 6013 are for modules up to 6 metres in length and 1.3 metres wide for a Class A solar spectrum and uniformity of ±2%. The module has an adjustable pulse length of 20–80 milliseconds and an adjustable intensity range of 200–100W/m².

Applied Materials' SunFab line modules first to meet UL master certification program requirements

Applied Materials SunFab thin-film modules have become the first to qualify for Underwriters Laboratories' Master Certification Program for the solar industry. The program, which was introduced in 2009, is an enhanced service offering with streamlined testing and certification procedures intended to help PV module and production equipment manufacturers get products to market faster.

With this qualification, all Applied Materials customers who produce modules on a SunFab production line qualify for UL's Fast Track Certification Program.

Oerlikon Solar receives UL, TÜV Rheinland IEC certifications for thin-film modules

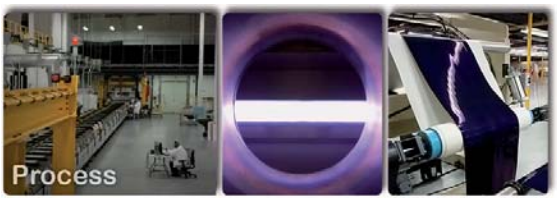
Oerlikon Solar has received an Underwriters Laboratories Master Certificate for solar PV, and an expanded TÜV Rheinland IEC certification for a new 130Wp highly efficient module design. Oerlikon Solar's recent research and development efforts have been focused on lowering its module manufacturing cost of thin-film silicon PV below US$0.70 per watt by the end of 2010.

Xunlight garners UL certification for flexible silicon thin-film PV modules

Thin-film photovoltaics firm Xunlight has received certification for its flexible, lightweight modules under the ANSI/UL 1703 standard for North American markets. The company says the certification applies to its XR-series of flexible photovoltaic rooftop modules for a range of power outputs up to 264W per panel, making Xunlight one of a handful of companies that have had their flexible PV panels certified.

ETL certification was granted following rigorous testing by Intertek, an independent product safety certification organization. ANSI/UL 1703 represents the standard for safety flat-plate photovoltaic modules and panels.

The certified modules incorporate Xunlight's triple-junction, amorphous-silicon thin-film solar cells produced using the company's high-speed, wide-web, roll-to-roll PECVD-based 25MW PV manufacturing line at its 122,0000-sq-ft production facility in Toledo, OH.



Xunlight utilizes its proprietary high-speed, low-cost roll-to-roll manufacturing process.

Product Briefings

Hüttinger

Continuous direct current power supply from Hüttinger enables homogenous layers

Product Briefing Outline: Hüttinger is launching a new generation of continuous direct current power supplies called the TruPlasma DC Series 3000 NEW. Available with outputs of 20 to 160 kilowatts, these generators deliver reliable, accurate power over a broad impedance range and are best suited for coating processes in solar cell manufacturing or in coating architectural glass, where stability and continuous throughput are essential. These new power suppliers have very fast response times with minimal residual arc energy.

Problem: To obtain a reliable, high-efficiency thin-film solar cell, good uniformity of the deposited layers and the need for the layer to be defect-free is crucial. Defects such as particles and splashes are created inside the plasma when an unwanted local discharge – a so-called arc – occurs. This arc can be eliminated by switching off the power supply. The faster this is done, and the less energy that is delivered into the arc, the smaller and more insignificant the defect creation will be; thus good arc management is very important to attain high-quality solar cell coatings.

Solution: Hüttinger has improved the arc management system so that in an arc event, the new 'CompensateLine' better compensates the energy stored in the output circuits of the power supply and cables connecting power supply and cathode. Consequently, the system features very fast response times and minimal residual arc energy. In addition, CompensateLine ensures that the arc energy is not dissipated. Instead, the energy is recirculated to the power supply and into the process. As a result, the generator is more energy efficient than air-cooled power supplies while also emitting less heat, considerably reducing the risk of overheating.

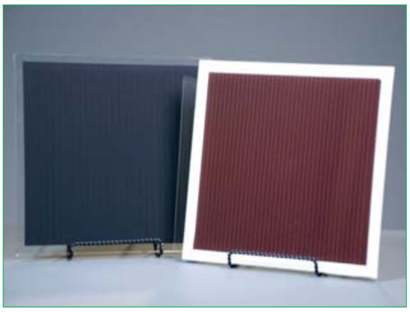
Applications: Wide range of sputtering material applications including TCO sputtering.

Platform: TruPlasma DC Series 3000 NEW has an output voltage of 1000 volts. Utilizing state-of-art, switch-mode power conversion technology, the generators operate at high efficiency resulting in less heat dissipation and lower operation costs. Due to their small size and air cooling, these generators can be easily integrated into new or existing systems.

Availability: Currently available.

Product Briefings

Saflex & Oerlikon Solar



Saflex & Oerlikon Solar present ultra-thin reflective solar encapsulant

Product Briefing Outline: Saflex, a business unit of Solutia, has launched the Saflex Radiant White PA27 encapsulant, which was developed in collaboration with Oerlikon Solar to improve conversion efficiencies of its tandem junction 'micromorph' thin-film module technology. Saflex PA27 is manufactured to an ultra-thin thickness of 0.51mm compared to standard PVB encapsulants and is the first ultra-thin reflective PVB encapsulant available for use in the solar market.

Problem: Traditionally, the role of encapsulants is to ensure long-term durability and performance of solar panels by protecting critical electrical components from rain, heat, and humidity. Currently, most solar modules utilize a reflective metallic stack or reflective white coat to redirect light back through the film for improved energy conversion, but adding to the process steps and manufacturing costs.

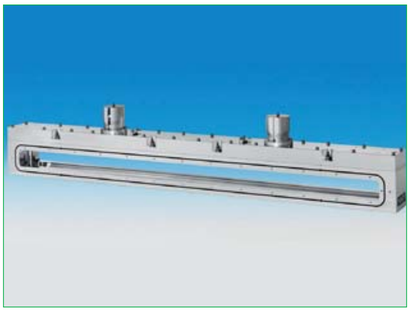
Solution: Saflex PA27 is manufactured to an ultra-thin thickness of 0.51mm compared to standard encapsulants, which typically range from 0.76mm to 1.14mm in thickness, representing a material reduction of 33% to 55%, respectively. It incorporates the reflective benefits provided by more traditional reflective material layers into the encapsulant, giving module manufacturers a cost-effective solution for increasing solar panel efficiency and simplifying the manufacturing process. Saflex PA27 also has improved electrical insulation with a two-order-of-magnitude increase in bulk resistivity. This equates to significant improvements in the wet insulation resistance of the module, resulting in a reduction in current losses to ground and an increase in the power collected from each module.

Applications: Thin-film modules.

Platform: Saflex PA27 is based on proven 3G PVB chemistry, which was first introduced in 1997. Test results confirm Saflex 3G PVB to be less moisture-sensitive, which enables high adhesion especially at the edges, even as environmental conditions, including humidity, fluctuate. PA27 is RoHS approved, with both IEC certification and UL testing pending.

Availability: Currently available.

VAT



'FlapVAT' large transfer valve increases flexibility in equipment design

Product Briefing Outline: VAT has launched a new transfer valve, the 'FlapVAT' that extends its product portfolio in the 'large transfer valve' series. The new product offers vacuum equipment manufacturers the ability to achieve what it claims is the best price/performance ratio available. VAT now has three large transfer valves in the portfolio for the PV industry, each of which can be customized in various ways to match each individual manufacturer's requirements.

Problem: Equipment suppliers working in the photovoltaic industry are facing continuous cost pressures from end users. Simultaneously the production throughput, yield and uptime have to be improved to reduce the manufacturing cost per watt, which requires high performance transfer valves at the lowest cost possible.

Solution: The FlapVAT is designed for vacuum production tools with slit heights smaller than 80mm. The valve technology is based on the common flapper valve that enables a swift exchange of the gate O-Ring and the integrated actuator allows for differential pressure opening wherever this is required. Depending on temperatures and outer conditions, the actuator can be placed on top or at the sides of the valve. Stainless steel or aluminium body and gate and horizontal or vertical orientation are other standard options that are available in this product range.

Applications: Transfer valves are used as gates to separate vacuum chambers and are suitable for various processes such as PVD or PECVD.

Platform: The FlapVAT is available from slit openings 30 x 500mm up to 80 x 3000mm with a flange to flange dimension of 160mm. It can be used in door, valve or insert configurations.

Availability: Currently available.

Bystronic Glass

Bystronic glass offers efficient buffering, storing and sorting of thin-film substrates

Product Briefing Outline: Bystronic glass has introduced sorting systems for buffer operation or for use as a direct connection to a production line for thin-film solar modules. Thin-film producers obtain modular configurable solutions designed for front-end operations for de-coupling the different production processes from each other as well as at the back-end for sorting the ready-made modules prior to packaging.

Problem: In order to sort ready-made photovoltaic modules according to quality, performance classes, physical sizes or other features, a sorting operation is required.

Solution: Depending on size and composition, the substrates are stored either vertically, at an angle of 6°, or horizontally. Loading and unloading is carried out by means of conveyors, sorting carriages or robots. The fixed storage systems or cartridges have more than 120 positions, which can be managed in a high-bay warehouse. In order to sort ready-made photovoltaic modules according to quality, performance classes, physical sizes or other features, a sorting operation is required. After leaving production in the sequence of manufacture, the modules are temporarily stored and then removed at the appropriate time according to the sorting criteria provided by Bystronic's solution. It is possible to integrate a number of inspection processes in advance – i.e. at the end of the production process and prior to storage and/or sorting.

Applications: The buffer and storage system is suitable for the storage of both substrates as well as ready-made modules with back rails and junction box. Applicable to all conventional glass sizes up to 2.20 x 2.60m.

Platform: The buffer and storage system and the sorting system all feature solid design, high positioning accuracy and gentle handling of substrates and/or modules. The systems are also equipped with their own control system for seamless object tracking, including interfaces to the different processes and the MES (manufacturing execution system).

Availability: Currently available.

Blythe spirit: Where First Solar's thin-film PV turns desert sun into grid-friendly juice

By **Tom Cheyney**

Photos by Tom Cheyney.

The road turns from rough pavement to graded dirt about a mile or so to the south of Interstate 10, just past the unincorporated community of Mesa Verde west of Blythe in southeastern California. Following 15th Street's dusty grade beyond a funky residential neighborhood out into a mix of desert and agricultural lands, you soon come upon a large fenced-off area to the south that stretches for acres and acres. Inside the double-fence line is the Blythe solar project, the reigning (for now) largest thin-film photovoltaic power plant in the U.S. — and a harbinger of much bigger things to come.

First Solar's engineering/procurement/construction arm developed and built the 21MW (AC) system in the latter part of 2009. The project started in early September, with clearing, grubbing, grading, and other preparing of the fallow 200-acre site over the course of a month, and the first of 47,000 posts (a little under a million kilos of steel) being jabbed into the desert floor in a 45-day stretch from mid-September to early November.

Once a few thousand posts had been driven into the dry, hard ground, the first of 47,000 tilt brackets (another million kilos plus of metal) started to be placed in late September/early October, a job that was completed in 38 days. Workers started installing the module support rails, horizontal beams, and other 'table' components during the same timeframe and also completed that work in 38 days.

As the completed arrays started to sprout from the desert floor in early October, it was module time: 351,000 cadmium-telluride FS-275 panels, representing some 68 acres of glass weighing close to 2 million metric tons, were mounted three-high, clipped, and plugged in.

While the metal and glass were being put in place, other teams laid the cable: 127 miles of copper DC cable in 44,000 feet of trenches and 54 tons of HV AC cable in 18,000 feet of trenches — in 35 days.

Breaking it down from start to finish, including the seven weeks of engineering and 15 weeks of construction, the on-the-ground project velocity came in at about a megawatt per day. Not bad for 140,000 man-hours of work.

NRG Energy bought the site Nov. 24, and the sun juice officially began flowing into Southern California Edison's portion of the grid Dec. 18, under the terms of a 20-year power purchase agreement. As part of the deal, First Solar has a long-term arrangement with NRG to handle the operations and maintenance chores at the plant.

But don't expect to find a large team of operators and maintainers at the Blythe site. A trailer houses the onsite team, led by First Solar's plant supervisor, Allen Krawcheck. Actually, the power generation industry veteran who used to build nuclear plants is the only member of the solar company's onsite team there on a daily basis.

Krawcheck was my tour guide in early April when I came to check out the massive PV installation on my drive back from Phoenix. The weather was mild and warm that day, with a thin layer of high clouds mingled with the vast desert sky blue. When not driving or walking among the ground-mounted arrays of thin, black cadmium-telluride panels, he spends his time at work in the air-conditioned trailer that houses the command center for the operation.

We drove out to the southeast corner of the 200-acre site, where the view – with one of the many stark mountain ranges as backdrop – was spectacular. Looking out over the 350,000-odd modules, tilting three-deep on their tables at 25 degrees toward the south, the layout of the solar farm became more apparent.

Divided into 21 arrays of 1MW (AC) each (or 1.2MW [DC]), which are then subdivided into four 250kW blocks, each megawatt array includes sturdy, shack-like structures known as power conversion stations (PCS), each of which houses a pair of 500kW Siemens inverters inside its thoroughly HVACed confines.

Nestled next to each numbered PCS is a 1MW, 34.5kV transformer that sends the array's juice back through one of four feeder lines to the main combining switchgear. If you know where to look, you can find eight DC combiner boxes interspersed among the racks and mounts in each 1MW plot.

If one were to go back and forth along each row of modules around the entire project, Krawcheck estimates the distance at 95 miles — a road trip he will soon have to make as the time approaches for the annual, personal inspection of each and every module in the yard. So far, he explained, six or seven modules have had to be replaced, and he expects that number to rise by another half-dozen or so once he completes his inspection.

Like every First Solar module, the Blythe panels can each be tracked back to the specific production runs that birthed them, in case the FA work calls for a root-cause analysis of what might have gone off-spec in the manufacturing process (a rare occurrence in the company's high-yielding fabs).

He couldn't be sure whether the problems with the panels occurred as a result of construction or quality issues, although the inspection after next may reveal more clarity on the range of failure mechanisms at work. But a failure rate of 0.0034%, or one module out of every 29,166 (calculated assuming a dozen failed modules out of 350,000), is not likely to raise any red flags.

Tucked inside the control trailer are sets of computer monitors filled with displays of the site monitoring system. The set-up can 'see' how well each and every part of the plant is performing in real time, setting off alarms if there's a module string outage or something else creeping outside normal parameters. There are also data streaming from the two meteorological stations positioned in the solar field and measurements coming from an instrumented module positioned near PCS 5.

At the end of our tour through the arrays, Krawcheck let me have a real-time peek at how the plant was performing. Pretty darn well, as it turned out.

The power output actually registered 21.93MW and had reached 22MW earlier in the day — an amount that the site super has seen go as high as 23MW during the first few months of operation. That amount converted to an average of 1204W/m^2 among the 250,000m^2 of

PV glass, well above the 1000W rating. A glance at the inverter performance monitors revealed many of them working in classic overachieving form — at 110%.

Krawchuck thinks that the plant should perform at its peak in May, when the longer days bring more sun to bear but the temperatures will not have risen to the torrid summertime levels associated with the U.S. southwest.

One of my companions on the power plant tour, First Solar's director of investor relations, Pamela Hegerty, told me that the company has a new network operations center (as in "don't NOC it") at its Tempe, AZ, headquarters. The center's technicians monitor not only what's going on at Blythe, but also at two other plants where the company has O&M responsibilities: Sarnia 1 in Ontario and El Dorado in Nevada.

By year's end, she noted that they will also have their eyes on the second of two Sarnias (at a combined 80MW, the duo will become the largest North American PV plant of any kind) and 48MW of additional CdTe panels that will come online in Boulder City, NV, adjacent to the existing 10MW facility.

Krawcheck, who was a supervisor at the Indian Point nuke plant in Westchester County, NY, really loves the peace and quiet of the solar farm, marveling at how what once was abandoned agricultural land became a working solar power plant within a matter of months. Other than the mild racket kicked up by the inverters and support gear in the PCS huts, there are, as he put it, "no moving parts" — something not to be discounted in an area where gale-force winds can kick up a hellacious amount of desert sand. Inadvertently waxing PV poetic, he recounted how each morning, as soon as the sun pokes over the mountains, he hears the inverters start to wake up.

Apart from the romanticized notions of solar power elicited by a visit to a site as serenely impressive as the Blythe plant, a detour on my drive from Phoenix reminded me just how far solar has to go to be truly considered "utility scale" on a magnitude with other, more conventional forms of energy generation.

Some 45 miles west of central Phoenix, several miles to the south of the interstate near Wintersburg, AZ, sits the Palo Verde nuclear generating station, the largest power plant of its kind in the United States. Its three independent reactors can generate a total of approximately 3.7GW of electricity, some of which (15.8%) is fed to Blythe's customer, SoCal Edison.

Construction of Palo Verde took well over a decade in the 1970s and '80s, a velocity equivalent to hundreds of megawatts per year — something well within reach of a company like First Solar that has proven it can install a meg a day and has made huge strides in increasing its own construction speed. Permitting and other red-tinged paperwork takes up an annoyingly inordinate amount of the project development timeline (it was 103 weeks in the case of Blythe and who knows how long in the case of any new nuke plant).

The size of Blythe may pale in comparison to Palo Verde, yet it's not hard to imagine the scalability — and bankability — of future PV power projects that can be engineered and built much faster than the speed of nuke. Within a few years, the first triple-digit megawatt solar PV farms will come online, and with them, the true promise of solar utilities may start to live up to the hype.

This feature is a revised version of a blog that originally appeared on PV-Tech.org

Forecast for thin-film PV equipment market calls for sustainable growth

John West, VLSI Research, Bedford, UK

ABSTRACT

The demand for equipment used to manufacture solar photovoltaic solar cells and modules has grown at an explosive rate over the past five years, and the fastest-growing segment has been for systems used to manufacture thin-film cells and modules. In 2009, demand for this type of equipment reached US$1.9 billion, up from US$0.1 billion in 2004, representing an astonishing 80% compound annual growth rate over the period. However, as with the rest of the industry, 2009 saw sales flattened and the business model change from one of rapid growth to that of sustainability. The result of this transition has been some consolidation, with several major equipment vendors strengthening their position through acquisitions. The outlook for 2010 calls for sales of thin-film production equipment to recover and continue growing at a compound annual growth rate of around 15% over the next five years (see Fig. 1).

Thin-film PV manufacturing can be broken down into two major sectors: silicon thin film on glass and non-silicon thin film on glass. Each of these segments has evolved very differently, and two distinct market landscapes have emerged.

Silicon thin film on glass

The key process technologies for producing Si TF-on-glass solar cells and modules are directly derived from semiconductor and flat-panel-display manufacturing, so it is not surprising that the equipment market is dominated by vendors with strong positions in these industries. Indeed, tool suppliers were quick to identify the opportunity to expand into the solar market and did most of the development work in providing manufacturing solutions. The outcome of these efforts resulted in the equipment manufacturers possessing much of the process technology for Si TF, so it was only natural for them to provide complete manufacturing packages. The overwhelming majority of the market for Si TF equipment is supplied as part of a turnkey solution, and this indicates just how much process technology is held by the tool companies.

The three main players in the turnkey space are Applied Materials, Oerlikon Solar, and Ulvac. Since these companies have their origins in vacuum-based thin-film deposition, they have had to buy companies or partner with others to offer a complete production line. Because of this factor, only around half the value of the equipment in these turnkey systems is provided by the supplier of the complete line, while the remainder is provided by third-party equipment manufacturers.

In addition, because the recognition of revenue on these turnkey lines depends on reaching predetermined targets, there can be a long time-lag between shipping tools and getting paid for those tools – which makes it a very difficult market to measure.

However, in 2009, new orders for Si TF manufacturing equipment reached US$900 million, but revenues received exceeded US$1.5 billion as companies worked through their backlog from the previous year. Looking at this from the perspective of the turnkey market, new orders during the year were only US$300 million while revenues recognized on turnkey lines were around US$1.4 billion. It is also worth noting that although revenues for silicon TF turnkey lines were up 50% in 2009, orders fell by 75%, making it a truly unusual year.

The evolution of this market as a mainly turnkey business raises questions about the long-term development of the sector. Successful businesses are typically those that are able to differentiate their product, raise barriers to entry, and lower costs. Si TF cell/module manufacturers that have established their manufacturing capability on the back of turnkey suppliers fail to meet any of these criteria, so the question is, why would they choose this option? The answer is simple: because at the time they made the decision it did not matter, since the PV market was growing rapidly and the most urgent needs were to invest money quickly and get into production as soon as possible.

As the market starts to show signs of stability, big questions about this business model have to be addressed: how do two different companies with the same turnkey solutions compete against each other, and how do groups of companies using the same tool set and process technology compete against companies using rival turnkey solutions?

So far it is not clear how two different companies running the same turnkey lines can compete against each other, since both companies are locked into the same equipment vendor's tool set and process technology. Over time, this issue may be resolved as the Si TFPV manufacturers develop their own process technology, but the most pressing problem appears to be how to compete against rival turnkey solutions and alternative technologies.

Non-silicon thin film on glass (CdTe, CIGS)

In contrast to the Si TF-on-glass equipment market, most of the process technology in the CdTe and CIGS thin-film PV sectors remains in the hands of the cell and module manufacturers, giving the equipment market a very different structure. In particular, manufacturers have their own processes so they have been instrumental in developing their own process equipment. Many have the production tools made to their own specifications, and equipment vendors are simply "building to print." This arrangement results in a more fragmented equipment market and, until recently, turnkey solutions from equipment vendors have not been available.

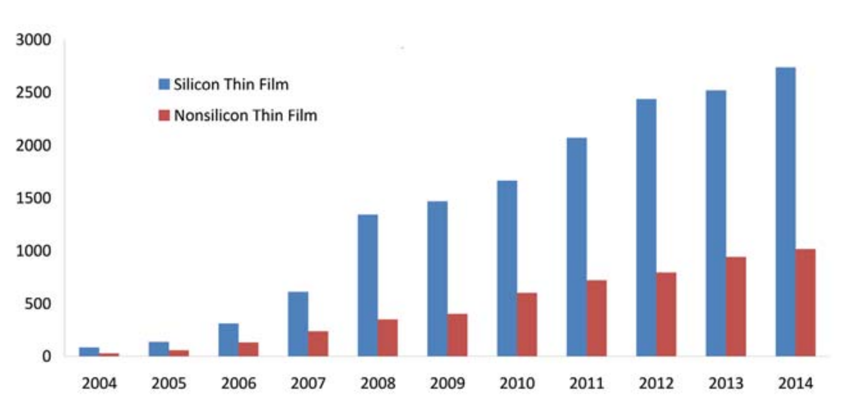


Figure 1. Historical and forecasted sales of thin-film photovoltaic production equipment, 2004-2014.

The industry is dominated by one cell/module manufacturer, First Solar. This company has perfected the CdTe manufacturing process, and it now accounts for around two-thirds of TFPV manufacturing capacity. The implication for the equipment market is that there will continue to be a large captive element until other cell/module manufacturers, which source their equipment from the merchant market, gain traction.

The equipment market is characterized by many small players and a handful of larger players, with Von Ardenne being the main supplier. Sales of equipment for nonsilicon TF manufacturing are difficult to measure because of the captive element provided by machine shops and contract manufacturers, but sales of tools from recognized equipment vendors exceeded US$400 million in 2009. The market for turnkey solutions finally got under way, with sales of around US$200 million made during the year. This is significant because the main barrier to entry for this market is technical, and if viable turnkey solutions are available, this could open up the market to other cell/module manufacturers.

Flexible substrates

While the market for equipment used to process a-Si and CIGS solar cells/modules on flexible substrates is currently very small – around a few tens of millions of dollars in 2009 – it is worth a mention since this technology has the potential to stimulate huge demand in the future. In this sector the equipment suppliers and cell/module manufacturers have been working closely together to solve manufacturing problems and reliability issues inherent in roll-to-roll/flexible web processing, with neither party being dominant. This partnership is clearly working, as commercially viable cells/modules are on the market, and ECD Uni-Solar, the biggest supplier of flexible modules with its triple-junction a-Si laminates, has established itself as one of the leaders in the thin-film sector.

However, to put things into perspective, Uni-Solar is still dwarfed by First Solar. Of the tool suppliers, CIGS systems vendor Veeco looks set to be the main beneficiary, since the market for equipment in 2010 – based on orders already placed – is expected to at least triple.

Conclusion

There are two very different market structures for silicon TF and non-silicon TF cell/module manufacturing equipment. The defining feature of the Si TF-on-glass equipment market is that it has grown as the result of a push from the tool vendors rather than a pull from cell/module manufacturers. As a consequence of this, the main battle is being fought among the major equipment vendors rather than the cell/module manufacturers. By contrast, the non-silicon TF equipment market is dominated by one cell/module producer. The competition is among cell/module manufacturers and until other cell/module manufacturers can gain market share from First Solar, there will continue to be a large captive element to the equipment market. Overall, because there is greater scope to reduce manufacturing costs and improve cell/module efficiencies, the market for thin-film PV manufacturing equipment is predicted to grow faster than the market as a whole.

About the Author

John West is the managing director of VLSI Research Europe, a firm focused on market research and economic analysis of technical, business, and economic aspects within the photovoltaic, semiconductor, nanotechnology, and related industries. He has been analyzing the PV capital equipment market since 2006.

Enquiries

Tel: +44 1234 834 662
Email: johnwest@vlsiresearch.com

Applied knowledge management for complex and dynamic factory planning

Martin Kasperczyk, Oerlikon Solar AG, Trübbach, Switzerland; **Fabian Böttinger**, **Marcus Michen** & **Roland Wertz**, Fraunhofer IPA, Stuttgart, Germany

ABSTRACT

This paper describes the functionality, applicability, and the development of dependency maps which are the basis for standardized information exchange between responsible parties during the fab design process. Examples and experiences are related to the solar industry; however this generic approach may be applied to a wide range of different industry sectors with similar challenges. The aim is to provide a guideline for realizing a fab design of dynamic and complex production systems. Its main benefit is a higher degree of transparency regarding dependencies within the production system, which results in a reduction of risk for incorrect planning. In addition, it enables the factory designer to execute the fab planning process and further continuous improvements for achieving respective targets.

Introduction

A production system typically comprises objects such as production equipment, buffers, operators, infrastructure or production control software. These objects, which play a major role in the fab design process, are referred to as 'Fab Planning Objects' (FPOs) in this document.

Due to the dependencies that exist within production systems, changing attributes or requirements of single FPOs directly affect other FPOs. This is especially true in the planning phase where changes resulting in additional complexity are a frequent occurrence.

Suppliers of end-to-end factories are faced with this complexity in particular, as they are involved in planning multiple lines simultaneously. Moreover, the variation in planning and implementation phases as well as the different releases of single equipment increases the complexity of the whole planning process.

In addition to that, great effort is required to coordinate the high number of responsible parties arising from the large number of objects existing in complex production systems. If there is no structured and standardized process for information exchange between the affected persons in charge, the organization can barely keep pace with the changes that so frequently occur. The result could be a high risk of information loss and a wasted use of human resources. The opportunity to react rapidly and reliably to changing conditions becomes limited.

Generic planning processes are described in guidelines such as VDI 5200 for "Factory planning – Planning procedure" [1]. More than this, however, an information management system is necessary to identify changes in production systems and to find suitable solutions quickly. Such a solution enables persons who are responsible for FPOs to (re-)act efficiently in changing conditions. The FPOs are structured in a hierarchical way, such that one FPO may consist of several underlying FPOs up to the topmost entity that represents the whole fab. Depending on the vertical level in the FPO structure, the basis for decision-making may differ.

Functionality of the dependency map

Fab planning objects

To assess the functionality of a production system it is necessary to divide it into its integral parts [2], hereafter referred to as FPOs. These include all those units that have to be considered during the fab design process and which are the responsibility of the Fab Planning Department, such as:

- Production equipment
- Operators
- Transport routes
- Handling equipment
- Production control software
- Facilities, like power supply
- Environment, health and safety.

There also exist a range of objects that are not the liability of the Fab Planning Department. However, they also have to be integrated into the planning procedure. Among these, the product design, production process, and process-related requirements shall be mentioned.

Elements of the fab planning objects' interface

Every FPO is engineered, designed, or at least represented according to its quantity in the fab. The actual configuration is based on the properties of the preceding objects. Based on the configuration, each FPO owns special properties that are fundamental to the planning of subsequent objects.

Therefore, almost all objects have requirements regarding previous FPOs. In addition, FPOs have their own properties which reflect the required set of information as well as the obligation of forwarding the information in the case of change. These two aspects, 'requirements' and 'properties' respectively, compose the two interfaces of each single FPO.

> "Such a solution enables persons who are responsible for FPOs to (re-)act efficiently in changing conditions."

1. Requirements interface of the Fab Planning Objects

The most important part of this interface is the list of the requirements for preceding FPOs. The person responsible defines requirements for its FPO and places a request to the person in charge of the previous FPO to be aware of relevant changes. In cases where the properties of the previous object are changed, the person that placed the request will be informed. 'Relevant' changes are basically those that require confirmation or lead to re-evaluations or further actions.

It is in the nature of things that successive FPOs will have to decide on changes and for others to assume such changes. Therefore, it is enough to inform the person in charge. In some cases, the changes may be considered as being of minor importance and for this reason the responsible person doesn't have to be informed at all. The decision to contact the relevant party lies with the person responsible for the FPO that places the request. It is up to him/her to establish the criteria and the bandwidth for defining

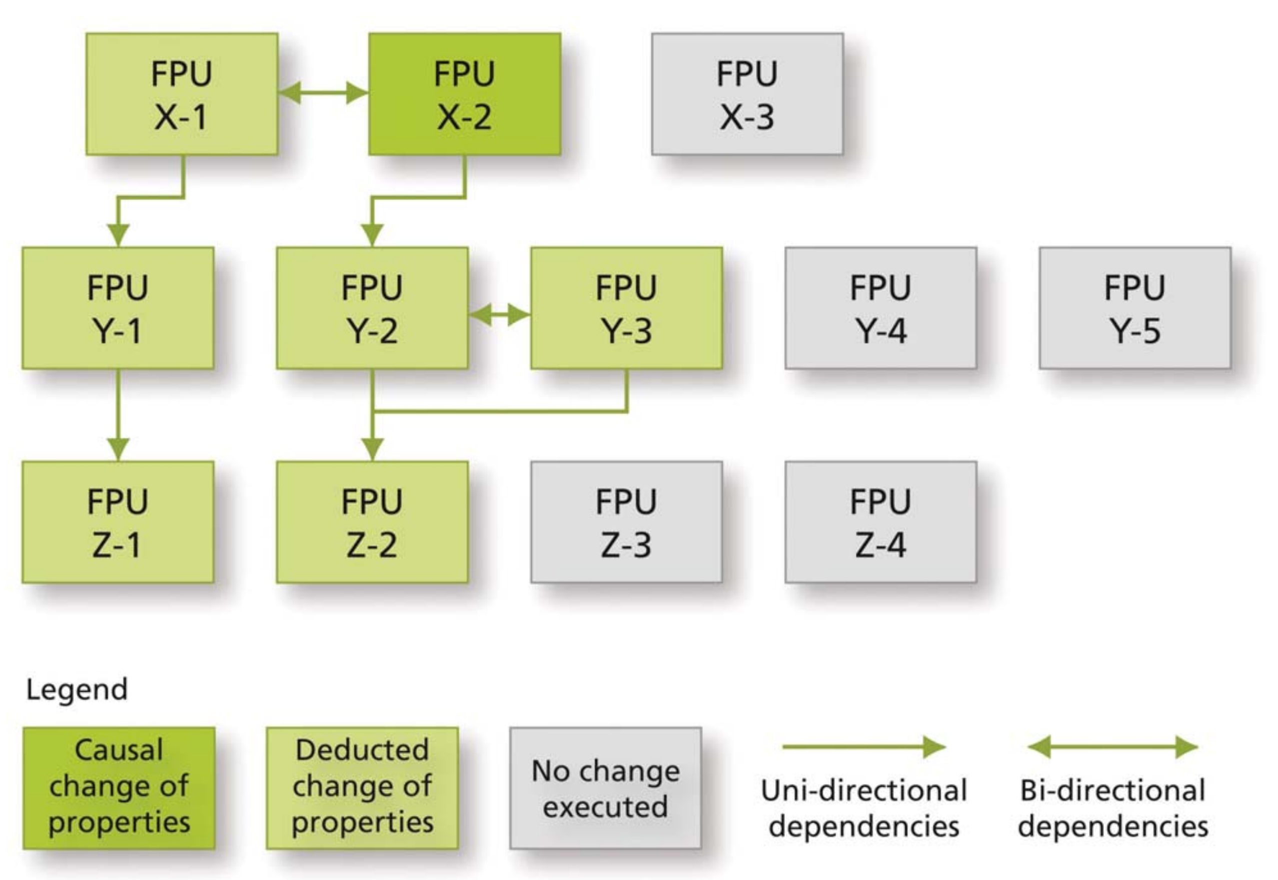


Figure 1. Generic dependency diagram of Fab Planning Objects.

the following categories that classify the changes to the previous object:

"*To-be-confirmed (FPO/TBC)*": Confirmation of the person in charge required. (In the case of measurements which demand the adaption, the confirmation is no longer needed and will be replaced by the highlighting of its relevance if the change meets the criteria of this category.)

"*Information (FPO/I)*": The person responsible for the precedent object may assume that the adjustment will be confirmed. The person in charge of the downstream object will be informed about the corresponding change.

"*No-action (FPO/NA)*": No information will be communicated.

A representative requirement could look like the following:

Process capacity exceeds 20 pieces per minute → category: *To-be-confirmed*

Process capacity ranges from 15 to 20 pieces per minute → category: *Information*

Process capacity is beneath 15 pieces per minute → category: *No-action.*

The requirements and the corresponding categories and bandwidths should not only reflect the normal case but also special lots such as worst case-/ breakdown-/ rescue-/ and other scenarios which generally require exceptional handling.

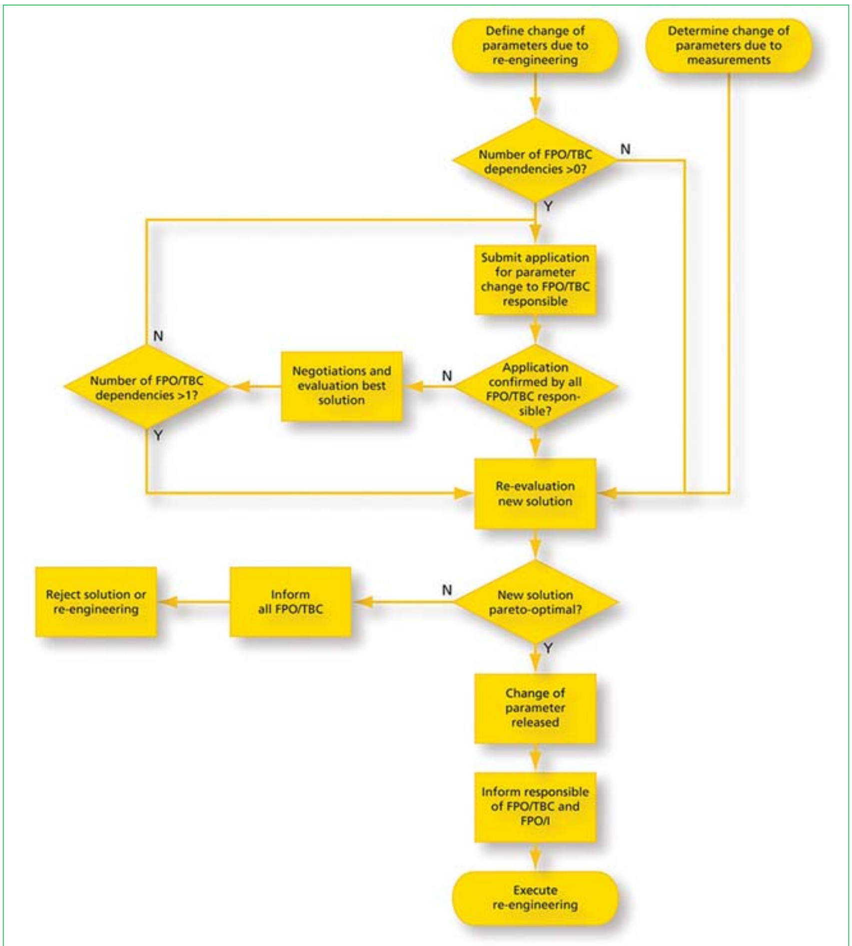


Figure 2. Simplified process flow diagram for uni-directional dependencies of Fab Planning Objects.

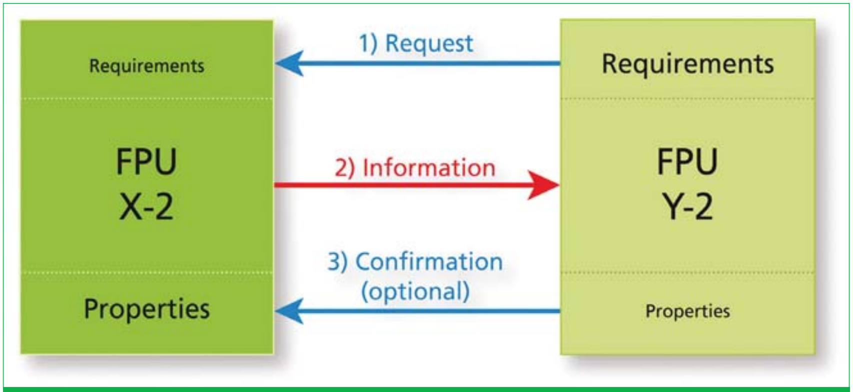


Figure 3. Interfaces of Fab Planning Objects.

The 'requirements' interface should also contain information about the respective person in charge and should provide a possibility to add further comments to the change request.

2. Properties of the Fab Planning Objects

In accordance with the requirements of a FPO, the overview of single properties is a core part of this interface. Such information, for example, can refer to the properties of mechanical handling, the process time, the temperature of the material after finishing the process, the process flow to produce the product or the maintenance rate. In general, the interface describes the FPO and all properties that are of importance to the succeeding object.

It is therefore mandatory to have links to successive objects. These links, controlled by the categorization of the related change, highlights the obligation to forward the information to the person responsible for the objects according to the dependency map. The necessity of stating the particular person in charge and the flexibility of attaching comments remain the same.

Specification of the dependency map

Caused by the dependencies of the FPOs there is a steady need to re-evaluate and adjust all succeeding FPOs which meet the corresponding criteria.

By using the functionalities of the dependency map it is possible to quickly communicate these changes to the person in charge and to enable him to adapt himself to the new situation. In exceptional cases there might also exist regressions and interdependencies among objects at various levels. However, most of the dependencies have been proven to be hierarchical.

Depending on which object is changed, the result could have a significant influence on multiple succeeding objects. A change in a solar module design, for example, could have an influence on process recipes. This might affect the amount of required production equipment, handling devices or ID-readers, which, in turn, cause alterations in the fab infrastructure. The requisite supply of electricity is one such example.

In other cases, changes to an FPO might have little or no influence on dependent FPOs. Altering the setup of an ID-reader, for example, does not change the overall required power supply of the fab. The question therefore is how to decide whether the implementation of additional grippers of a handling machine needs to be communicated to the power supply planning team or not? And, with that, is the initial re-engineering still profitable or will the expected benefits of the optimization be overcompensated by the required investments in equipment, automation, ID-reader and electricity-infrastructure, so that the original solution (without the change of the module design) is more viable?

> "Caused by the dependencies of the FPOs there is a steady need to re-evaluate and adjust all succeeding FPOs which meet the corresponding criteria."

When deciding whether to go for an optimization action, a holistic analysis incorporating all resulting impacts is needed. The person in charge for the whole fab manages the planning process, merges and concentrates the information for all FPOs. Taking into consideration output, cost, qualitative facts and risks he finally decides if planned changes will lead to a Pareto optimal solution.

For this purpose, a comprehensive mapping of all FPOs and their relationships needs to be accomplished. This is the primary aim of the dependency map. Additionally, it helps persons in charge of the FPO to identify other parties that need to be informed, if necessary.

Another use case for the dependency map occurs when finding new constraints, attributes or requirements that are caused, for example, by measurements. In this case, the change is enforced and no decision process is needed.

Regarding the preceding object and its modification of properties, the dissemination of the corresponding information is generally used for releases or for announcements in advance to all participants (if new facts have been determined).

The final release of the original and subsequent adaptation of the configuration will not occur until:

- All FPOs associated with critical paths are confirmed by a person in charge (in this case a critical path corresponds to FPOs of the category "*To-be-confirmed*").
- The person responsible for a substantive section of the entire fab has confirmed the complete package. It is possible that different evaluation criteria will be used depending on their position within the hierarchy (responsible for one FPO, for several FPOs, or for the overall fab).

Provision of information

The specification of the demand for information is stated by the person responsible for the succeeding FPO, who requests the person in charge of the previous object to submit the changes in a kind of obligation to perform. Fig. 3 depicts the interface of a FPO and the corresponding paths of communication.

In the case of interdependencies, an optimal solution will be found among the affected objects before any uni-directional dependent, subsequent object is informed. The dependency map supports the project manager by making the fab design more transparent while ensuring that the whole project adheres to the given timeframe.

The implementation of IT assistance should be based on standardized communication interfaces. A central database comprising all information should be accessible to responsible persons via remote access, such as a web browser. It is imperative that users are provided only with information which is relevant to him to enable efficient information update.

Development of the dependency map

Building up the dependency map is certainly the most difficult and most critical part of the process. However, even before the map has been developed, one can profit significantly from this tool. The following description shows how to proceed in creating the map and how to benefit from it during the development phase:

Step 1: Listing of Fab Planning Objects: Having a complete overview of all FPOs results in a kind of checklist to be used by the planner. Based on this, any change within the production system can be verified, whether it has an impact on a certain FPO or not. Even if the involvement of the person responsible for the downstream object will not be triggered

automatically, there is a reasonable probability that this person will be requested to comment on the modification.

Step 2: Listing of requirements and properties: A significant number of FPOs, such as production equipment, handling devices, controlling software, etc., have to be specified and documented. By doing so, a list of requirements and properties provides a considerable amount of information to be integrated into these documents.

Step 3: Create (inter)dependencies: The dependency map links several FPOs by establishing connections between their requirement and property interfaces. As such, it ensures a standardized and automated way of communication.

> "The earlier the dependency map is set up during the planning phase of the fab, the more effective it is."

The earlier the dependency map is set up during the planning phase of the fab, the more effective it is. However, even if the process has progressed considerably or the fab is already erected, it is worth building up a dependency map or enlarging its battery limits with new attributes (thereby increasing its degree of detail) as long as it can be expected that flexibility is needed to react to future challenges.

Summary

The complexity of an existing production system generates a high demand for communication and exchange of information. Particularly during the planning phase, the available pool of information is very large due to the results gathered by constant engineering. Suppliers of end-to-end solutions are faced with the challenge of handling such a large amount of information as they have to deal with several production lines being planned and implemented simultaneously.

The dependency map aims to capture, structure, and standardize the exchange of all relevant information, requests and confirmations in the case of modifying integral parts of the production system. This capability has to be transparent to ensure that all persons in charge of certain FPOs – which might be affected by any modifications – can raise their hands. A process that not only considers output and cost but also qualitative aspects and possible risks has also to be evaluated by the one responsible for the fab or a segment of it. Such a procedure ensures or at least comes close to a Pareto optimal solution and avoids single-sided, political or individually-motivated optimizations.

Establishing a comprehensive and accurate dependency map will require process-discipline, commitment of the management and well-defined responsibilities for FPOs. Continuous content validation and updates will keep the quality of the dependency map at a high level.

The benefits will compensate all efforts as the advantages are manifold:

- As information is tailored for the corresponding target group, the cost of communication (mainly time) can be lowered and the supply of information made more reliable.
- Higher transparency of dependencies and reduction of tacit information [3] results in the reduced risk of incorrect planning.
- The flexibility in fab design enables the fab planner to execute continuous improvements in order to achieve a Pareto optimal result.

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About the Authors

Martin Kasperczyk is project manager at Oerlikon Solar AG, Trübbach, Switzerland, and holds responsibility for factory planning, process controlling, and business process management. He received a diploma in economics from the University of Applied Sciences in Düsseldorf. His role at Oerlikon is to develop new concepts and optimize output and cost at existing automated thin-film photovoltaic manufacturing lines. Martin has experience in the photovoltaic market, supply-chain-management, and controlling.

Fabian Böttinger is a project manager at Fraunhofer IPA (Institute Manufacturing Engineering and Automation) in Stuttgart, Germany. Prior to joining Fraunhofer he studied computer engineering at the University of Applied Sciences, Konstanz. His fields of expertise within the photovoltaic and semiconductor industry are modelling and simulation of logistic processes and factory IT.

Marcus Michen is a project manager at Fraunhofer IPA. He studied computer science at the University of Applied Sciences, Furtwangen. His main expertise is in the field of knowledge management, the design and evaluation of logistic processes and factory software.

Roland Wertz is a project manager at the Fraunhofer IPA. He received his diploma in engineering cybernetics from the University of Stuttgart, Germany. Roland's field of expertise deals with the topics of manufacturing automation, simulation and logistics. Beside several industrial projects he is involved in a number of EU-funded research projects.

Enquiries

Email: solar@ipa.fraunhofer.de

Glass washing challenges in thin-film PV production

Eric Maiser, VDMA, Frankfurt, Germany; **Iris Minten**, Bystronic glass, Neuhausen-Hamberg, Germany; **Karl-Heinz Menauer**, ACI-ecotec, Zimmern ob Rottweil, Germany; & **Egbert Wenninger**, Grenzebach Maschinenbau, Asbach-Bäumenheim, Germany

ABSTRACT

Thin-film module production has proven itself as a forerunner in the race to drive down costs for photovoltaics. The type of semiconductor material used is the most differentiating factor for thin-film photovoltaics, playing the decisive role for determining which core processes are employed and what type of equipment is used. This explains why discussions related to thin-film costs and technologies usually focus on the semiconductor type. However, the effects of glass production, processing and handling are often underestimated: factors such as scaling, yield, unit cost and total cost of ownership of the equipment are defined by the glass-production side of the industry. This paper discusses the challenges faced in glass washing and handling in thin-film PV production.

Introduction: the role of glass in thin-film photovoltaics

While classic PV modules are produced in a production process of several steps by wiring crystalline silicon wafers, in thin-film module technology, the semiconductor layer is directly applied to the substrate in a thickness of a few micrometers. This saves material, process steps and energy. Several alternative semiconductor materials have been developed to substitute silicon for this technology. Moreover, thin-film technology's use of semi-transparent PV glasses opens up new markets such as window and automotive glass provision.

In commercially available thin-film photovoltaics, modules most commonly consist of a glass front and backplane with a foil layer in between (Fig. 1). This proven approach provides durable and secure encapsulation of the modules. The side of the module that faces the sun is usually an extra-clear float glass with low iron content to reduce absorption. Additionally, anti-reflection coatings or structured surfaces are applied to reduce reflections. The front side is 3-4mm thick and edge-seamed to ensure mechanical and thermal stability. Depending on the

Thin Film

process depth of the manufacturer, the front glass is delivered with or without a transparent conducting oxide (TCO). The TCO can be coated directly after the glass melting furnace, which reduces cost.

Since glass adds significantly to the materials bill of a thin-film module, the solar industry needs high quality glass but at the same time considerably cheaper glass. Lately, concepts to use modified rolled glass were brought to the table, which can provide considerable cost savings. Textured rolled glass decreases reflectance, which allows for raw materials with a 30% higher iron content than for float glass [1] or results in a better overall module efficiency. Furthermore, the success of this format would render obsolete the extremely energy-intensive floating process.

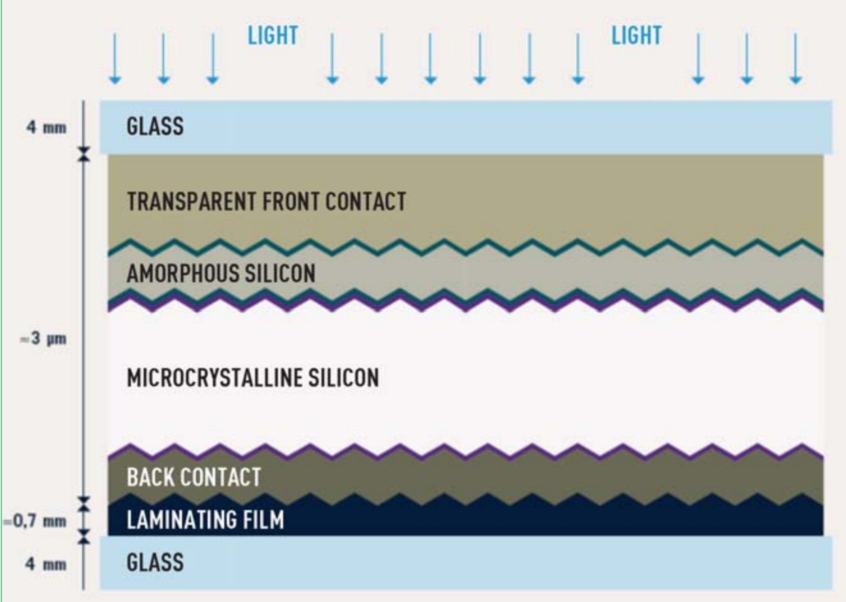
"The solar industry needs high quality glass but at the same time considerably cheaper glass."

Benefits are possible in the texturing process itself. Instead of using a separate process, the texture can be applied to the surface of the glass during the rolling process. In addition, rolled glass factories can be built at a considerably lower cost than float glass facilities. These facilities can be built practically anywhere, in the immediate vicinity of solar energy factories, for example. Another great potential lies in weight reduction using the rolled glass procedure to produce 2mm-thick, surface finished, toughened safety glass as is also used by the solar energy sector [1].

The next technological revolution will be the mass production of plastic-based, printable organic semiconductors (organic PV) on flexible substrates, which will further reduce production prices and open new fields of applications. The share of costs for machines varies among the three technologies; for crystalline PV, the availability and the price of silicon is crucial. While capital expenditure for the production (with a large share for machines and equipment) for crystalline PV is not more than one sixth of total expenditure, it amounts to one third with thin-film technology and almost two thirds with new technologies such as organic PV.

Glass washing: a common but crucial step

Glass washing and handling are steps that are common to all thin-film PV technologies. Washing is carried out whenever the substrate is processed in any way: in the front end of line after loading and seaming, and after laser scribing of the TCO, the functional layers and edge deletion. The same applies for the cover glass. Photovoltaic glass cleaning is not just performed for aesthetic purposes, however. Although it seems trivial at first sight, glass washing is a critical step, especially in thin-film module production. The semiconductor layers need a clean and smooth surface – on the molecular level – to perform properly. Any trace of particles on the glass leads to poor adhesion or contamination of the photovoltaic layers and therefore reduces the performance of the product from the semiconductor side. Moreover, dirty substrates and covers can lead to a number of reliability problems, from incomplete scribing of the cells, decreased light transparency to delamination in some cases. The latter also applies in the case of crystalline modules where antireflective coatings for the cover glass can be affected.



Source: Sontor

Figure 1. Cross-section through a thin-film photovoltaic module.

Source: Bystronic glass

Figure 2. Vertical setup reduces footprint, avoids sag, and employs gravity for rinsing.

Different types of concepts and features

So where are the differentiating factors, the technological and cost challenges for glass washing? Most glass washers for the PV industry are derived from machines for architectural glass. But with the aforementioned boundary conditions, it is clear that solar-glass washing equipment has to be extremely accurate and efficient. On the other hand, solar glass has not reached architectural glass sizes (yet), although substrate scaling has been on the roadmaps of thin-film producers for quite a while. In the flat-panel display industry, this turned out to be the major cost saver. Substrate sizes in that industry have reached approx. 2.8 x 3m² (Generation 10), whereas the biggest panels used in the PV industry are 2.2 x 2.6m² (Generation 8.5).

Depending on the size of the glass, manufacturers offer horizontal or vertical stainless-steel systems from the traditional glass-equipment industry for use as both substrates and cover glass. The vertical concept has advantages over the horizontal due to glass sagging. Compared to a horizontal washing machine, the vertical version also has the advantage that the water runs off top-down, preventing water from aggregating as it does in a horizontal construction. Therefore, an associated formation of algae is avoided.

Flexible substrates like plastic or metal foils are playing an increasingly important role in thin-film photovoltaics. Roll-to-roll processing involves totally different setups for the washing machines. Sag does not play such an important role here. The supply industry offers horizontal washers with plastic casings for glass and foils, adapted from the semiconductor industry.

> "Flexible substrates like plastic or metal foils are playing an increasingly important role in thin-film photovoltaics."

Various cleaning concepts are employed for the different applications. From the architectural glass side, mechanical brush cleaning is a common standard that is also applied to the PV industry. The machine shown in Fig. 2 has chainless brush and transport drives outside of the machine as well as variable brush rotation speed. The water-protected bearings of the brushes are maintenance-free.

Source: acp – advanced clean production GmbH

Figure 4. The CO_2 snow-jet does not use water and does not require manual handling.

Apart from the glass sizes, glass thicknesses vary in different types of machines from below 1mm up to 50mm; for flexible substrates the dimensions are down to 50µm.

Transport speed is also an important factor for in-line processing. Speeds range from below 1m/minute up to 25m/minute, while for some machines speed can be adjusted without steps. This latter factor is important as it allows for the adjustment to other in-line processes such as layer deposition.

Mechanical stress enhances breakage

Any mechanical stress on the substrate – be it the sag, handling between machines and in the machine, the brushing – increases the probability of breakage. Therefore, handling robots must be extra smooth, glass size and defect tolerances must be tight, the quality of edge treatment and holes are paramount, and brushes must be soft. The product shown in Fig. 3 is equipped with an automatic coating recognition and a frequency control of brush drives for especially sensitive coatings as well as a reversible transport drive for glass plates.

Some equipment makers have already introduced non-contact cleaning processes such as an ultrasonic cleaning technique. An innovative method introduced in PV glass washers is a carbon-dioxide (CO_2) snow-jet cleaning process (see Fig. 4). CO_2 snow-jet cleaning systems use solid CO_2 ice crystals as a jet medium. With its combination of mechanical, thermal and chemical properties, CO_2 snow is able to gently detach and remove a whole variety of surface contamination. Developed at the Fraunhofer IPA in Stuttgart, Germany, the sublimation-impulse technique is the most efficient process to date for cleaning with CO_2 snow worldwide. As the liquid CO_2 expands at the nozzle outlet, CO_2 snow is formed and accelerated to supersonic speed using a compressed-air jacketed jet and blasted onto the surface to be cleaned. The CO_2 snow cleans gently; it is dry, residue-free and suitable for use with a wide variety of materials and material combinations. CO_2 gas is non-flammable, non-corrosive, non-toxic and environmentally friendly. The method is suitable also for large surfaces and can help reduce breakage to a minimum.

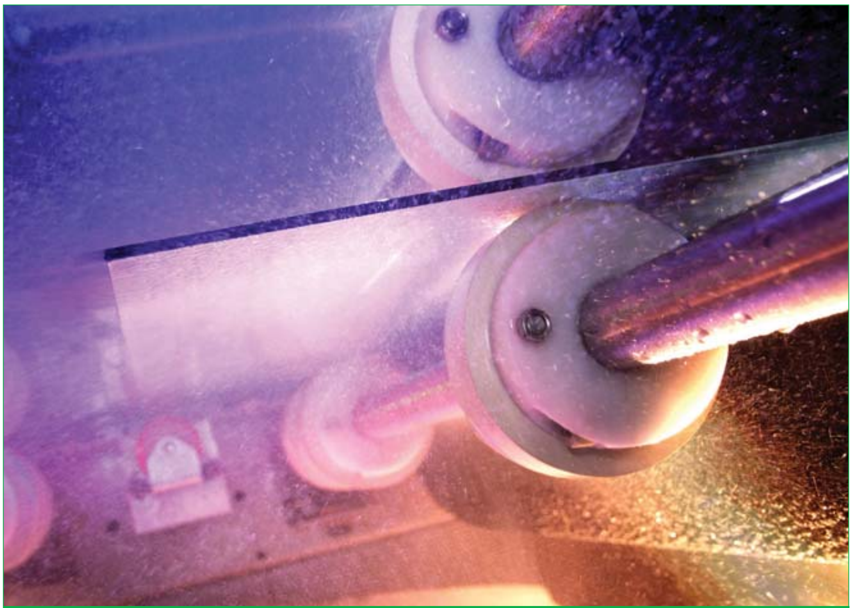

Source: Bystronic glass

Figure 3. Glass washing is a common production step for all thin-film technologies.

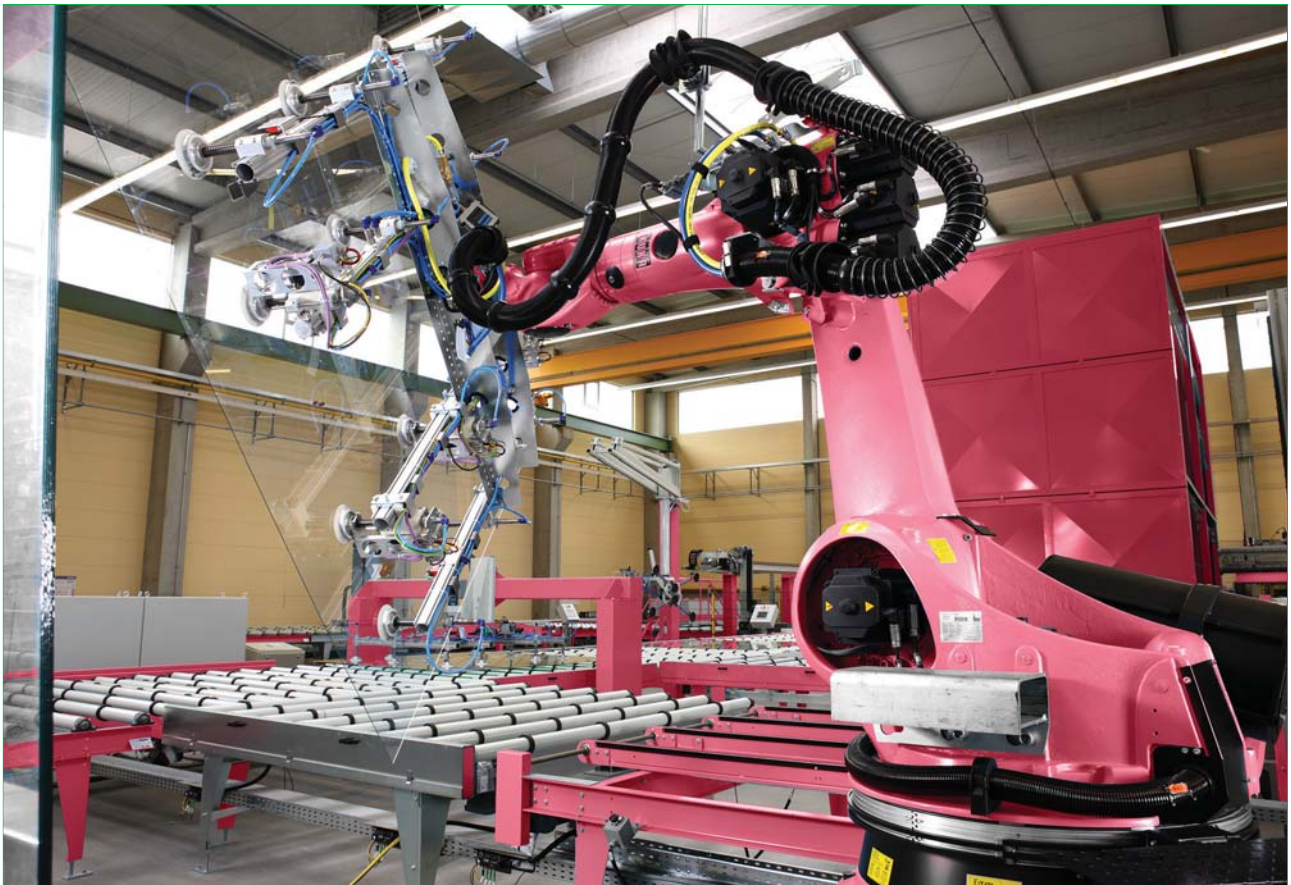

Source: Grenzebach

Figure 5. TCO-coated glass needs extra careful handling from the back side.

Total cost of ownership and environmental issues

For an eco-energy like photovoltaics, production should be energy- and resource-efficient. This ensures a low total life-cycle cost of a machine. Another parameter adding to the cost of ownership is the machine's footprint, reducing cost for (clean) space. With this in mind, companies have been introducing technologies to save water and energy. Using DI water in extra cycles can save on detergents or chemicals, which not only improves on lowering the environmental impact but also saves money. Air knives also make the rinsing and drying process very effective. Washing machines from suppliers from Germany, Italy, the U.S. and China are currently on the market for between €14,000 and €600,000 [2].

> "The sublimation-impulse technique is the most efficient process to date for cleaning with CO_2 snow worldwide."

Summary and conclusion

The machinery industry will continue to offer significant cost reductions for the PV sector in order to aid in making PV more competitive compared to conventional energy. In cooperation with the manufacturers, the equipment makers play an important role for the optimization of production technology while at the same time broadening production – charting their way along the learning curve. They have the ability to supply efficient, less expensive and long-lasting products to the market by ensuring the input of fewer materials and energy, higher effectiveness and optimized production methods. A higher degree of automation results in faster throughput and higher output, thereby leading to more efficiency and quality and reduced production costs.

Further development of machines for mass production as well as the standardization of interfaces again brings potential for lower investment in machinery. With increasing mass production, positive scaling effects in production will be used and lower costs per piece can be achieved. Glass production, processing and handling play a vital role in this endeavour.

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About the Authors

Eric Maiser has been Managing Director of the Photovoltaic Equipment Association within the German Engineering Federation (VDMA) since 2007. He also heads the VDMA Electronics Equipment association. From 2000 to 2007 he was responsible for Flat Panel Displays (DFF). He was appointed one of the Managing Directors of the German OLED Reference Line (DORAn) GmbH with coordination responsibility from 2002 to 2008. He earned a master's degree in physics in 1993 and a Ph.D. in solid-state physics in 1997, both from the University of Karlsruhe, Germany. He also worked as a researcher at the University of Maryland, College Park, USA.

Iris Minten has worked for Bystronic glass since June 2008, and has responsibility for Public Relations and Online Communication in all topics concerning the Bystronic glass group and its machinery. Prior to this role, she graduated from Gießen University, Germany in natural scientific studies, completed an extra-occupational study in public relations in Heidelberg, and also worked in various communications agencies until joining Bystronic glass.

Egbert Wenninger is on the Grenzebach Group Board of Management and is Head of the Grenzebach Group Glass Technology Sales Division accounting for worldwide sales activities. After graduating in engineering, he worked as a software developer with Pfister Systemtechnik in Augsburg and joined the Grenzebach Maschinenbau GmbH team as Sales Engineer in 1994. For the past eight years he has been responsible for the company's worldwide glass technology sales activities. A member of the glasstec advisory council for the Düsseldorf trade fair, member of the board of VDMA Photovoltaic Equipment as well as the VDMA Glass Technology Branch, Egbert has published articles in several specialist magazines.

After completing his degree in electrical engineering at the University of Stuttgart, Germany, **Karl-Heinz Menauer** worked at the Fraunhofer IPA in Stuttgart as a scientific employee. He then gained international marketing and management experience working for Alcatel SEL AG in Stuttgart and BOSCH Telecom GmbH in Munich. Since 2002, Mr. Menauer has been CEO of acp – advanced clean production GmbH, a spin-off of the Fraunhofer Gesellschaft. Since 2004, he has also held the role of managing director of ACI-ecotec GmbH & Co. KG. Mr. Menauer is also member of the board of VDMA Photovoltaic Equipment.

Enquiries

Dr. Eric Maiser
VDMA Photovoltaic Equipment
Lyoner Str 18
60528 Frankfurt
Germany

Tel: +49 (0) 69 6603 1433
Email: eric.maiser@vdma.org
Web: www.vdma.org/pv

Iris Minten
Bystronic glass c/o Bystronic Lenhardt GmbH
Karl-Lenhardt-Str. 1-9
75242 Neuhausen-Hamberg
Germany

Tel: +49 (0) 723 460 1120
Email: iris.minten@bystronic-glass.com
Web: www.bystronic-glass.com

Egbert Wenninger
Grenzebach Maschinenbau GmbH
Albanusstr. 1
86663 Asbach-Bäumenheim (Hamlar)
Germany

Tel: +49 (0) 906 982 2459
Email: egbert.wenninger@grenzebach.com
Web: www.grenzebach.com

Karl-Heinz Menauer
ACI-ecotec GmbH & Co. KG
Albring 18
78658 Zimmern ob Rottweil
Germany

Tel: +49 (0) 741 175 115 0
Email: info@aci-ecotec.com
Web: www.aci-ecotec.com

PV Modules

IMS Research: top 10 PV module producers in 2009 named

It should come as no surprise that IMS Research named First Solar as the largest PV module manufacturer in 2009, having shipped over 1GW last year. The market research firm said that the same top 10 module producers appeared in the rankings for 2008, although there was some shuffling in the positions for this year's results.

IMS Research estimates that shipments of PV modules were far higher than its estimate of installations in 2009 of 7.5GW. Shipments exceeded installations due to the record amount of modules shipped in the final quarter of the year to serve installations completed in the first quarter of 2010 in booming European markets such as Germany, Italy, France and Czech Republic.

With the rapid rise of thin-film leader First Solar, the previous year's leader, Suntech, only fell one place, followed once again by Sharp in third. Trina Solar climbed two places by increasing its annual shipments by nearly 90%.

However, Sharp, Kyocera and Sanyo all moved downwards compared to 2008, and for the first time, the amount of modules sold by U.S.-based suppliers exceeded that of Japanese suppliers.

World PV Module Supplier Rankings

MW Shipments

	Company Name	Change 08-09
1	First Solar, Inc.	2
2	Suntech Power Holdings Co Ltd.	-1
3	Sharp Electronic Corporation	-1
4	Yingli Green Energy Hodling Co Ltd	-
5	Trina Solar Limited	2
6	Sunpower Corporation	-
7	Kyocera Corporation	-2
8	Canadian Solar Inc.	1
9	SolarWorld AG	1
10	Sanyo Electric Co. Ltd	-2

Full Market Share Tables available in IMS Research's Annual and Quarterly World Market for PV Cells & Modules Reports

Source: IMS Research May-10

World PV module supplier rankings.

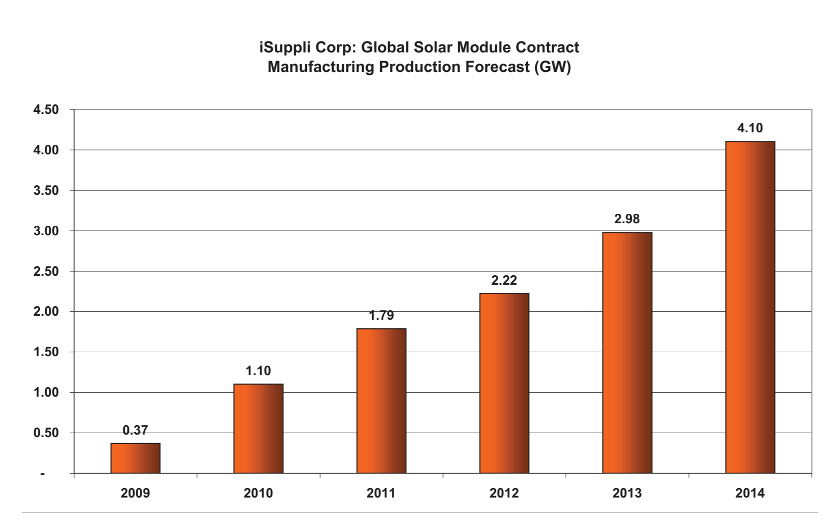
Module Production News Focus

The rise and rise of subcontracting in the solar manufacturing industry

The latest slew of announcements from various sectors of the solar manufacturing supply chain to establish partial or complete production outsourcing is no accident and a trend that will continue grow, according to iSuppli. The market research firm noted that the latest SunPower news of a contract manufacturing deal with major electronics manufacturing services firm Flextronics is only representative of the early stages of a boom, especially in module assembly outsourcing.

"iSuppli believes SunPower's move is part of an emerging trend in the solar market that closely parallels the situation in the electronics market in the early 1990s," said Greg Sheppard, chief research officer for iSuppli. "Faced with rapidly exploding demand, the need to produce products close to end markets and the requirement to obtain sufficient capital, electronic OEMs in the early 1990s turned to EMS companies like Flextronics for help. This led to a massive boom in electronics outsourcing and explosive growth in the EMS business. In the early 2010s, a new EMS boom is starting up, this time in the solar panel business."

According to iSuppli, contract manufacturers will manufacture 1.1GW worth of solar panels in 2010, up 200% from 369MW in 2009. One major factor



iSuppli Corp: global solar panel outsourcing forecast.

causing solar-panel makers to turn to EMS providers is the rapid expansion of the market and limited funds to expand internal capacity. iSuppli recently updated its global solar installations forecast to a significant new level of 13.6GW in 2010, an increase of 93.6% from 7.0GW in 2009.

REC's Singapore facility rolls out first commercial product

REC's new manufacturing plant in Singapore has produced its first commercial product with the REC peak energy module. Available worldwide for purchase, the module is expected to give more power per square inch metre, stemming from design improvements.

REC's new manufacturing plant in Singapore.

In REC's new design, three bus bars and enhanced contact between the cell and metal fingers is shown to improve electrical flow to 9W. Additionally, using Sunarc's technology, energy production has increased by 2%. The modules are considered easy to install and are touted as being able to support a large mechanical load.

SunPower to have new 75MW module plant in U.S., courtesy of Flextronics

Electronics manufacturing services company Flextronics will utilize production floor space in its Silicon Valley operations for a 75MW module assembly facility for SunPower. The Silicon Valley-based PV manufacturer is carrying out a solar cell capacity expansion program at its own facilities in Asia. The new subcontract production should be operational by the end of the year and will service module installations throughout the western U.S. from its Milpitas facility. Approximately 100 jobs will be created at the facility.

SunPower said that establishing a U.S. manufacturing facility was a direct result of a three-year agreement with the Department of Energy under the Solar Energy Technologies Program, which would lead to a possible maximum US$24 million of federal funding to implement improvements across the value chain that reduce solar system costs through improvements in the design and manufacture of integrated solar power systems.

The company also plans to apply a U.S. federal manufacturing tax credit awarded to it from federal stimulus dollars by the DOE to support its investment in the manufacturing equipment purchased for Silicon Valley, which includes equipment from four U.S.-based suppliers.

Solarfun to increase module capacity to 900MW

Due to a high demand in the second half of 2010, Solarfun Power Holdings will be expanding its module capacity to 900MW, having already reached its original announced capacity of 700MW. The company also announced that it has purchased a cell line from SMIC to increase its cell capacity to above 500MW by July 1, 2010.

Solarfun power module manufacturing line.

The module capacity expansion is scheduled to be completed by August. Its newly acquired line from SMIC, with an annual capacity of 25MW, is set to be operational this in May.

Canadian Solar sees limited shipment increases as capacity constraints hit

Regardless of its planned manufacturing capacity expansion plans, Canadian Solar has limited ability to boost c-Si module shipments that could stretch through the first half of 2010 and beyond. The company has updated its shipments and selected financial figures for operations in the first quarter of 2010, which include module shipments expected to reach between 189MW to 191MW compared to previous guidance of shipments reaching between 180MW to 190MW.

In a research note, Barclays Capital financial analyst, Vishal Shah noted that Canadian Solar could be impacted by solar equipment delivery lead times due to over 200 c-Si cell lines currently under construction globally. Shah said that Canadian Solar may not reach its cell capacity expansion plans of 720MW until late August, 2010 due to lead times on equipment.

The company was also having problems with expansion of its internal ingot/wafer manufacturing, which could result in wafer capacity only reaching 350MW by the end of the second quarter, compared with plans to reach 500MW.

SolarWorld's manufacturing expansions in the U.S. create 350 new jobs

Championing its job creation credentials overseas, German headquartered solar module manufacturer, SolarWorld has highlighted that its previously announced module capacity expansion plans in the U.S. will generate approximately 350 new jobs at its facility in Hillsboro, Oregon.

SolarWorld announced plans in October 2009 to expand capacity to 350MW by 2011. However, a month later the integrated module manufacturer said it would increase production further in the U.S. to as much as 500MW, though no timing details were given.The headcount in Hillsboro will increase from 650 to approximately 1,000 people.

Solon celebrates new production line in Greifswald, Germany

Solon has officially celebrated its newest solar module production line in Greifswald, Germany. The minister president of Mecklenburg-Vorpommern, state minister for economic affairs and the mayor of Greifswald were on hand at the ceremony and sanctioned the beginning of production. In addition to the 60 new jobs the production line has created, Solon has


Sovello's highly automated module assembly plant in Germany.

increased its site manufacturing capacity to 185MWp.

The new line will see an added 900 solar modules produced with a 50MWp capacity. The line generates solar modules based on crystalline technology with the flexibility of being used on various Solon modules.

Sovello has been acquired by Ventizz Capital

The sale of 'string-ribbon' PV module producer, Sovello has been completed, according to a joint statement from its previous backers, REC, Evergreen and Q-Cells. However, just under a month ago, the partners announced that Sovello had been sold to Ventizz Capital Fund IV, L.P, part of Ventizz Capital Partners for an undisclosed sum.

REC reiterated that its subsidiary REC Silicon would continue to supply polysilicon to Sovello, but at lower annual volume rates than previously contracted.

Ventizz Capital Partners currently advises four funds with €675 million capital under management and is one of the largest private equity funds for venture capital and medium-sized tech buy outs in the German-speaking region. Ventizz Capital Fund IV L.P. is the largest of the four funds set up to date.

Day4Energy to acquire ACI-ecotec

Pending the final approval from its board of directors, Day4Energy has entered an agreement in principle to purchase the German-based PV equipment company, ACI-ecotec. Day4 will attain 100% of ACI in all stock transaction of up to 10.8 million shares of Day4, subject to postclosing adjustment. In addition to the board's approval, the acquirement of ACI rests in definitive documentation and all required consents and approvals – including that of the Toronto Stock Exchange.

Day4 says it will combine its technology with ACI's specialized industry knowledge and equipment to be able to more readily offer its turnkey manufacturing technology solution for the production of PV cells and modules. Both companies look to close the acquisition in the first half of 2010.

PV module maker Solaria lands another US$45 million in financing

Crystalline-silicon module developer-manufacturer Solaria has closed US$45 million in a financing round led by CMEA Capital and DBL Investors. Other participants in the round include current investors Sigma Partners and NGEN Partners and new investors Mitsui Ventures and Savitr Capital. Solaria said it will use the financing to meet rapidly increasing global demand for cost-effective solar modules for large and utility-scale projects, adding that its aggressive growth plans demonstrate the capital efficiency of its business model.

Solaria's flat-plate low-concentrator PV modules are designed specifically for ground-mounted tracking systems and certified to UL1703 and IEC61215 standards. The Fremont, CA-based company says its proprietary manufacturing processes require only a fraction of the capital expenditure per watt of manufacturing capacity needed by standard industry processes.

Solar Source to build PV module manufacturing facility in Windsor

Two hundred new jobs will be brought to Windsor with the Windsor Essex Economic Development Corp.'s (WEEDC) announcement that Solar Source will build its new manufacturing facility at the Windsor International Airport. The 45,000 square foot plant will produce crystalline-silicon solar PV panels and serve as Solar Source's and its manufacturing partner's initial investment in North America.

Solar Source, a Canadian company, plans to bring 150 full-time jobs with the first 30MW phase of the manufacturing project. The second phase will bring an additional 50 jobs to total 200 jobs for the plant.

2BG completes delivery of first production line of 50MW PV modules

2BG has completed its delivery of its first 50MW PV module production line to Italia Solare. The line has been operational since December 2009 with a production capacity of 25MW. Full production is expected by May. The company looks to continue expansion in July 2010 with an added 50MW to be later followed in first quarter 2011 with another 50MW. Total capacity is expected to reach 150MW.

P. Energy supplies 5MW PV line in Saudi Arabia

P. Energy has supplied an automated PV assembly line with a 5MW per year production capacity to KACST in Saudi Arabia. This new PV line is the first ever installed in the country.

KACST is an independent scientific organization, administratively attached to Prime Minster, King Abdul Aziz. The program aspires to propose a national policy for the advancement of science, technology and research programs for the kingdom's development.

Testing and Certification News Focus

Evergreen Solar's ES-A solar panels pass IEC certification

Evergreen Solar's ES-A series solar panels have recently passed IEC 61701 salt mist corrosion testing for PV panels. The IEC certification exposed the panels to a concentrated salt solution for at least 96 hours and no mechanical deterioration or corrosion of the panel components was found.

"This recent certification extends the ability of Evergreen Solar panels to be installed virtually anywhere that solar power is viable, and makes our powerful, environmentally-friendly solar panels available to more people," said Scott Gish, Evergreen Solar's VP of sales and marketing.

ProLogis debuts dedicated rooftop solar PV test array, featuring eight different module types

ProLogis' renewable energy group has opened what it calls the first dedicated comparative test site for solar modules operated by a real estate development company. The 11kW (DC) rooftop system, located in Denver, CO, includes 99 photovoltaic panels from eight different manufacturers and features a range of thin-film and crystalline-silicon module types.

The initial configuration of the system, which is already generating power, provides side-by-side comparisons of several PV technologies, including monocrystalline silicon (Suniva), glass-on-glass CdTe, a-Si, and CIGS thin-film (First

Solar, GS-Solar, MiaSolé, Solyndra), and membrane-applied CIGS and a-Si thin-film (Ascent Solar, ECD Uni-Solar, Xunlight).

The installation on top of the ProLogis Stapleton Business Center also incorporates 16 individually monitored strings, each designed to test a certain system parameter, according to the company. As a part of the test site, in partnership with HatiCon Solar, ProLogis said it has designed a new racking system especially for utility-scale rooftop solar installations.

Matt Singleton, VP of renewable energy at ProLogis, explained that as a "real estate developer and owner, we seek the most compatible solution for our rooftop installations, both in terms of structural loads and roof integrity. This new attached rack design combines standardized, lightweight aluminium parts with the long-term assurance of a maintainable and warrantable watertight connection to our buildings."

The test site marks the first Colorado project for MiaSolé and is the seventh testing facility in the United States to feature the company's CIGS modules. ProLogis said it has solar projects installed or under construction on 32 buildings throughout France, Germany, Japan, Spain, and the United States, covering more 984,800m² of roof space and totaling 24.6MW in capacity. The company has more than 42m² meters of roof space worldwide available for PV installations.

ProLogis' 11kW (DC) rooftop module test system, Denver, CO.

The company also recently announced a deal with Southern California Edison to deploy up to 40% of the utility's 250MW distributed-generation solar power project on the rooftops of ProLogis distribution warehouses in the Inland Empire region of Southern California, with installation of the first five systems slated to begin during 2010.

Chevron and GreenGulf to test various solar technologies in Qatar

An experimental facility to study different solar technologies best equipped for the country of Qatar has been given a boost with the involvement of Chevron Qatar Energy Technology, an affiliate of Chevron Corporation. GreenGulf, a Qatar-based renewable energy and clean technology company had originally planned to collaborate with the Qatar Science & Technology Park and other partners to study different solar-to-electricity conversion methods in March, 2009, which had the patronage of Her Highness Sheikha Mozah Bint Nasser Al-Missned, Chairperson of Qatar Foundation. The project will still be located at the Qatar

GlobalWatt selects KUKA Systems liquid encapsulant line

Crystalline-silicon module manufacturer, GlobalWatt had chosen KUKA Systems' advanced liquid encapsulant line for its new plant in Saginaw, Michigan. The initial semi-automated line is expected to cost under US$10M and be operational by November 2010 with production to begin in the first quarter of 2011. GlobalWatt has a plan of a total capacity over the next three to five years of 500MW in module manufacturing.

LDK Solar to supply modules to Phoenix Solar

Cost competitiveness or supply constraints or both could be behind a new c-Si solar module supply deal between LDK Solar and major project developer, Phoenix Solar. Under the terms of the agreement, LDK Solar is supplying Phoenix Solar with approximately 20MW of solar modules during the second quarter of 2010.

Many major module producers have already said that due to strong demand, especially in Germany and key European markets that they were sold out through the first half of the year and expected continued strong demand throughout the year. Currently, LDK Solar is aggressively ramping its in-house module production to 1.5GW in 2010, boosted by its merger with Best Solar.

Solaria starts shipping PV modules to global customers

Solaria has begun shipping its tracker-optimized, monocrystalline-silicon photovoltaic solar modules to customers in North America, Europe, and Asia. Although the company would not reveal the amount of shipments nor the financial details of any of the agreements, sources said that the modules have been designated for project-level installations.

Solaria's 1.6 × 1m modules use patented technology, incorporating a low-concentration PV design with singulated cell strips combined with special optics, to provide the reliability, performance, and quality of a standard silicon module at a low cost. The Fremont, CA-based company says it uses only proven, UL-listed, industry standard materials, thereby eliminating risks associated with new materials.

The Solaria module, available in 210-, 220-, and 230W models, is the first low-concentration flat-plate module to achieve international certification, having met both the UL1703 and IEC61215 standards. Its performance and reliability has also been validated by independent laboratories.

According to Columbia University's Center for Lifecycle Analysis, the carbon footprint per watt of modules manufactured with Solaria's technology is approximately one-third less than that of competing technologies, with an energy payback time of less than one year.

Spire to supply turnkey PV module manufacturing line to New York start-up Solartech

Spire has signed a deal with solar manufacturing start-up Solartech Renewables to provide a turnkey PV module manufacturing line for the new company's factory in Kingston, NY. The crystalline-silicon line will include Spire's state-of-the-art equipment, process knowledge, training, and module certification assistance.

Solartech will begin production on its initial 12MW line using Spire's UL/IEC-certified ST220 module, a 60-cell (156mm, poly c-Si) 220W design. The start-up has said its production facility will become operational in 2010. Financial terms of the deal were not disclosed.

Solon expands Greek business: delivers 1.5MWp modules to NRG-Orion

Solon has signed an agreement with Greek company, NRG-Orion, for the delivery of 1.5MWp of solar modules. The Solon modules will be used to construct a ground-mounted PV system at the headquarters of canned peach company, Kronos. Once complete, this will be Greece's largest single-axis tracking solar power plant to date. The power plant is scheduled to be connected to the grid in August 2010.

Solon SE signs 5MW module and partnership deal with Czech-based Energ Servis

Solon SE is expanding its global reach with a strategic partnership agreement with Czech turnkey project developer Energ Servis. Solon has also agreed to, under the terms of the agreement, supply Energ Servis with 5MW of PV modules throughout 2010.

Energ Servis will use the modules for rooftop and ground-mounted solar installations of varying size within the Czech Republic. Energ Servis has constructed 100 photovoltaic power stations in the Czech Republic since 2008. The Czech Republic recently announced its plans for feed-in tariff cuts, which are making the country more attractive for investors.

Scheuten Solar places follow-on order with Bürkle

As part of its module production expansion plans for 2010, Scheuten Solar has placed a follow-on order with Robert Bürkle for its multiopening Ypsator module lamination tool. The machine will be delivered and commissioned in the second quarter of 2010. According to Bürkle, Scheuten Solar will be able to produce a module every 45 seconds on two Bürkle lines from the middle of 2010.

Spire ships 100th Spi-Sun Simulator 4600 SLP

Spire has shipped its 100th Spi-Sun Simulator 4600 SLP to Saflex Solar Encapsulants, a unit of Solutia. The equipment is designed to create a stable uniform single long-pulse (SLP) of light during which the entire I-V measurement is performed. Manufacturers of both crystalline silicon and thin-film modules use the simulator.

Energy supplies 5MW PV line in Saudi Arabia

Energy has supplied an automated PV assembly line with a 5MW per year production capacity to KACST in Saudi Arabia. This new PV line is the first ever installed in the country.

KACST is an independent scientific organization that aspires to propose a national policy for the advancement of science, technology and research programs for the kingdom's development.

Kyocera supplies modules to 4MW project in Czech Republic

Pan Ökoteam is using PV modules from Kyocera at one of the largest single projects to date in the Czech Republic. At the end of 2009, the plant had reached 1.6MW and is expected to expand to 4MW in 2011.

Science & Technology Park.

Chevron announced in February, 2009 that it would establish its Center for Sustainable Energy Efficiency (CSEE) at QSTP and is now in the process of building out the Center. The Center is scheduled to open in mid-2010.

The project will study the performance of different photovoltaic and solar thermal technologies at a 35,000 square metre solar test site at QSTP. The partners said that the project supports QSTP's strategy for assisting in the development of a national solar energy industry in Qatar.

Day4 Energy receives IEC certification

Day4 Energy's 60MC-I module with guardian technology has received International Electrotechnical Commission (IEC) 61215 and 61730-2 certification. The IEC's certification are recognized industry standards that assure modules have passed a required set of tests and are therefore appropriate for operation in outdoor climates. The IEC certification is also a requirement for PV module sales in Europe.

Day4 Energy first announced its 60MC-I module with guardian technology in September 2009, stating that it could improve the performance of the PV modules in partial shading, snow, debris or other external factors that could deteriorate power yield.

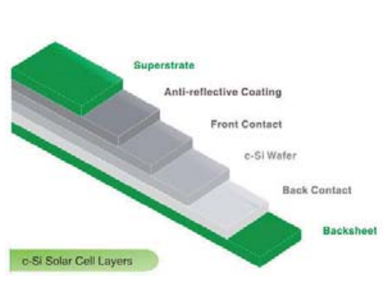
Materials News Focus

BioSolar begins commercial production for bio-based backsheets

The high-volume commercial production and sales of BioSolar's BioBacksheet has officially begun. Its bio-based backsheet for solar panels is a protective backing for PV solar modules, which aims to take the place of the petroleum-based backsheets currently used.

David Lee, CEO of BioSolar, commented, "We have finally completed the development of the world's first commercial-grade green backsheet and are ramping up production and are able to accept and fulfill orders..."

BioSolar's BioBacksheet consists of a polyamide resin produced from castor beans. The material is compounded with a secondary nonpetroleum material during the extrusion process forming a PV backsheet film.



BioSolar: c-Si cell composition.

Dow Corning, Reis Robotics join forces in PV moduling encapsulation collaboration

Dow Corning and PV equipment supplier Reis Robotics have formed an alliance to promote the materials company's PV-6100 silicone-based encapsulants for solar module production applications. The new encapsulants, when used in conjunction with the manufacturing process, are said to outperform the industry standard EVA resins as a way to protect the solar cells in a PV panel.

The companies say that the liquid silicone-based materials exhibit better durability, module efficiency, and manufacturing efficiencies than the incumbent materials, providing an improved total cost for solar modules. The encapsulant technology will help reduce the cost per kilowatt-hour of solar power by reducing the total cost of ownership through lower processing temperatures, faster throughput, lower capital, and less factory space needed for the equipment, according to the partners.

Demonstration lines for customer evaluations will be installed at Reis' facility in Germany, as well as at Dow Corning's site in South Korea.

Product Briefings

Bluestar Silicones

Bluestar Silicones' new module sealing and bonding range offers good elasticity over a wide temperature range

Product Briefing Outline: Bluestar Silicones has introduced 'CAF 530', part of a new range of high-performance adhesives. CAF 530 is claimed to optimize the longevity performance of solar modules by extending their resistance to weather erosion under conditions where performance must be constant for at least 25 years.

Problem: Long-term sticking and sealing of solar modules is required to provide long-life protection of photovoltaic cells and associated connections against humidity, the main cause of efficiency troughs in modules over time.

Solution: Bluestar Silicones' CAF 530 adhesive has a very high degree of elasticity, which resists and absorbs differential dilations of the assembled materials. This new range includes mono- and bi-component silicone elastomers (RTV 1 & 2) designed for sticking and sealing the frame and junction box as well as bi-component products designed for the encapsulation of components in the junction box and of photovoltaic cells. CAF adhesives are room temperature vulcanizing (RTV-1) silicone elastomers which cure at room temperature as soon as the product comes into contact with atmospheric moisture. The cure rate also increases with temperature and ambient moisture level.

Applications: Sealing and bonding of PV junction boxes and general module applications, including thermal solar panels. The adhesive is quick curing, has high mechanical properties, self-adheres to metal and plastics, and is non corrosive.

Platform: Bluestar Silicones has performed ageing tests according to IEC 61215 in order to check the bonding properties of the CAF adhesives on PVF and also on composite PVDF/PET composite materials for 1000 hours at 85°C with 85% relative humidity, known as the damp heat test.

Availability: Currently available.

Intertronics

'BlueWave' 200 UV curing spot lamp from Intertronics offers long-life adjustable operation

Product Briefing Outline: Intertronics has introduced the 'BlueWave' 200 UV curing spot lamp, designed to provide the highest intensity and the most user-friendly operation. A new, patent-pending Intensity Adjustment feature also allows simple, manual intensity adjustment during initial UV process validation and production.

Problem: As with any manufacturing process, defining an acceptable processing window is a crucial step in developing a UV curing process. Low cost and fast curing are key performance parameters for the UV curing process.

Solution: The new Intensity Adjustment feature permits engineers to evaluate the full range of intensity produced by the BlueWave 200 spot lamp, from 0 to 100%. Thus, the upper and lower intensity limits of a UV curing process can be easily identified in an actual production setting. When in production, routine radiometer measurements performed in accordance with good manufacturing practices will determine if any further intensity adjustments are required. The average BlueWave 200 bulb varies less than 1% over eight hours of normal use, so daily or weekly adjustments are typically adequate to maintain a tightly controlled process.

Applications: The spot lamp primarily emits UVA and blue visible light (300-450nm) and is designed for UV curing of adhesives, coatings and encapsulants. It contains an integral shutter which can be actuated by a foot pedal or PLC making it ideal for both manual and automated processes.

Platform: BlueWave 200 features a useful bulb life of up to 2000 hours with 20W of UV/visible light curing power, coupled with a choice of two, three or four split wand light guides. One unit provides the performance of multiple spot/wand units – thus ensuring faster, deeper adhesive curing of UV and visible adhesives, coatings and potting materials.

Availability: Currently available.

Reis Robotics

Reis Robotics uses a single robot for its new High Speed Module Taping System

Product Briefing Outline: Reis Robotics has launched a new High Speed Module Taping System that handles tape application by a single robot. This newly developed system could substantially increase the process stability compared to some systems available on the market.

Problem: Edge taping of solar modules prior to framing is a critical step for the protection of the module. Long warranty periods make the fit and function of the taping a vital process step.

Solution: The High Speed Module Taping System uses a single robot to apply tape to the module. This taping cell achieves a sequence cycle of only 35 seconds for a standard 60-cell module. After lamination and trimming, the tape is applied to all four laminate edges, while being simultaneously corner-edge-folded and lubricated for frame pressing. It also supplies a higher level of precision in resulting edge cut. The liner is loosened shortly before the application, so the glue side is not touched even once prior to application onto the laminate edge. The application head is directly controlled with the robot control, thus the tape will be applied in a synchronous manner and free from strain. Tape spools are changed without any interruption of workflow. The system features a very simple and durable design.

Applications: This process step can be implemented on new or existing lines. Automated taping is particularly well suited to high volume production, both from cycle time and quality perspectives.

Platform: The system features a simple and durable design, capable of achieving a sequence cycle of only 35 seconds for a standard 60-cell module.

Availability: Currently available.

Komax's 'Xinspect' series string testers offer intelligent defect assessment

Product Briefing Outline: Komax has developed an extensive product portfolio of testing equipment within its 'Xinspect' series. It combines three testing procedures in one equipment backlight and electroluminescence inspection and completes these results with monochromatic I-V curve measurement. Theses approaches allow having a robust automatic quality inspection during module production in-line as well as off-line, and are also applicable for thin-film modules.

Problem: Currently, many defects that impact the peak power of the module are not seen during production or are not measurement after each process step. As a result, power losses are detected on the finished module where it is too late to find out which process in detail caused the problem. Furthermore, it is also too late in the process to perform some reparation. In order to include a sun simulator after each process, very high investment would be needed and often the space requirements makes such an approach unrealistic.

Solution: In addition to the classic backlight image processing approaches, electroluminescence testing highlights normally invisible defects such as micro-cracks, dark areas and printing defects. The additional verification of the electrical performance by a monochromatic I-V curve measurement allows having a cost- and space-optimized solution. The monochromatic I-V curve measurement allows the system to distinguish between good and defect-ridden modules by setting a previously determined acceptance threshold. In such a case, repeatability is more important than absolute values.

Applications: String testing standalone (Xinspect 3000s); string testing fully-integrated in layup system GL30 (Xinsepct 3500ic); standalone module testing pre-lamination, post-lamination without junction box, post-lamination with junction box (Xinspect 4000s). In-line module testing pre-lamination, post-lamination without junction box (Xinspect 4000i).

Platform: Electroluminescence and I-V curve measurement are available separately. Detection results and EL images are all stored in a database for further detailed statistical analysis. Customer-specific information such as cell type, batch number etc. can be stored with each measurement either manually or by barcode reader.

Availability: Currently available.

Product Briefings

KUKA

Cell stringer system from KUKA handles 750 cells per hour

Product Briefing Outline: KUKA has introduced the ACS 600 process tool, an advanced cell stringer system that has an output of 750 cells per hour and can process both polycrystalline and monocrystalline cells, from 160µm to 220µm in thickness, with two or three bus bars. The alignment accuracy range is less than ±0.2mm, while the breakage rate of the cells is less than 0.5%.

Problem: Early monitoring of cells for quality and possible cracks or breakage is of utmost importance for the entire module production process. Early defect detection prevents costly rejects later in the production cycle, thus reducing costs.

Solution: The key to the automatic string manufacturing process is the patented soldering technology, KUKA's SoftTempProfile. In a preliminary stage, the cells are pre-tempered from both sides in order to achieve the best possible reliable soldered connections with the patented temperature profile in the ensuing infrared soldering process. The cell string is subsequently cooled in a three-stage process that is continuously monitored. The load on the cells caused by the thermal induction is thus reduced and physical expansion of the cells and bars is prevented. The cells are positioned quickly and precisely by a KUKA KR 5 Scara with a vacuum suction gripper. A single handling process for the gripping of the cell, measurement and visual inspection under a stationary camera, solder application and positioning of the cells on the high-tech vacuum conveyor also reduces the load on the cells and minimizes potential sources of damage to the solar cells.

Applications: Solar cell stringing and inspection.

Platform: The KUKA ACS 600 is also available as the KUKA ACS 600/2 dual stringer with an hourly throughput of 1500 cells and integrated layup and string inspection.

Availability: Currently available.

OK International

OK International's thermal technology enhances PV tabbing and bussing soldering results

Product Briefing Outline: OK International has developed a proprietary 'SmartHeat' Technology, which consists of a high frequency alternating current (AC) power supply and a self-regulating heating element. The heater utilizes the electrical and metallurgical characteristics of two different metals: a magnetic material with high resistivity to reduce micro-cracking of solar cell substrates during the soldering operation, and copper.

Problem: Micro-cracking of delicate solar cell substrates is a common defect that can occur during PV tabbing and bussing soldering processes. The soldering temperature must be reduced to a minimum so that the solar cells are not subjected to mechanical or thermal stresses from the soldering process. During the soldering operation, differential thermal expansion of the copper and the silicon elements can occur at temperatures greater than 300°C. This differential can result in the formation of micro-cracks that may not be detected during the manufacturing process and result in reduced field lifespan. The need for precise time and temperature control is made additionally critical by the precise intermetallic layer requirement of 1-2µm that must be created during the solder joint formation.

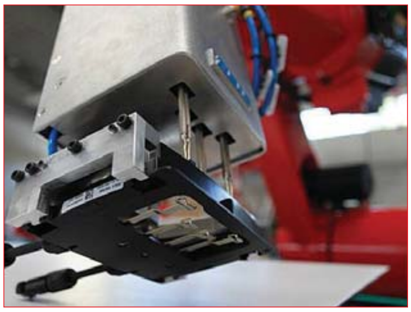
Solution: The SmartHeat PS-900 soldering system with specially designed STV-DRH440A hoof tip geometry optimizes the power delivered to the solder joint, thus providing high performance efficiency with increased tip life. Its temperature-sensitive "T" heater series ensures low temperature soldering, thus minimizing thermally-induced stresses on the surface of the solar cells.

Applications: c-Si cell tabbing and bussing soldering processes.

Platform: SmartHeat Technology consists of a high frequency alternating current (AC) power supply and a self-regulating heating element.

Availability: Currently available.

Reis Robotics



Reis Robotics' fully automated junction box assembly system

Product Briefing Outline: Reis Robotics has introduced a fully-automated assembly system for junction box mounting to modules. The system is designed to eliminate common faults in the mounting process that can be employed on new or existing production lines, virtually regardless of line MW capacity.

Problem: The quality and appearance of a solar module can be affected by the attachment of the junction box. Look and integrity are impacted when adhesives are not applied properly, joints are not made consistently and placement is not accurate.

Solution: The new system for fully automatic setting of the junction box is mounted on a platform completely ready for operation and thus, can be integrated in any existing production line with minimum expenditure. With this new concept, critical work steps before lamination are omitted such as foil stamping, manual threading of the contact leads, and no emerging EVA during lamination as well as the elimination of soiling of the membrane. It also avoids the risk of damaging the membrane during lamination due to protruding contact leads. Optimum cost savings can be achieved from both a materials and manual/automated labour perspective, also lowering breakage rates.

Applications: Full automation at the junction box process step can be implemented on new or existing lines. High volume production is not a prerequisite, as Reis has implemented this solution on lines as small as 20MW.

Platform: Reis Robotics offers a performance range from technology development, development of new production methods, planning and putting into practice individual production cells, as well as delivery and commissioning of complete production lines. The degrees of automation range from manual, semi-automatic up to fully automatic production lines in the ranges thin film, silicon and solar heat.

Availability: Currently available.

Snapshot of spot market for PV modules – quarterly report Q1 2010

pvXchange, Berlin, Germany

ABSTRACT
Solar enterprises will each be faced with the occasional surplus or lack of solar modules in their lifetimes. In these instances, it is useful to adjust these stock levels at short notice, thus creating a spot market. Spot markets serve the short-term trade of different products, where the seller is able to permanently or temporarily offset surplus, while buyers are able to access attractive offers on surplus stocks and supplement existing supply arrangements as a last resort.

Introduction

What will 2010 bring? That was the question on many an anxious module manufacturer's lips at the beginning of this year. The first weeks of Q1 had a note of uncertainty as the vast majority of manufacturers avoided answering the question of where the industry was bound. Overall, the industry experienced a difficult year in 2009, with a combination of the impact of the financial crisis, the collapse of the Spanish market, and huge falls in the price of solar modules due to growing capacity. Only those companies that had a good market position and strong sales dared to look to the New Year with anything resembling hope. However, this optimism seems to have been founded, as the international market continues to grow strongly at the end of Q1 2010. Even the supposed crisis of 2009 has ended with a healthy installed capacity of around 6.5GW, of which some 3.8GW is in Germany alone.

Although reductions in Germany's feed-in tariff will take effect this summer, the new FiT legislation being introduced by several other nations will spur intense growth later in the year. German consumers will most likely rush to install PV systems before that incentive becomes less compelling. A market correction will hopefully come about in the third quarter, culminating in a huge fourth quarter due to the onset of other countries' FiT deadlines in January 2011.

These insights are currently reflected on the international spot market. Globally, many module manufacturers made significant price reductions in January to coincide with the lowering of the German feed-in tariff on January 1st, 2010. Crystalline modules from Asia were 5% more popular on February's spot market than they were in December 2009, while the average selling price of modules from Europe-based manufacturers shows a similar trend. Silicon modules should also fall in price further, in line with the expected commodity prices of 2012.

Prices continued to fall in February, placing pressure on the Chinese manufacturers to reduce their margins. Many buyers will respond to the lower prices by stocking up with internationally known module brands that are guaranteed to be of good quality, and will for the most part be eligible for financing by banks. As a result, the relative cost of inverters, cabling, and frames for use within the PV systems will increase significantly.

Module demand

In the crystalline sector, polycrystalline modules from the largest Chinese manufacturers (Yingli, Suntech, CSI, Trina Solar...) have seen the most trading activity on the spot market. But March brought with it a change. Although prices are still falling slightly, the sharp decline seen in previous months has ceased. The fact that module prices in March are stable or slightly decreasing does not mean that all producers have decided on a price reduction. The stars of the Chinese manufacturers or their distributors have announced price increases almost every week while continuing to provide those who are not on the top rung of the Asian production ladder with their goods cheaper than ever before. Despite the fact that there are clearly enough modules on the market, bottlenecks continue to occur because the current high demand is dependent on a small number of producers, leading to price increases for the most coveted modules. A note of panic can be heard from the German market as everyone rushes to feather their own nests before

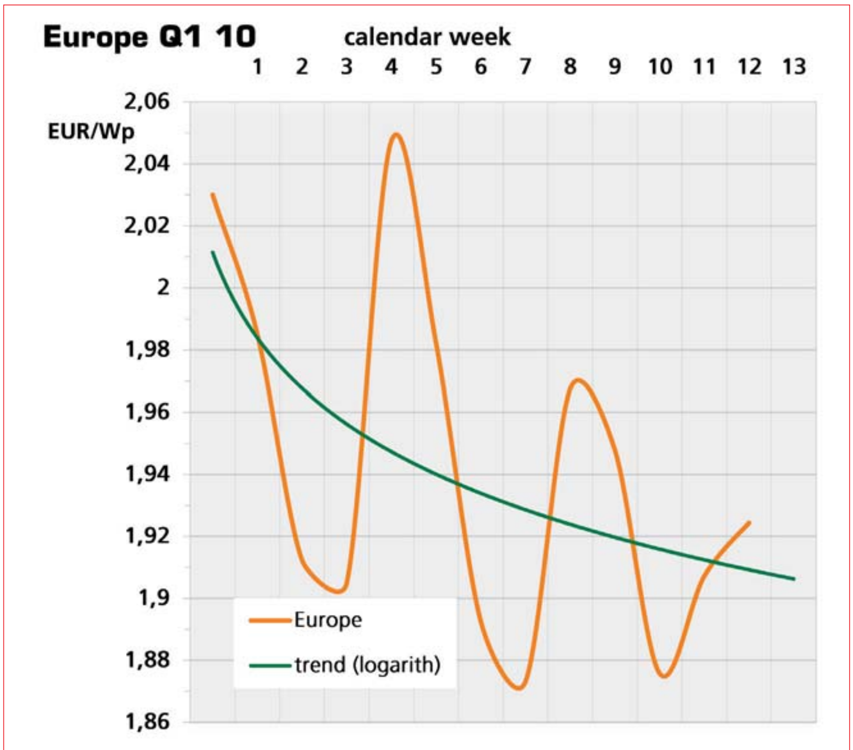


Figure 1. Development of module prices for modules produced by European manufacturers from January to beginning of April 2010.

July. With installing capacities fully utilized, products such as highly priced inverters pose bottleneck issues for many installations. This would be the right moment to look around on the market with an eye to purchasing innovative and quality products, with some products from European producers – Spain in particular – offering very good deals.

The high market demand coupled with the ceasing of price declines and the extra cut in Germany's FiT begs the question: Que sera, sera, what will it be like when the leading market loses some of its attraction?

Nevertheless, there are huge overcapacities in the whole value chain for 2010's industry. Ongoing mass production will bring further price reductions in solar installations over the course of the year. New impetus and direction will, however, not be provided by the Chinese manufacturers alone. Powerful Japanese companies have recently announced massive expansions of their solar businesses and the establishment of large thin-film production lines; for example, Japanese Shell's subsidiary Showa, which has announced plans to increase its production capacity tenfold to an annual 900MW. Sharp has also revealed that it expects to hit 1GW of thin-film production in 2010. This is not a bad idea when you take into account the continuing high sales of thin-film products on the spot market. Despite increasing prices, First Solar's modules were more expensive in Q1 than the partially polycrystalline modules of the most coveted Chinese producers. Sharp's microcrystalline modules have also done well in the last few months.

Other Japanese companies such as Kyocera, Mitsubishi and Toshiba are planning expansions of their solar businesses. Neither are South Korean competitors Samsung and LG Electronics allowing dust to settle on their plans. Manufacturers will get good prices for their products only if the markets grow as predicted in the coming years. In addition to strong brands, the efficiency of distribution channels will determine the economic success of these companies.

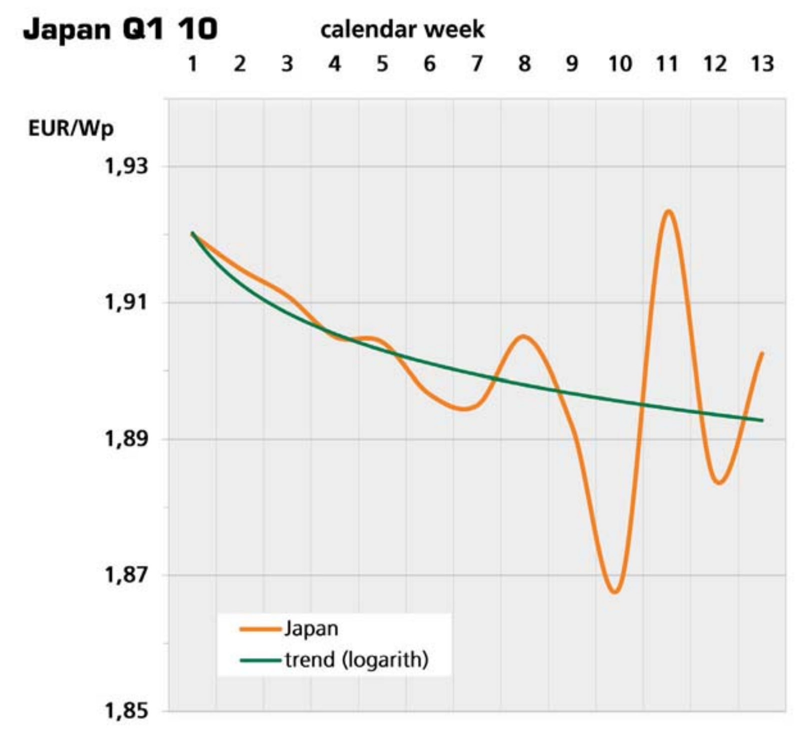


Figure 2. Development of module prices for modules produced by Japanese manufacturers from January to beginning of April 2010.

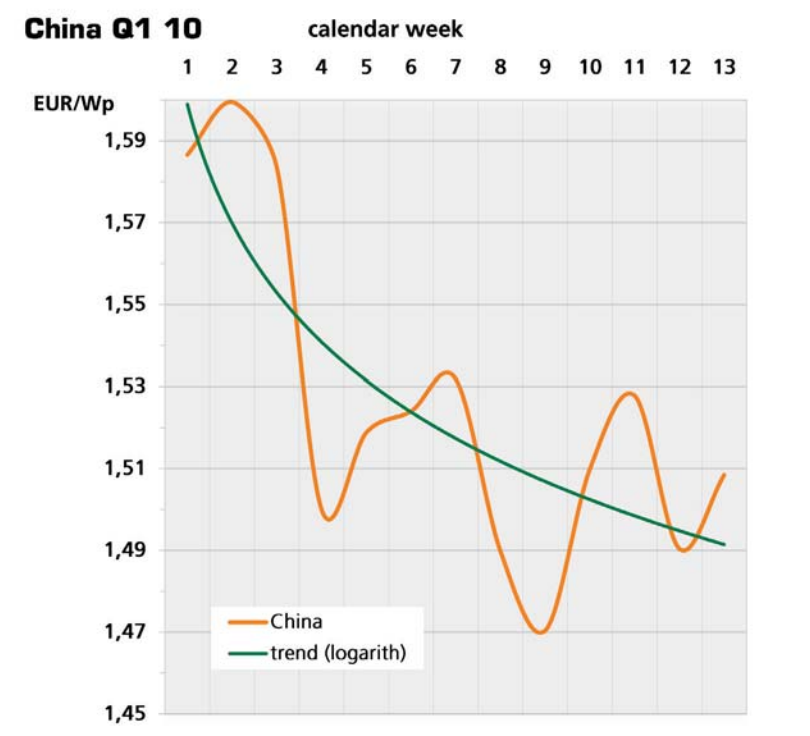


Figure 3. Development of module prices for modules produced by Chinese manufacturers from January to beginning of April 2010.

About the Authors

Founded in Berlin in 2004, **pvXchange GmbH** has established itself as the global market leader in the procurement of photovoltaic products for business customers. In 2009, the company procured solar modules with an output of around 75MW. With its international network and complementary services, pvXchange is constantly developing its position in the renewable energy market, a market which continues to grow on a global scale. Based in Europe, pvXchange also has a presence in Asia and the USA.

Enquiries

pvXchange GmbH
Obentrautstr. 57
D-10963
Berlin
Germany

Tel: +49 (0)30 236 31 36 0
Fax: +49 (0)30 236 31 36 23
Email: info@pvxchange.de
Website: www.pvxchange.com

Meet the pvXchange market experts at Intersolar Europe at booth A3.444.

Actual issues on power measurement of photovoltaic modules

Paul Grunow[1], **Alexander Preiss**[1,2], **Michael Schoppa**[1] & **Stefan Krauter**[1,2,3]
[1] Photovoltaik Institut Berlin, Germany; [2] University of Technology Berlin, Germany; [3] University of Applied Sciences Biberach, Germany

ABSTRACT

Power measurements of PV reference modules can, at standard testing conditions (STC), show tolerance deviations of up to ±3%, greatly affecting the maximum power output and thereby lowering the overall energy yield of the installation. Despite some existing technical problems, there is an urgent need on the part of the photovoltaic community to achieve more accuracy in power measurements in respect to the ever-growing production volumes. Some approaches being undertaken to carry out high-quality power measurements are addressed in this paper. The deviation from an ideal simulator performance are shown and discussed for two types of simulators, with reference to the most relevant parameters: irradiance level, deviation from homogeneity, spectral mismatch and temporal stability.

Introduction

Maximum power output P_{max} at standard testing conditions is directly related to the commercial value of photovoltaic modules (€/W_p). Its actual deviation from the nameplate value is a hot topic as it is the most obvious reason for reduced energy yields in the field. Other common explanations for low yields are factors such as bad system design or installation issues and/or poor performance ratios, instabilities or failures of the modules in the field. Deviations from P_{max} are the result of a combination of the width of the sorting classes used by the manufacturer, the uncertainty of the measurement by their sun simulator, and the tolerances of the reference module used for calibration. The reference modules are provided by independent institutes, which perform precision measurements in accordance with given international standards. Actual round-robin comparison tests demonstrate that the tolerances on STC power outputs show a deviation of ±3% for c-Si single-junction reference modules and even more for multi-junction cell modules.

$$Non-uniformity\,[\%] = \left[\frac{\max irradiance - \min irradiance}{\max irradiance + \min irradiance}\right] \times 100\%$$

Equation 1.

Deviation from homogeneity of irradiance

The definition for deviation from homogeneity or relative non-uniformity is given in IEC 60904-9:2007, Ed.2 as shown in Equation 1 below.

Figs. 1 and 2 show the measured deviation from uniformity of irradiance distribution for two different solar simulators.

According to IEC 60904-9:2007 Ed.2, the maximum deviation in uniformity for a class A sun simulator is ±2%. The measured uniformity of ±0.3% on a Pasan SSIIIb achieved that requirement very easily. Uniformity of a simple light-soaking test bench (class C) is given in Fig. 2. The standard states that the maximum non-uniformity is ±10%, which is 33 times higher than that of the Pasan simulator. The resulting effect of non-uniformity on the I-V characteristics of a PV module is shown in Fig. 3.

A uniformity of 2% – the permitted limit for a class A sun simulator – leads to an underestimation of up to 1.7% of STC power output (P_{max}) as shown in Fig. 3. The actual deviation depends on the mismatch of the short-circuit currents of the cells or balance of currents in the module.

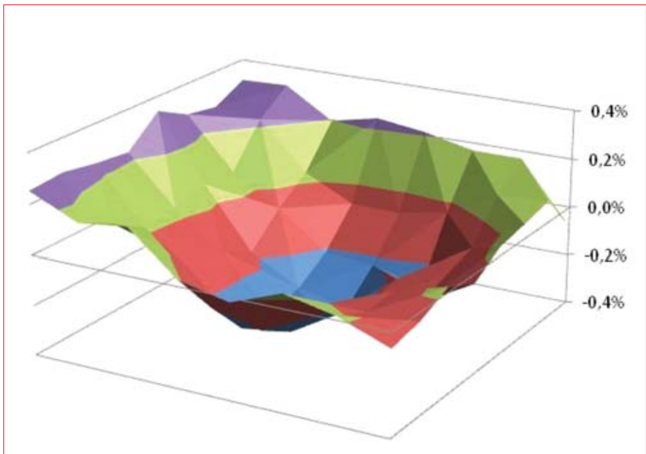


Figure 1. Deviation from uniformity distribution of irradiance on a 3.0m × 3.0m plane of measurement for a class A sun simulator (Pasan SSIIIb).

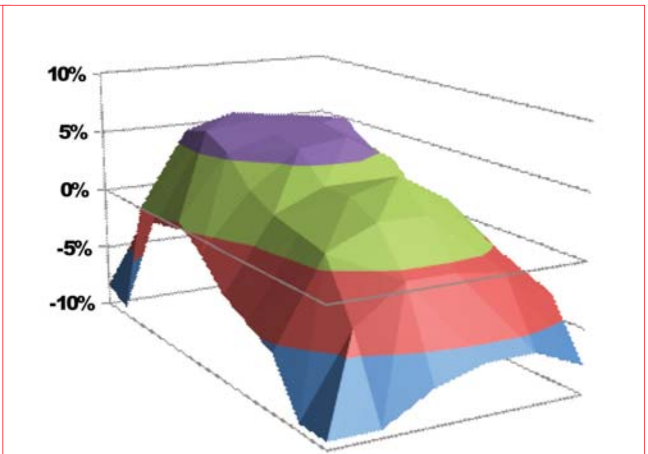


Figure 2. Deviation from uniformity distribution of irradiance of a class C sun simulator (PI light soaker using 8 HQI lamps at PI Berlin) on a 2.2m × 1.3m plane.

For the most relevant characteristics of a module (I_{sc}, P_{max}, FF, V_{oc}), the effects brought about by the deviation of irradiance from uniformity on the change power output measurement are demonstrated in Fig. 4.

As can be observed in Fig. 4, the decrease in uniformity leads to a slight increase in FF, but an overall drop of P_{max} as a result of the dominating decrease of I_{sc}. We must conclude that uniformity of irradiance is quite relevant for the correct measurement of P_{max}. It is usually not possible to correct the measurement by a simple factor for compensation, but the Pasan IIIb sun simulator showed a minimal error due to this effect.

Spectral mismatch of the simulator spectrum

The IEC 60904-9:2007 Ed.2 standard states that a class A simulator is allowed to deviate less than ±25% from the AM 1.5_G spectrum (as defined in IEC60904-3 Ed.1). It also says that a class B simulator should deviate less than ±40% and a class C sun simulator less than -60%/+100%.

In order to overcome the problems posed by different spectra, a correction factor for the current depending on the spectrum of the sun simulator – the Mismatch Factor (MMF) – is introduced. The MMF is a correction of the current of a test specimen according to IEC 60904-7:1998 Ed.2, as shown in Equations 2 and 3. MMF is essentially a function of the relative spectral response of the specimen and the reference cell, and of the mismatch between the reference spectrum (AM 1.5_G) and the spectrum of the sun simulator. Only the current is affected by this correction, and, as a consequence, the current P_{max}.

$e_{STC}(\lambda)$ relative reference spectrum AM1.5_G

$e_{sim}(\lambda)$ relative simulator spectrum

$s_{TC}(\lambda)$ relative spectral response of the Test Cell

$s_{RC}(\lambda)$ relative spectral response of the reference cell (e.g. WPVS)

$$I_{SC}^{AM1.5} = \frac{1}{MMF} \cdot I_{SC}^{Simulator}$$

Equation 2.

$$MMF = \frac{\int_{\lambda_{01}}^{\lambda_{e1}} e_{STC}(\lambda) s_{RC}(\lambda) d\lambda}{\int_{\lambda_{01}}^{\lambda_{e1}} e_{sim}(\lambda) s_{RC}(\lambda) d\lambda} \cdot \frac{\int_{\lambda_{00}}^{\lambda_{e0}} e_{sim}(\lambda) s_{TC}(\lambda) d\lambda}{\int_{\lambda_{00}}^{\lambda_{e0}} e_{STC}(\lambda) s_{TC}(\lambda) d\lambda}$$

Equation 3.

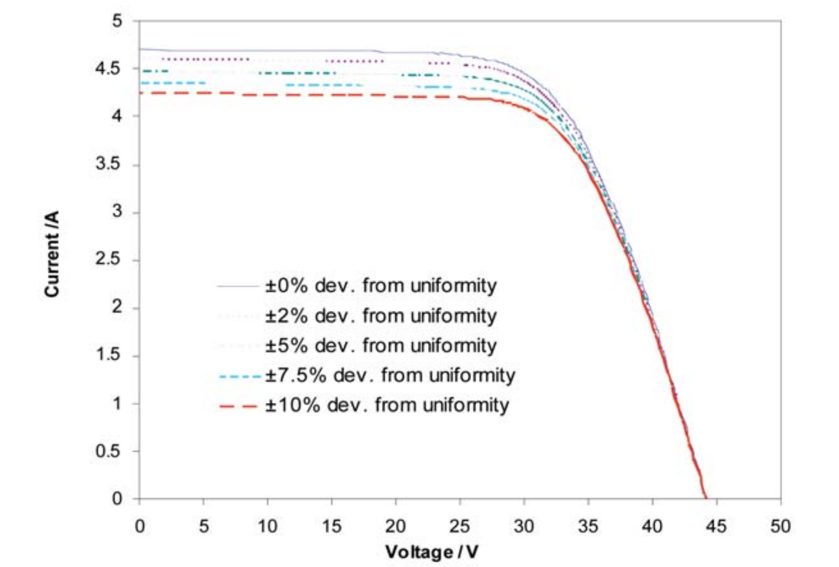


Figure 3. Change of I-V characteristics using the deviation from uniformity of a sun simulator as a parameter. The curve of this module has been calculated by summing up the voltages at equivalent currents of the single cell curves involved. The currents were then modified with the deviation from uniformity of irradiance in the plane of measurement as described in [1].

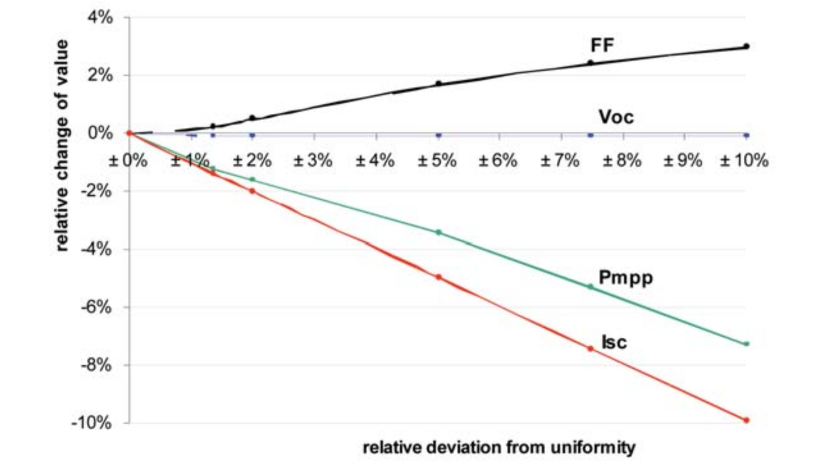


Figure 4. Change of curve parameters FF, V_{oc}, P_{max} and I_{sc} as a function of the simulator's deviation from uniform irradiance on the test plane (as shown in Fig. 1). Graph shows a slight increase in FF and a strong decrease in I_{sc}, leading to a decrease in P_{max} (P_{mpp}). Test conducted on a module comprised of 60 crystalline silicon cells.

Fig. 5 shows the measured spectral deviation of the Pasan class A sun simulator from the AM 1.5_G spectrum and of the aforementioned light-soaking test bench. As expected, the class C simulators will produce larger scattering in P_{max} than the class A simulator. The larger spectral deviation from AM 1.5_G results in larger spectral mismatch correction factors for the modules and therefore in an increased uncertainty of P_{max}. The uncertainty of P_{max} is caused by the uncertainty of the spectral response of each test specimen.

Modern class A simulators (as the Pasan SSIIIb) show spectral mismatches of less than ±6% for all spectral intervals over the whole time interval of the flash duration, as demonstrated in Fig. 6 (measurement by PI, Pasan and TÜV Rheinland). Due to the increasing bulb temperature during the measuring period of 8ms, the blue part of the spectrum increases at the final part of the measurement and therefore the mismatch factor MMF changes slightly (by less than 0.001). This leads to a change of less than 0.1% in P_{max} for single-junction cells.

The Pasan SSIIIb sun simulator at PI Berlin saw an MMF variance of ±0.4% for all single-junction cell technologies

(relative to a MMF of 1.007 for single-crystalline silicon). The 'secondary reference' is provided by PTB (German National Institute for Scientific and Technical services), which is referred to their primary reference in cooperation with NREL (National Renewable Energy Laboratory) in the USA, JQA (Japan Quality Assurance Organization) in Japan and TIPS (Tianjin Institute of Power Sources) in China. Fig. 7 shows the MMF for different single-junction cell technologies.

For single-junction-celled modules the MMF is a simple function of the spectral response and the spectrum of the sun simulator. The deviations from true P_{max} are caused by variation of spectral response within the technologies. The current mismatch between top and bottom for tandem cells is even more sensitive to the simulator spectrum than single-junction cells, as shown in Fig. 8.

Fig. 9 shows the spectral responses of a tandem cell. The top cell absorbs the bluish, and the bottom cell the reddish part of the irradiance. The current mismatch of both cells depends on the spectrum, thickness, and absorption coefficient of both layers. As the mismatch between the top and the bottom cell at AM 1.5_G lowers P_{max} at STC, it also needs to be minimized for AM1.5_G. Optimizing the energy yield per module also accounts for the degradation in-field and real sky spectra at a certain location.

The standards currently propose mismatch correction using outdoor data at clear sky conditions close to AM 1.5_G (diffuse share <30%). Though spectral mismatch corrections for these cells is not feasible within a straightforward correction algorithm, the spectrum of the simulator needs to match AM 1.5_G (IEC 60904-3 Ed.2) as closely as possible.

The class A simulator being used in this experiment differs by 3% to AM 1.5_G in terms of current mismatch between the top and bottom cell for three different tandem cells under test, as shown in Fig. 8. In accordance with the difference in uniformity effect of P_{max} and I_{sc}, an additional error of ±1% was estimated for P_{max} due to the actual spectrum of the Pasan SSIIIb simulator at PI Berlin.

Transient effects

The time taken to trace through and measure a whole I-V curve of a PV module in a sun simulator is known as sweep time. For modules with transient effects (such as CIGS, CdTe, CIS, and high-efficiency single-crystalline Si modules) the sweep time affects the measured P_{max}. In a simple model this effect can be described as a capacity in parallel to the generator, which has to be charged and discharged during the I-V tracing and the corresponding measurements. In order to avoid deviation in P_{max} brought about by transient effects,

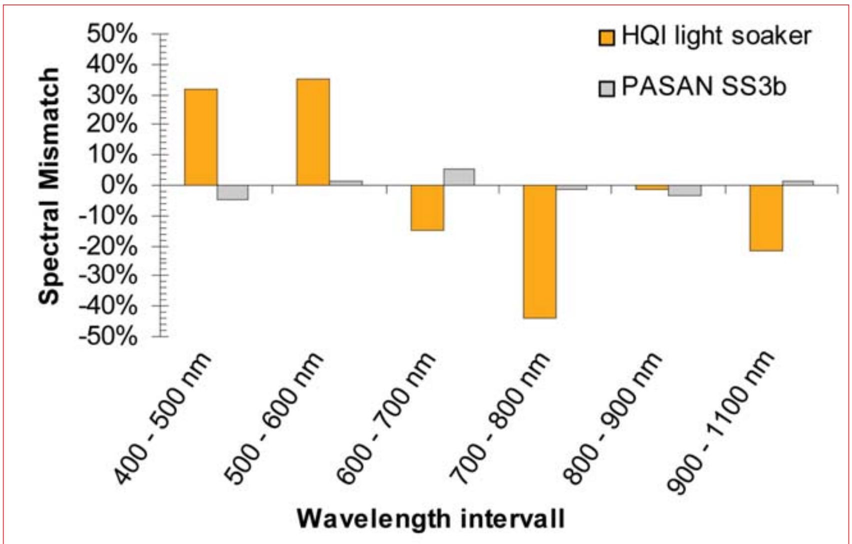


Figure 5. Deviation from AM 1.5_G of two different solar simulators. Class C simulators will produce even larger scattering of P_{max}, because their spectral deviation from AM 1.5_G results in larger spectral mismatch factors for the modules under test.

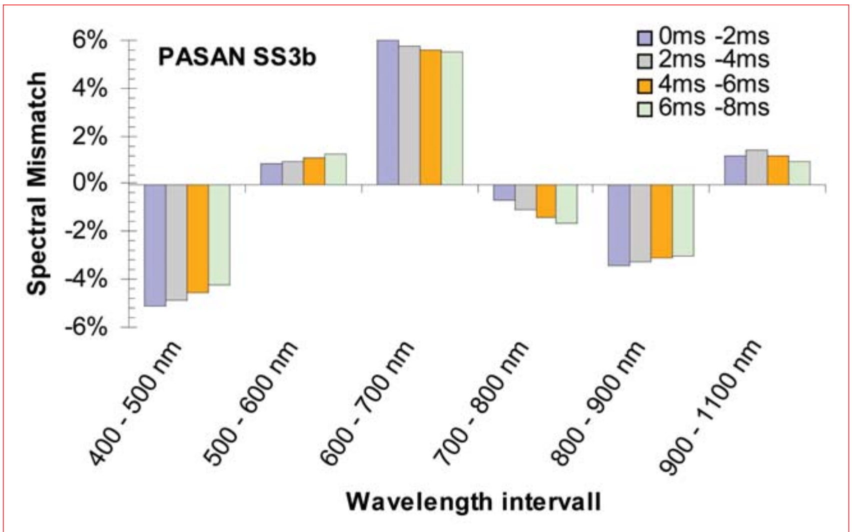


Figure 6. Relative spectral mismatch compared to the AM 1.5_G reference spectrum as a function of flash duration of the Pasan SSIIIb sun simulator (measurements by TÜV Rheinland).

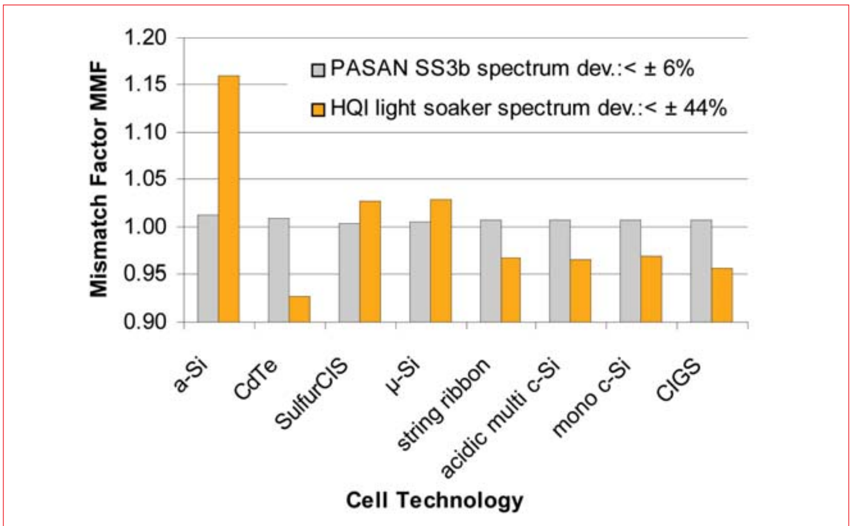
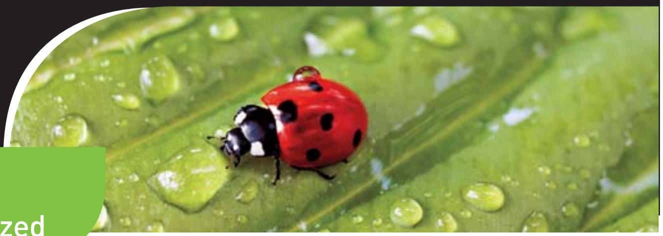
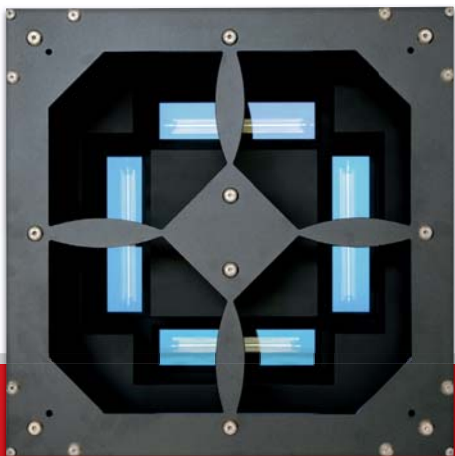


Figure 7. Spectral mismatch factor for different solar cell technologies at two different solar simulators.





it is necessary to sweep through the I-V curve using an appropriate time to allow charging of that capacity.

The graph in Fig. 10 shows the I-V curves resulting from the use of different sweep times for a CIGS module. The effects on the resulting P_{max} for different technologies are shown in Fig. 11.

The maximum sweep time of the Pasan SSIIIb is 8ms, which proved to be sufficient for standard a-Si, mc-Si, and sc-Si modules (max. deviation of 0.5%). For the technologies shown in Fig. 11, a partial trace trough the I-V curve during the sweep time of 8ms is recommended in order to reduce measurement errors.

Conclusion & outlook

In our experience, energy rating is most critical for thin-film technologies. For tandem-junction structures of e.g. µ-Si/a-Si, prediction of energy yield is complicated because of the interdependence of degradation and spectral effects. The main factors of uncertainty for STC measurements are given in Fig. 12.

The uncertainty of the P_{max} measurement with a secondary reference from PTB in WPVS design leads to a combined expanded uncertainty of P_{max} at ± 2.2% for U95 (coverage factor k = 2) for single-junction modules.

"For modules with transient effects, the sweep time affects the measured P_{max}."

The error bars are garnered from c-Si modules measured at PI Berlin with their individual deviations from average values for the temperature coefficients $\beta = -0.33\%/K$; $\alpha = 0.06\%/K$; curve correction factor $\kappa = 6.7 \cdot 10^{-4} \Omega/K$ and the spectral mismatch of MMF = 1.007 with the Pasan SSIIIb sun simulator at PI Berlin, broken down as follows:

1. Spectrum deviation from AM 1.5_G, IEC 60904-3 Ed. 2

   400–500nm: -5%;

   500–600nm: 1%

   600–700nm: 6%

   700–800nm: -1%

   800–900nm: -3%

   900–1100nm: 1%

2. Deviation from uniformity: ± 0.3% on 3m × 3m plane

3. Temporal stability (deviation 0.5%).

The combined expanded uncertainty of P_{max} for tandem cell modules is 2.9% (k = 2) including an additional error of ±1.1% for the current mismatch experienced with that simulator spectrum.

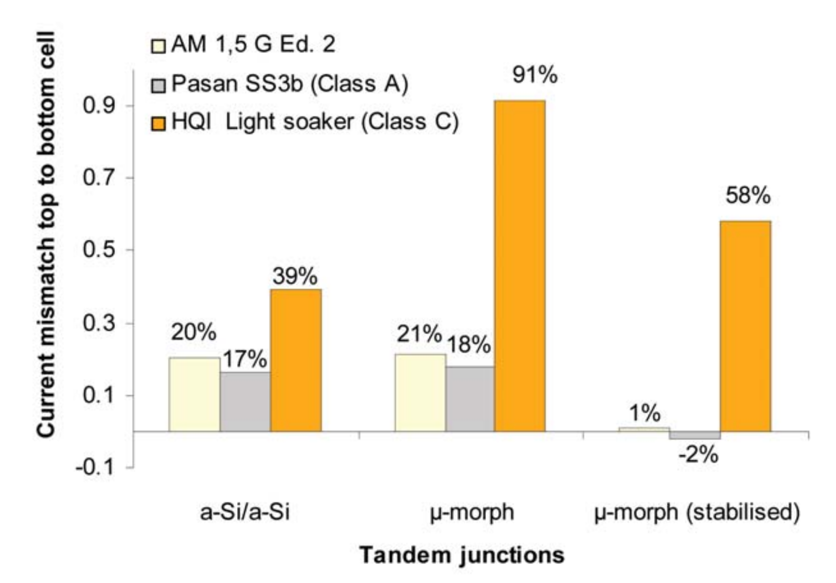


Figure 8. Mismatch of electrical currents between top and bottom cell for different spectra and tandem cell technologies (always in combination with a-Si as top cell). Although the cells are connected in series, the cell with the lowest current determines the performance.

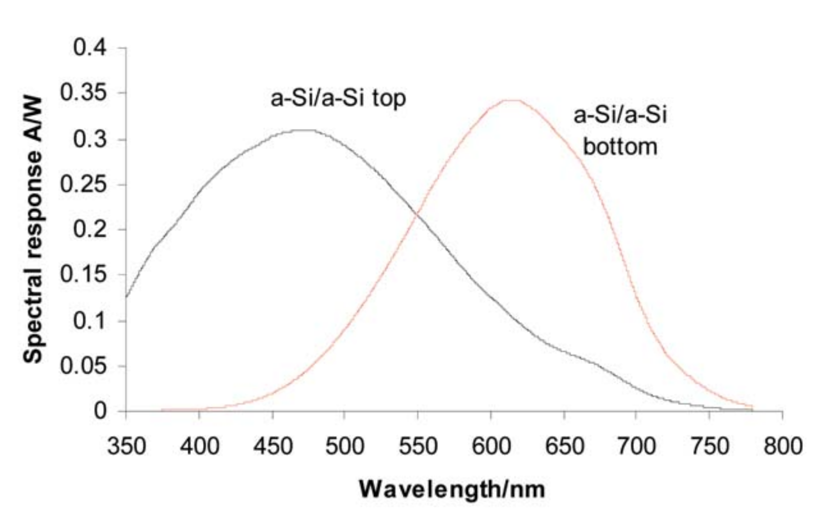


Figure 9. The spectral response of a tandem cell, showing the spectral responses of the top and bottom cell independently.

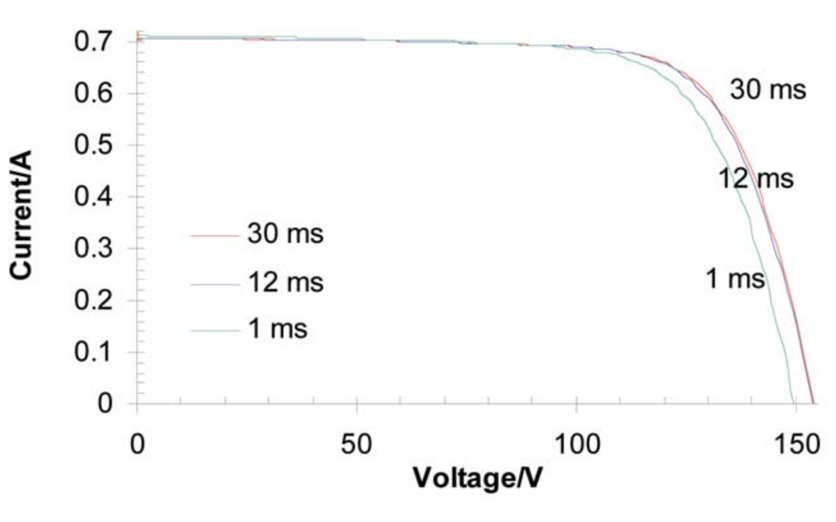


Figure 10. I-V curves resulting from use of different sweep times for CIGS.

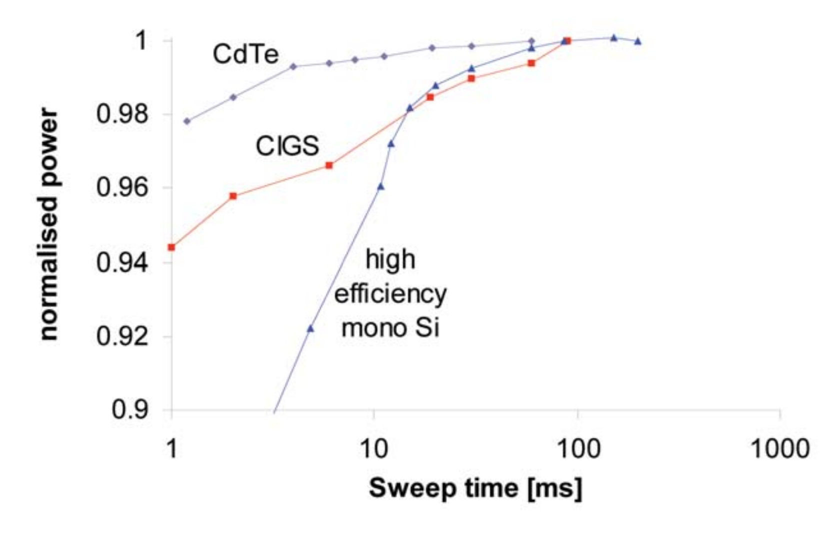


Figure 11. Normalized power for different technologies vs. sweep time. The 'high efficiency mono-Si' cells are high-end back-contact sc-Si cells with efficiencies above 20%).

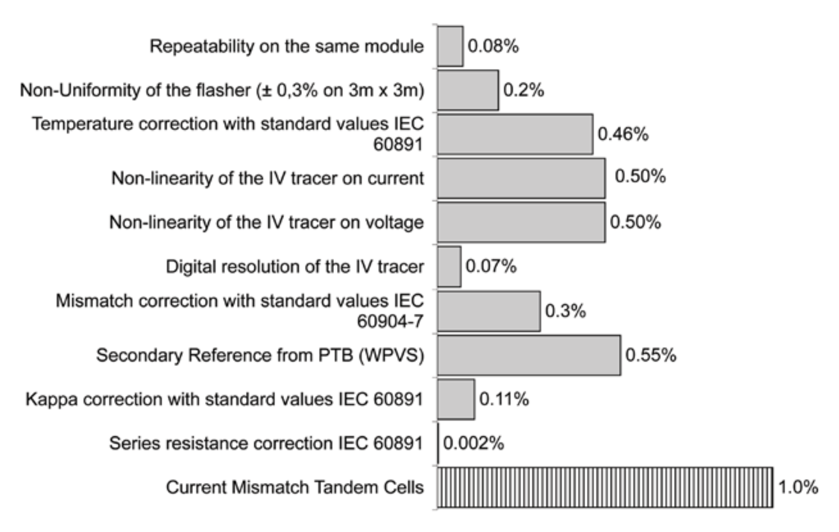


Figure 12. Uncertainties of P_{max} measurements.

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About the Authors

Prof. Stefan Krauter received his Ph.D. in electrical engineering on the topic of 'Performance modelling of PV modules' from the University of Technology Berlin in 1993. In 1996 he co-founded Solon, and in 1997 he received a visiting professorship for PV systems at UFRJ-COPPE in Rio de Janeiro, and later at UECE in Fortaleza. On his return to Germany in 2006, he co-founded the Photovoltaic Institute Berlin where participates in the board of directors and acts as a senior consultant. He is a professor for PV Energy Systems at TUB and at the Biberach University for Applied Sciences (HBC).

Dr. Paul Grunow received his Ph.D. in physics in 1993 on 'Analysis of dynamics of charge carriers in Silicon and Silicon solar cells via photo-induced deflection of laser beams' from the Hahn Meitner Institute (now the Helmholtz-Center) and at the University of Technology Berlin (TUB). He pursued his post-doc studies on thin-film solar cells at the Federal University of Rio de Janeiro in Brazil (UFRJ-COPPE) and co-founded Solon AG in 1996. Together with Reiner Lemoine, he founded Q-Cells AG in 1998 and in 2006 he co-founded the Photovoltaic Institute Berlin where he is a member of the board of directors and acts as a senior consultant. He also lectured at the University of Applied Sciences for Technology and Economics Berlin (FHTW).

Michael Schoppa is head of the accredited and internationally accepted PV-testing laboratory of the PI Berlin AG. Since 2004, he has been a research associate at the Monash University in Melbourne, Australia and later worked at the Hahn Meitner Institute in Berlin where he was engaged in long-term stability on new solar concepts. From 2006 to 2007 he worked as a project engineer for TÜV Rheinland in the domain of international certifications. In addition to the formation of PI Berlin's PV-testing laboratory and quality management, Michael led the laboratory to national accreditation in 2008 and admission to the international CB Scheme (NCBTL) in 2009.

Alexander Preiss is responsible for the PV-Outdoor laboratory of PI Berlin AG, which is run in cooperation with the University of Technology in Berlin. From 2000 until 2007 he studied physics at the Humboldt University in Berlin and received his Master's degree in experimental solid-state physics. In his thesis he worked out a feasibility study for the optimization of CIS solar cells at the Hahn Meitner Institute. In 2007, he began the set-up of the outdoor laboratory of the PI Berlin AG and started his Ph.D. in the Department of Electrical Drives on 'Yield Simulation of PV generators' at the University of Technology Berlin.

Enquiries

Photovoltaik Institut Berlin
Wrangelstr. 100
10997 Berlin
Germany

University of Technology Berlin
Sek. EM 4
Einsteinufer 11
10987 Berlin
Germany

University of Applied Sciences Biberach
Energy Systems
Karlstr. 11
88400 Biberach
Germany

Email: grunow@pi-berlin.com

PV Modules

Testing the reliability and safety of photovoltaic modules: failure rates and temperature effects

Govindasamy TamizhMani, TÜV Rheinland PTL & Arizona State University, Tempe, Arizona, USA

ABSTRACT

Photovoltaic modules are designed to meet the reliability and safety requirements of national and international test standards. Qualification testing is a short-duration (typically, 60-90 days) accelerated testing protocol, and it may be considered as a minimum requirement to undertake reliability testing. The goal of qualification testing is to identify the initial short-term reliability issues in the field, while the qualification testing/certification is primarily driven by marketplace requirements. Safety testing, however, is a regulatory requirement where the modules are assessed for the prevention of electrical shock, fire hazards, and personal injury due to electrical, mechanical, and environmental stresses in the field. This paper examines recent reliability and safety studies conducted at TÜV Rheinland PTL's solar module testing facility in Arizona.

Introduction

TÜV Rheinland PTL (formerly Arizona State University Photovoltaic Testing Laboratory) has been involved in PV testing and standards development activities for over 18 years. TÜV Rheinland PTL, a joint venture between TÜV Rheinland and ASU, is one of six TÜV Rheinland laboratories around the globe. The Arizona branch was created in October 2008 with additional testing services, capabilities, test/engineering personnel, and indoor (40,000 square feet) and outdoor test areas (five acres). The PV module testing and applied research activities at TÜV Rheinland PTL and ASU include:

- Performance at standard test conditions
- Performance at nonstandard test conditions
- Performance characterizations as per Sandia National Laboratory method
- Design qualification testing of flat-plate PV modules (IEC 61215, IEC 1646)
- Design qualification testing of concentrator PV modules (IEC 62108)
- Safety testing of flat-plate modules (IEC 61730, ANSI/UL 1703)
- Evaluation of polymeric components used in PV modules
- Reliability research to predict lifetime of modules in the field.

The results of various qualification and safety testing conducted at TÜV PTL are presented in this paper. The first section discusses the failure rates obtained in the qualification testing of flat-plate modules (per IEC 61215 and IEC 1646 standards) over 13 years [1,2]. The second discussion centres on one of the major safety tests (per IEC 61730 and ANSI/UL 1703 standards) – the 'temperature test' [3,4]

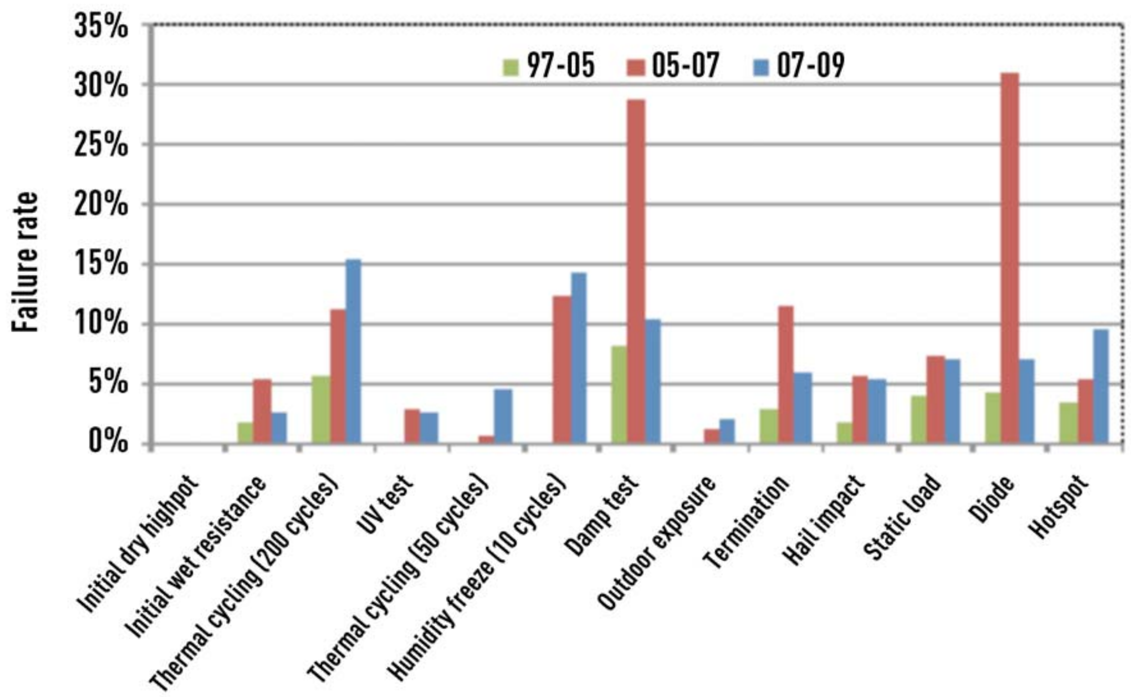
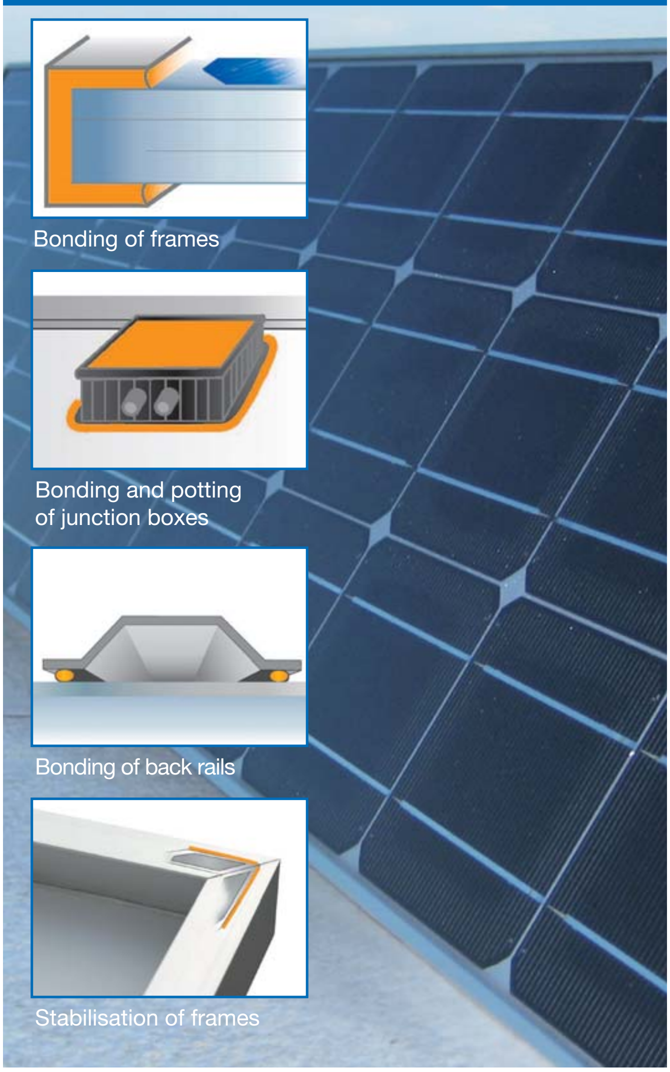


Figure 1. Failure rate comparison of crystalline silicon modules for 1997-2005, 2005-2007 & 2007-2009.



Bonding of frames
Bonding and potting of junction boxes
Bonding of back rails
Stabilisation of frames

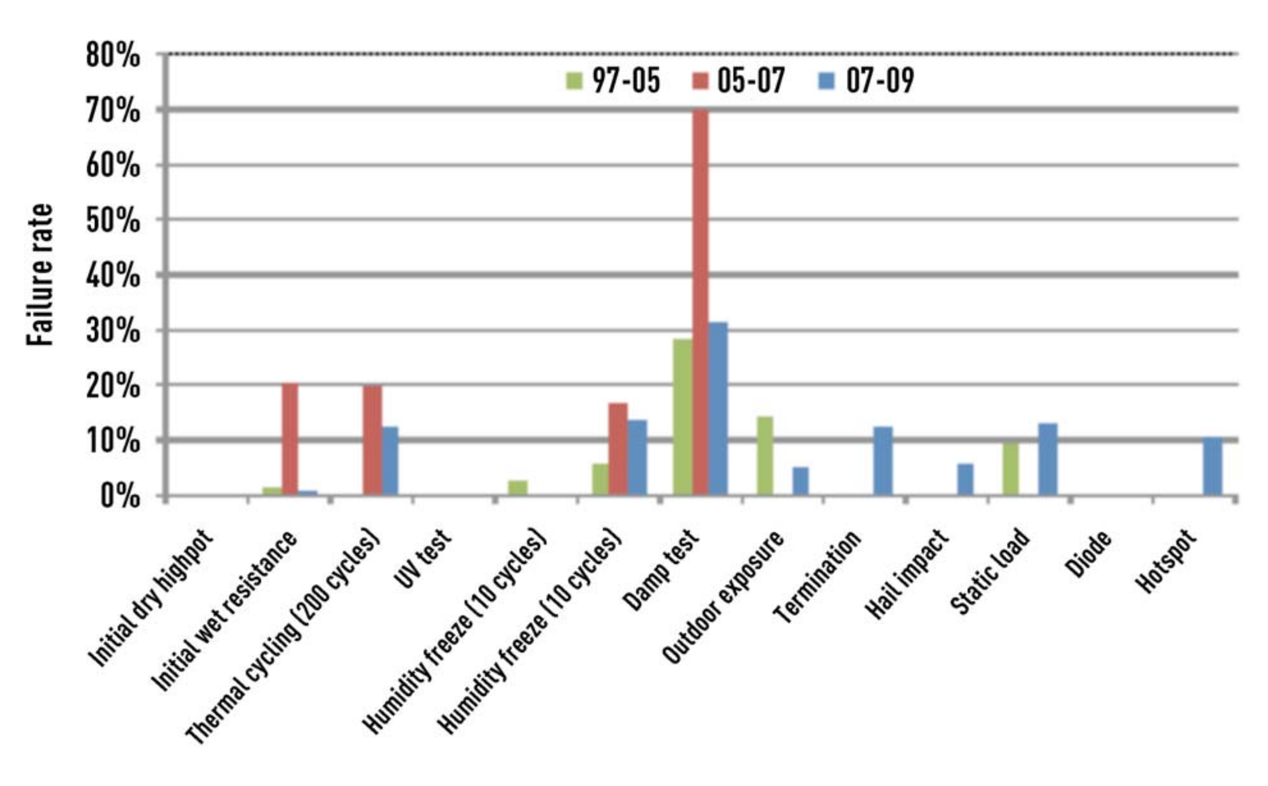


Figure 2. Failure rate comparison of thin-film modules for 1997-2005, 2005-2007, and 2007-2009.

– with results obtained for more than 140 modules compared with data obtained on actual rooftop PV modules.

Module reliability: failure rates in qualification testing

Qualification testing is a set of well-defined accelerated stress tests – irradiation, environmental, mechanical and electrical – with strict pass-fail criteria based on functionality/performance, safety/insulation, and visual requirements. The qualification testing does not, as anticipated, identify all the possible lifetime/reliability issues that would be encountered in the field; however, it does identify the major/catastrophic design quality issues that would initially occur in the field. The type, extent, limits, and sequence of the accelerated stress tests of the qualification standards have been stipulated with two goals in mind: one, accelerate the same failure mechanisms as observed in the field but without introducing other unknown failures that do not occur in the actual field; and two, induce these failure mechanisms in a reasonably short period of time (60-90 days) to reduce testing time and cost. As an ISO 17025 accredited laboratory, TÜV Rheinland PTL has tested more than 5,000 photovoltaic modules from nearly 20 different countries and issued several hundred qualification certificates.

The following section presents a failure analysis of the design qualification testing of both crystalline silicon and thin-film modules for three consecutive, multiyear periods: 1997-2005, 2005-2007 & 2007-2009. A detailed analysis of the failure rates in the qualification testing is presented elsewhere [5].

> "About 3% of the crystalline silicon modules failed in the initial wet resistance test right out of the box."

In the 1997-2005, 2005-2007, and 2007-2009 periods, about 1,200 (87% c-Si), 1,000 (93% c-Si), and 1,470 (83% c-Si) modules, respectively, were tested for the qualification certification. In the latter two periods, about 52% and 39% of them, respectively, were manufacturers that were new to the test laboratory.

Fig. 1 shows a comparison of the failure rates of crystalline silicon modules in various initial and stress tests for the 1997-2005, 2005-2007, and 2007-2009 periods. For the latest timeframe, the thermal cycling 200 test, humidity freeze test, damp heat test, and hot spot test showed the highest failure rates of 15%, 14%, 10%, and 10%, respectively. About 3% of the crystalline

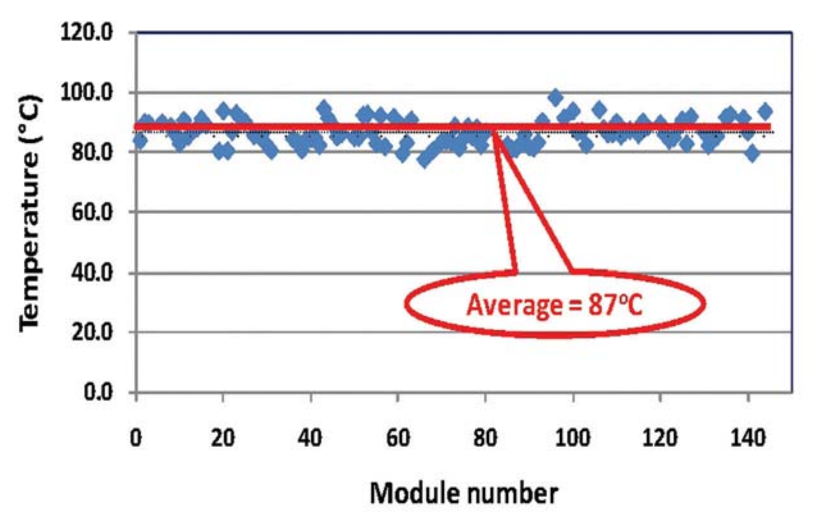


Figure 3. Normalized cell temperature, standard testing (ambient temperature 40°C; irradiance 1000W/m²).

silicon modules failed in the initial wet resistance test right out of the box, a result that could have been easily avoided if the module manufacturers had implemented the wet resistance test in the production line.

For the purposes of this paper, the analysis represented in Fig. 1 is limited to only the two longest duration (about 42 days) but most stringent tests for the three time periods, namely, the damp heat test and the thermal cycling 200 test. While it is interesting and comforting to see that there has been a decrease in failure rates in damp heat testing from 29% (2005-2007) to 10% (2007-2009), this 10% failure rate is still higher than the rate of the modules tested in the 1997-2005 period (8%). Considering that these modules are expected to have 20-25 years of lifetime in humid climatic conditions, the 10% failure rate may not be acceptable to consumers.

As for the thermal cycling 200 test results, it is a little discouraging to see an increase in the failure rate from 11% (2005-2007) to 15% (2007-2009). When the testing data from the entire 13 years are examined, the top four test failure categories in the qualification testing of c-Si modules have been determined to be damp heat, thermal cycling, humidity freeze, and diode.

Figure 4. Simulated rooftop structure in the testing yard (front view, bottom row = 0-in. air gap; top row = 4-in. air gap).

Fig. 2 shows the failure rate of thin-film PV modules in various initial and stress tests for the 1997-2005, 2005-2007, and 2007-2009 periods. For the most recent timeframe, the damp heat test (31%) and humidity freeze test (14%) showed the highest failure rates, followed by the static load, termination, and thermal cycling 200 tests (12-13%). About 1% of the thin-film modules failed in the initial, right-out-of-the-box wet resistance test.

As in the c-Si module analysis, for the purposes of this article, the comparative analysis for thin-film modules is limited to only the longest duration tests – damp heat and thermal cycling 200. A dramatic decrease in failure rate in the damp heat

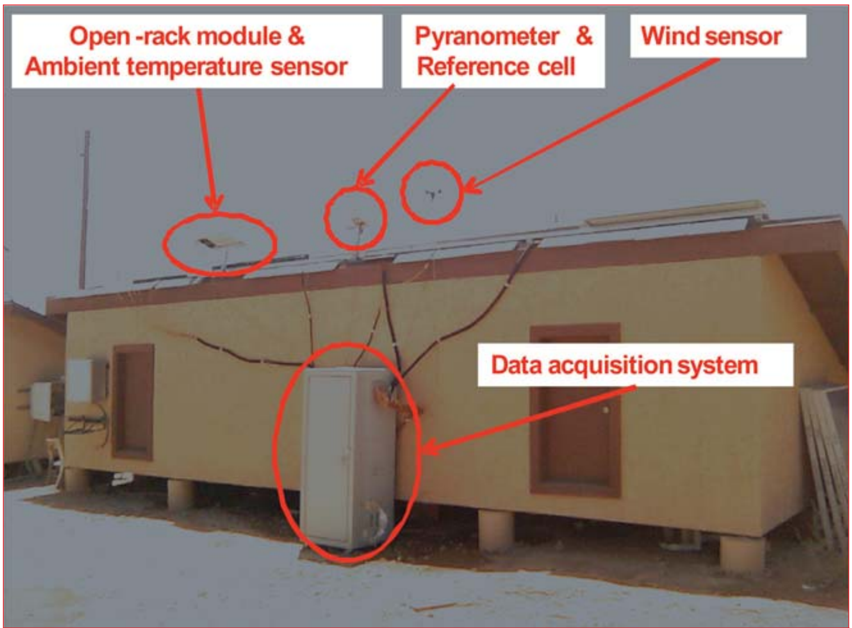


Figure 5. Simulated rooftop structure in the testing yard (rear view, with various sensors and DAS).

test can be seen, going from 70% (2005-2007) to 31% (2007-2009). Since the modules are expected to have 10-20 years of lifetime in humid climates, this 31% failure rate will certainly not be acceptable to consumers.

Encouragingly, the failure rate for the thermal cycling 200 test has fallen from 20% (2005-2007) to 12% (2007-2009). An examination of the data from the 13 years of testing reveals that the top four test failure mechanisms in the qualification testing of thin-film modules are damp heat, thermal cycling, humidity freeze, and static load.

Rooftop PV module safety: temperature effects

The operating temperatures of various components of rooftop PV modules are dictated by various parameters, including ambient temperature, irradiance, wind speed, bias condition (open-circuit, short-circuit, maximum-power point and shading), and installation configuration (air gap between module and roof surface). In hot climatic conditions, such as Arizona, the module temperature could reach as high as 85°-95°C, depending on the mounting configuration. In the following section, a brief comparison of the test results obtained during the temperature tests (per IEC 61730 and ANSI/UL 1703 standards) and the test results obtained on the actual rooftop installed modules are presented. The detailed results related to these studies are discussed elsewhere [6,7].

The purpose of the temperature test identified in the safety standards is to ensure that no part of the module attains a temperature that would ignite materials or components, exceed the temperature limits of materials, and cause creeping, distortion, sagging, or charring. The IEC 61730 and UL 1703 temperature test method closely mimics the close-roof (direct mounting) model. During the temperature test, the operating temperatures of nine components of each module were monitored and recorded under prevailing field conditions. These components include front glass (superstrate), substrate (polymer backsheet), cell, junction-box ambient (inside volume), junction-box surface (inside surface), positive terminal (inside the junction box), junction-box backsheet (polymer backsheet inside the junction box or bottom surface of the J-box), field wiring, and diodes. The component temperatures were then normalized, as shown in Equation 1, to those expected for an ambient temperature of 40°C and 1000W/m² plane-of-array irradiance as required by the standards.

The normalized temperature (in °C) of each component was calculated using the following equation:

$$T_{norm} = (T_{max} - \text{Mean } T_{amb}) \times \frac{1000}{\text{Mean Irradiance}} + 40 \quad (1)$$

where T_{norm} is the normalized temperature, T_{max} is the maximum component temperature during the test, and T_{amb} is the ambient temperature during the test.

In this paper, only the normalized cell temperatures obtained under open-circuit condition (standard testing) are compared with the monitored cell temperatures of rooftop modules under open-circuit condition (rooftop testing). Fig. 3 shows the temperature test results for the open-circuit condition obtained for approximately 140 c-Si modules (with glass/cell/polymer packaging) from approximately 60 different manufacturers during 2006-2009.

A simulated rooftop structure was designed and installed at ASU's Photovoltaic Reliability Laboratory in Mesa, Arizona. The concrete flat-tile roof was 32 feet by 17.5 feet, with a south-facing orientation and a pitch from horizontal of 23 degrees. Front- and rear-view photographs of the simulated rooftop structure are shown in Figs. 4 and 5, respectively.

The array and module installation specifications of the roof were as follows:

- Test technologies: mono-Si and poly-Si
- Module electrical termination: open circuit

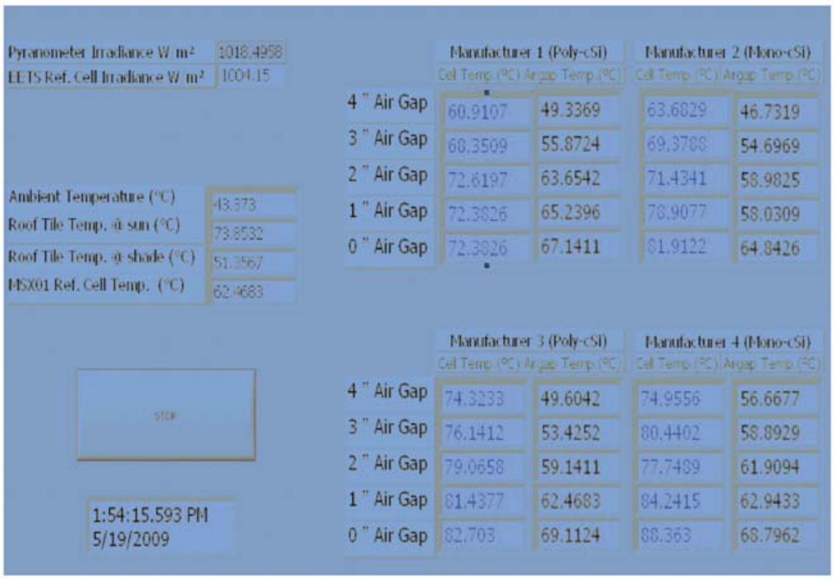


Figure 6. A screenshot of front panel of data acquisition system (cell temperature = thermocouple under the cell; air-gap temperature = temperature between module laminate and roof tile).

PV Modules

- Number of test modules: 20 (10 mono-Si; 10 poly-Si)
- Array matrix: four columns (five modules each) x five rows (four modules each):
  - Column 1: poly-Si (manufacturer 1)
  - Column 2: mono-Si (manufacturer 2)
  - Column 3: poly-Si (manufacturer 3)
  - Column 4: mono-Si (manufacturer 4)
  - Row 1 (bottom row): 0-in. air gap
  - Row 2: 1-in. air gap
  - Row 3: 2-in. air gap
  - Row 4: 3-in. air gap
  - Row 5 (top row): 4-in. air gap
- Distance between modules in each column: 2-6 in.
- Distance between modules in each row: 1 in.
- Depth of module frame: ~2 in.

The monitored parameters on the rooftop test bed and details of data acquisition system (DAS) were as follows:

- Irradiance:
  - Plane-of-array irradiance using a pyranometer (Eko, Japan)
  - Plane-of-array irradiance using a c-Si reference cell (EETS, UK)
- Ambient temperature
- Wind speed
- Wind direction
- Roof-tile temperature exposed to sunlight
- Roof-tile temperature shaded by a module
- Backsheet temperature of an open-rack module (installed at the top edge of roof structure)
- Air-gap temperature under each of the 20 modules
- Cell temperature: average temperature of two middle cells (through backsheet cut)
- Data collection: recorded every minute; averaged and saved every six minutes
- DAS: National Instruments NI-9172
- DAS software: a dedicated LabView-based software developed in this work.

Fig. 6 features a real-time screenshot of monitored data on a hot sunny day when the ambient temperature was 43°C and irradiance was about 1000W/m^2. It shows that the lower air gaps significantly increase the module temperatures as compared to higher air gaps. The average daily temperature of tiles under PV modules is lower by about 15°C when compared to tiles exposed to direct sunlight. This indicates that the rooftop PV modules help significantly reduce the summer cooling load of the buildings just by simply shading the roof tiles.

The temperature test (Fig. 3) indicates an average cell temperature of 87°C, while the rooftop results for the 0-inch air gap modules noted in Fig. 6 show cell temperature ranging between 72°C and 88°C, depending on the module column number. Because of wind direction from left to right, the first column (left) modules experienced lower temperatures compared to the fourth column (right) modules. This study and a yearlong extension of this study clearly suggest that the temperature testing of the test standards closely simulates the temperatures of real-world rooftop modules.

Conclusion

The comparative failure analysis testing showed that the fraction of new manufacturers in the 2005-2007 period was about 52%, and the failure rate dramatically increased in the 2005-2007 period as compared to the 1997-2005 period. The fraction of new manufacturers in 2007-2009 period was about 39% but, encouragingly, the failure rates for most of the major stress tests have dramatically decreased for the 2007-2009 period compared to the previous period of 2005-2007. As for the temperature testing method of the safety test standards (ANSI/UL 1703 and IEC 61730), the lab's findings reveal that it closely simulates the temperatures of real-world rooftop modules.

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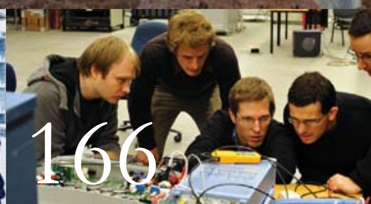
About the Author

Govindasamy "Mani" TamizhMani, Ph.D., is the president of TÜV Rheinland PTL (Photovoltaic Testing Laboratory) and a professor in the Department of Electronics Systems at Arizona State University (Tempe, AZ). He has been involved in R&D activities related to photovoltaics and fuel cells for over 26 years and photovoltaic module testing and certification activities for more than 12 years. He has also been working on test standards' development activities since 1996. Mani has served as a member of Solar ABCs' steering committee and of various standards committees, including the Canadian Standards Council, IEEE, IEC, and ASTM. Mani has served as a reviewer of numerous grant applications, and conference and journal publications, including the IEEE Photovoltaic Specialists Conference, *Progress in Photovoltaics*, and *Journal of the Electrochemical Society*.

Enquiries

Tel: +1 480 584 7296
Email: tmani@asu.edu

Power Generation



Suntech installs first Pluto cells in Australia on Sydney Town Hall

Suntech has supplied 240 solar panels for a 48kW rooftop installation on the Town Hall in Sydney, Australia. The installation marks the first use of Suntech's Pluto technology in the country.

The modules, which were installed and integrated by Stowe Electrical, will power the Town Hall and the Council Chambers. The installation is part of an AUS$18 million plan to improve the energy efficiency of city-owned properties in Sydney.

Suntech is also working closely with Swinburne University of Technology on the development of nanoplasmonic solar cells, which could potentially increase the efficiency of solar cells by enabling them to absorb a much broader spectrum of light. Suntech has pledged AUS$3 million to help fund the advanced research performed at Swinburne's new Advanced Technology Centre.

Sydney Town Hall.

U.S. Region News Focus

Dow Jones to build 4.1MW PV power plant on New Jersey campus

Dow Jones & Co. plans to build a 4.1MW solar photovoltaic power plant on the 200-acre campus of its corporate offices in South Brunswick, NJ. The design of the installation calls for more than 13,000 solar panels, covering nearly 230,000 square feet of parking space.

The PV system is expected to produce the equivalent of five million kWh of electricity per year, the company said. At peak performance, the arrays will be capable of supplying half the site's energy needs; on an annual basis, the system is expected to supply nearly 15% of the campus' requirements. Until an agreement is reached with the potential contractors, Hoffman said no further details about the project design, construction timeline, modules chosen, or other balance-of-system details could be disclosed.

Although Dow Jones would not comment on details of the overall financing of the project, the company did say that it intends to finance the PV system in part through local utility PSE&G's solar loan program. The investment is part of parent company News Corp.'s global energy initiative and is said to be its largest commitment to onsite renewable power to date.

San Diego Gas & Electric signs 20-year power-purchase agreement

San Diego Gas & Electric (SDG&E) has signed a 20-year power-purchase agreement with an LS Power subsidiary to secure up to 130MW of solar energy from the intended Centinela Solar Energy facility in Imperial Valley. The contract runs through 2033, wherein the PV facility will produce enough renewable energy for around 45,000 households. Final approval from the California Public Utilities Commission is still required.

The Centinela Solar Energy facility is scheduled for completion in 2014 with up to 130MW of solar power being sent across SDG&E's service territory via the Sunrise Powerlink. The power line is due to be completed in 2012 and is purported to be able to carry up to 1,000MW of electricity.

Constellation Energy to install 1.8MW system on McCormick distribution centre rooftop

Constellation Energy will develop a 1.8MW solar PV system at the McCormick distribution centre in Belcamp, MD. Once complete, this will be the largest single rooftop solar installation in Maryland, and the second solar installation developed for McCormick by Constellation Energy.

Constellation Energy will finance, design and construct the installation, owning and maintaining the solar power system for 20 years. McCormick will then purchase the energy produced. The project will feature 8,372 crystalline PV panels on the facility's 363,000 square foot rooftop. Construction will begin in late June 2010, with estimated completion by the end of the 2010.

PG&E launches 500MW solar energy initiative in California

Pacific Gas and Electric (PG&E) will implement a major new solar photovoltaic program with the California Public Utilities Commission (CPUC). The program, which was approved on April 22, will generate up to 500MW once complete.

PG&E's solar PV program is part of the company's five-year initiative to generate up to 250MW of utility-owned PV and a further 250MW provided by independent developers through a streamlined regulatory process. The projects targeted by PG&E's initiative will range from 1-20MW and will be located near company substations in the company's northern and central California service areas to reduce the costs and delays of interconnecting them to the power grid.

San Miguel Power and SunEdison to build PV plant in Colorado

The San Miguel Power Association and SunEdison are collaborating on a 2MW photovoltaic power plant in Norwood, Colorado, it is scheduled for power output by January 2011, SMPA will buy electricity over a 25-year period, while SunEdison will build, own and operate the plant, which is located on 40 acres in western San Miguel County. Groundbreaking for construction will be in September with a targeted completion in December 2010.

SunPower adds 40MW capacity to California Valley Solar Ranch for PG&E

SunPower has signed an agreement with Pacific Gas and Electric (PG&E), completing contractual arrangements between the companies for the development of a 250MW solar photovoltaic power plant in San Luis Obispo County, CA. The agreement adds 40MW of capacity to SunPower's existing contract with PG&E for 210MW, which was executed in August 2008. When complete, the 250MW California Valley Solar Ranch is expected to be one of the largest PV power plants in the world.

The California Valley Solar Ranch agreement was designed to accommodate the additional 40MW capacity, without having to amend SunPower's county permit application. The solar plant will be completed in phases, with the first phase expected to begin operation in 2011.

California Valley Solar Ranch plot.

SunPower has revised aspects of its original power plant design in response to feedback from the local community. The new plan minimizes environmental impact by reducing the amount of traffic in the area during construction to protect local wildlife habitat and migration patterns. Construction of the California Valley Solar Ranch is contingent on a number of factors, including the receipt of all applicable permits, completion of transmission upgrades and financing.

Mercury Solar teams with NREL for company's solar test-bed

Mercury Solar Systems and the U.S. Department of Energy's NREL have formed a partnership in the name of solar energy research advancement. The NREL will take data from its own long-term research of Mercury's solar test-bed. The system will be built on Mercury's corporate headquarters roof in New York with full operation expected to begin by the end of the summer. The project was partially financed with a grant from the New York State Energy Research and Development Authority. At 81kW, the PV system will have several hundred panels from eight different manufactures and is anticipated to produce around 90,000kWh every year. In addition, the system will also integrate a hybrid PV/solar hot water system.

European Region News Focus

Phoenix Solar to use First Solar modules in two new power plants

Phoenix Solar has won tenders for two new solar power plants using First Solar's CdTe thin-film modules from SWT Stadtwerke Trier, the city utility for Trier, Germany. The first project in Bitburg will start construction this week and employ 72,000 modules for an installed capacity of 5.6MW. The second project will use 28,000 First Solar modules, generating a peak power of around 2.2MW. Phoenix Solar has now worked on 11 such projects in the region. The company is also responsible for the delivery and installation of data monitoring as well as setting up the data link to SWT's control system, and will hand over the solar power plants in a turnkey state in June 2010.

Solyndra, Enerqos complete phase one of Nova Coop rooftop installation

Solyndra and Enerqos Group have completed the first stage of their multi-store installation project with the grid-connection of a 200kWp rooftop project for Nova Coop in the Vibo Valencia province of Italy. Enerqos implemented the Solyndra CIGS system through its


Source: Solyndra

Installation of a Solyndra system.

'Industrial Roof Business Unit' and with the help of local partner, PhotoVoltaic Systems.

Yohkon PV modules with Global Solar CIGS cells power 820KW rooftop system in Italy

Thin-film photovoltaics firm Global Solar Energy said that modules using its cells are powering what it calls the largest CIGS rooftop installation in the world, an 820kW system at a plastics manufacturer in Orgiano, Italy. Spanish solar company Yohkon Energia produced the modules, and Espacasa unit CDM Italy installed the copper-indium-gallium-(di)selenide-based solar energy system. Details such as the construction timeline and activation date of the array, further balance-of-system information, and the cost or financing arrangements of the system were not disclosed.

Solon wins contract for 12.5MWp project in Italy

Solon has been awarded the contract for construction of 16 greenfield installations in the Northern Italian provinces of Friuli and Veneto, with a total combined capacity of approximately 12.5MWp. The project is one of the invitations to tender announced throughout the EU in 2009 by SunTergrid, the wholly owned subsidiary of Rome-based independent power grid operator, Terna.

Solar power plants with a total capacity of 100MWp are also planned for 2010. They will be awarded by additional invitations to tender. The power plants of the current tender have a capacity of between 200kWp and 2MWp and will be constructed in the provinces of Padova, Vicenza, Verona, Rovigo, Treviso, Belluno, Venezia, Udine and Triest. Solon will assume the role of general contractor for engineering and project management as well as the turnkey implementation of the installations.

OPEL Solar, Tecneira launch new partnership with 1MW CPV plant

OPEL has signed an agreement with Tecneira, the renewable energy company of the ProCME group, based in Portugal. The companies will work together on a 1MW concentrated PV plant in the country, which will benefit from the Portuguese feed-in tariff. The 1MW solar plant will be located in Alqueva in the Moura Region of Southern Portugal. OPEL Solar will construct the plant using its Mk-I HCPV solar panels mounted on dual-axis trackers.


Source: Global Solar

Global Solar CIGS cells.

Recurrent Energy and BlueWatt team for PV plants across France

Recurrent Energy and BlueWatt have entered into a joint development to finance, build and operate PV power plants on industrial, commercial and logistic building rooftops across France. BlueWatt will develop and co-invest in rooftop solar projects with real-estate firms in the country, while Recurrent will finance, own and operate the PV systems for the first 50MW of joint projects.

Recurrent Energy has financed and engineered PV power plants in Barcelona and Madrid (4.8MW), Southern California (50MW), and in Ontario (177MW). The two companies look to give large building owners in France the opportunity to lease and utilize their unused rooftops for PV systems. The electricity produced by the rooftop PV systems will be fed back into the local utility grid. In return, Recurrent will be paid a feed-in tariff under French regulations.

Fotowatio and BP Solar team on multiple projects in Italy

Independent solar power producer, Fotowatio Renewable Ventures (FRV) is to work with BP Solar on a number of utility-scale PV projects in Italy, totalling 37.1MW. BP Solar will construct the facilities, while FRV will own and operate the plants at a cost of €125 million (US$167 million), which are expected to be completed by the end of 2010.

Premier Power to construct 19MW in Czech Republic through JV agreement

Premier Power Renewable Energy has entered a joint venture with Plaan Czech to develop 19MW of solar PV projects throughout the Czech Republic. The first 3MW, which includes the 2MW Jarsov and 1MW Verovice projects, are scheduled for completion by July. The companies will act as co-developer and engineering, procurement, and construction (EPC) partners on all projects under the JV agreement. The 19MW of projects are being completed for local investors.

Allianz obtains six of BP Solar's parks

Allianz has announced its recent acquisition of six solar parks, each up to 1MWp, from manufacturer, developer, constructor and operator BP Solar Italy. The solar parks are located in the Brindisi and Mesagne municipalities of the Puglia region of Italy. Operating since the end of 2009, the solar parks use BP Solar's mono- and polycrystalline panels on a fixed installation. Two additional 1MWp solar parks are still in construction. Once completed, Allianz will purchase them under the agreement with BP Solar.

Source: Abengoa Solar

Abengoa Solar's Solnova 1 plant.

Abengoa Solar's Solnova 1 is now online

After completing three days of operation and production testing, Abengoa Solar has begun commercial operation of Solnova 1 – the parabolic trough technology plant at the Solúcar Platform. The new 50MW Solnova 1 solar station, which is made up of around 980,000 square feet of mirrors that cover an area totalling approximately 280 acres, will generate enough clean energy to meet the electricity needs of 25,700 homes.

SunPower delivers solar power plant for EDF in Italy

SunPower is to construct a 1.3MW solar power plant in the Lazio region of Italy for Solar Green Energy-SGE, a joint venture between EDF-EN Italia, a subsidiary of EDF Energies Nouvelles, and Emmecidue, the Italian project developer. SunPower will install its 96-cell, E18 / 305 solar panels at the 4.7 hectare site in Ferentino, Frosinone province, on SunPower T0 Tracker systems. The plant is expected to be operational by the end of 2010.

Other News Focus

SunEdison to build 14 PV projects in Ontario

SunEdison has announced its intention to develop and build 14 rooftop PV projects that will total up to 3MW for The Remington Group. All of the PV systems will be located in the greater Toronto area and will commence a phased rollout this summer. SunEdison will build, own, operate, monitor and maintain the PV systems at Remington while the Ontario Power Authority will purchase the energy produced under the terms of Ontario's feed-in tariff program.

Australia's Alice Springs airport to build solar station using SolFocus arrays

SolFocus has partnered with Ingenero Pty to install a 235kW power station at Australia's Alice Springs airport located in the northern territory of Australia. The power station is expected to generate around 600MW hours of electricity into the airport's internal electricity grid. The project will account for approximately 28% of the airport's electricity demands and use 235kW of CPV arrays. Using SolFoucus' 1100S solar arrays, the project will receive AUS$1.132 million from the Australian government under its AUS$94 million Solar Cities program. Construction is

Power Generation Order Focus

Toshiba to buy 32MW of SunPower PV panels for Japanese residential market

SunPower has signed a strategic supply agreement with Toshiba, in which the Japanese company will order 32MW of high-efficiency monocrystalline-silicon solar panels from the PV firm this year. The SunPower modules form the cornerstone of Toshiba's new residential solar offering in Japan, which was launched on April 1. Financial terms of the deal were not disclosed.

Satcon wins further Chinese utility-scale projects

Satcon Technology has won a new order to supplier GCL Solar with 500kW 'PowerGate' Plus inverters for three separate solar power plants with a combined power of 38MW. The company previously won inverter sales for projects reaching a combined 23MW for ground-mounted and the largest rooftop projects in China in 2009.

The new projects are for a 10MW site in Youyu City, Shanxi Provence and will supply power to Shanxi International Power Solar Power Generation. Pingluo County Shizuishan City will be the location of another 10MW plant located in the Ningxia Hui Nationality Municipality, which will supply power to Ningxia State Power CSI New Energy Developer. The largest but unidentified project is a 20MW plant, said to be constructed in the first half of 2010 and operational this summer.

OZZ Solar to buy 18MW of Satcon PV inverters for Ontario rooftop projects

Satcon will deliver 78 of its PowerGate Plus inverters to rooftop PV developer OZZ Solar. The 18MW of units will be deployed on commercial rooftop projects across the province of Ontario, and will be fully compliant under the Ontario feed-in tariff program launched in 2009.

The 40 rooftop projects under development by OZZ Solar will use Satcon's PowerGate Plus 250kW and 100kW inverters, customized for 600V (AC), which became generally available in January.

The Satcon inverters designated for this program meet all requirements mandated under FiT regulations and are specially designed to operate at full performance at temperatures as low as –40°C. In addition, the power boxes will be manufactured in Burlington, ON, making them the only large-scale inverter solutions that are 100% compliant with the Ontario FiT local content requirements.

Satcon to supply 150MW of its 500kW PV inverters to GCL Solar

Satcon Technology has received an order from GCL Solar for 150MW of its PowerGate Plus 500kW solar PV inverters. The deal marks the second phase of Satcon's partnership with GCL, which was established in 2009.

Satcon began supplying the inverters in April, with all deliveries scheduled for completion in October of 2010. Satcon's 500kW units will be used on multiple utility-scale projects across China and will build on the collaboration between the two companies, which includes the 3MW and 20MW power plants completed in December of 2009, China's largest rooftop and ground-mounted installations respectively.

scheduled for completion by the end of the third quarter 2010.

1MW PV system using RIL modules with Suniva cells commissioned on New Delhi stadium

Solar modules incorporating Suniva's high-efficiency monocrystalline-silicon photovoltaic cells have been installed and commissioned on the rooftop of the Thyagaraj Stadium in New Delhi, India. The 1MW system, said to be the largest rooftop PV power plant in the country, was implemented by Reliance Industries (RIL) Solar Group, which also supplied the PV modules. The new "model green" stadium will be one of the primary venues of the upcoming Commonwealth Games.

The Thyagaraj power plant was developed using 3,640 280Wp modules. The project is expected to generate around 1.4 million kWh of electricity per year to fulfill the power requirements of the stadium, with surplus electricity being fed into the grid at 11KV. The Thyagaraj installation is the latest Suniva-powered PV system in India to be announced by the company. Last month, the Norcross, GA-based company said a 3MW array, done in conjunction with Titan Energy, had been commissioned in Karnataka.

Solar Millennium trough installation.

Kyocera to provide solar modules for Matsuyama solar power plant

Kyocera will supply 9,000 solar modules for the Matsuyama solar power plant in Ehime Prefecture, Japan. The modules will total 1.7MW for the spring 2011 on-line target of the plant. The Matsuyama plant is combining with the existing 2MW installation to become the biggest solar installation in Shikoku, Japan. Japan's government subsidies and feed-in tariffs are helping to boost the demand for solar power systems in the country. Once the Matsuyama plant is up and running it will provide 2,200MWh of electricity each year.

Solar Millennium company, Ferrostaal, delivers final collector for Egypt facility

Egypt's first large-scale solar thermal facility, located at they country's Kuraymat project site, 100km south of Cairo, has now received its final collector. The 150MW parabolic trough solar field is to be constructed by Flagsol in Cologne, the technology company jointly owned by Solar Millennium and Ferrostaal, based in Essen.

Flagsol designed the solar field and supplied the controls for the solar field as well as being responsible for supplying important key components, including the parabolic mirrors and absorber pipes. Almost 2,000 collectors with mirrors covering 130,000m² have been assembled and installed in the solar field. Each unit is 12 metres long and six metres wide. The heat transfer circuit for the entire solar field was scheduled to be commissioned in April 2010.

Solar Inverter News Focus

SMA Solar sold 1.3GW of inverters on record quarterly sales: semiconductor component shortages hit

The pull-in of solar installation projects in Germany to beat the July 1 feed-in tariff cuts coupled to lower PV module pricing resulted in SMA Solar Technology posting record first-quarter results, with demand even stronger in the second quarter. Sales topped €339.3 million, slightly exceeding previous guidance. SMA sold an inverter output of 1,288MW in the first quarter, restricted by semiconductor component shortages that are expected to continue until later this year.

SMA Solar inverter assembly.

SMA Solar said it had doubled its production capacities within the last few months to a total of 11GW. However, the shortages in semiconductor and other electronic components are not expected to be resolved until the second half of the year, subject to ongoing demand.

SMA conceded that it was not able to raise its production significantly beyond the output volume of the fourth quarter of 2009, as originally intended. Its new inverter production facility in Kassel-Waldau that came on stream in the first quarter of 2010 with an additional capacity of 5GW will only be able to produce low levels of inverters until the component supply constraints ease.

Satcon sees sales soar

Satcon Technology is seeing exceptional demand for its inverters as record bookings in the first quarter take its 2010 shipment backlog to approximately US$80 million, as of May 3rd, up from US$32.5 million in March 2010. Strong bookings were seen in the U.S. and Canada while other strong bookings came from key European markets.

Bookings for the first quarter reached US$66 million with China orders equivalent to 191MW on the back of announced projects with GCL Solar. North America totalled 61MW of booked orders, while Europe contributed 47MW. Revenue for the first quarter reached US$14.7 million but revenue is expected to increase significantly to between US$25 million and US$28 million.

The company shipped 234 units of its PowerGate Plus and Solstice inverters in the quarter, of which 71 were its 500 kilowatt PowerGate Plus inverter, representing 82% growth over the same period a year ago.

Advanced Energy acquires PV Powered

Advanced Energy has completed its purchase of PV Powered, enabling the company to service commercial utility installations between 30kW and 1MW and the residential sector for 5kW or smaller inverters. According to the terms of agreement, Advanced Energy paid $50 million: $35 million cash and $15 million in Advanced Energy common stock. Additionally, there is a $40 million potential earn-out based from PV Powered's full-year 2010 financial results. For the rest of this year, PV powered will operate as a wholly-owned subsidiary, continuing its sales of PV Powered branded inverters.

With its new acquisition, Advanced Energy has revised its guidance for its second quarter 2010 total sales of $100 million to $111 million, fully-diluted earnings per share of $0.21 to $0.31 and fully-diluted shares of 43.3 million.

SolarEdge expects product installations to top 3,000 alone in France in 2010

Distributed solar power harvesting start-up SolarEdge has seen a rapid adoption of its integrated module power harvesting technology in France through one of the top three residential integrators in the country, Solelux Toiture. According to SolarEdge, several hundred of its systems have already been installed this year and the company expects approximately 3,000 to be installed by year's end, equivalent to 10MWp. The firm claims that its power harvesting technology can boost solar energy system production by as much as 25%.

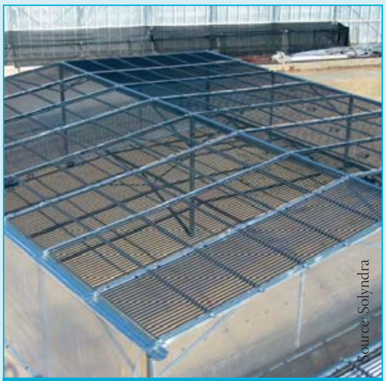
SolarEdge said that due to the new safety regulations enforced by the National Committee for the Safety of Electricity Users (CONSUEL), the SolarEdge solution is more compelling to the French market as it has a fully-automatic solution for electrocution prevention and fire safety.

BIPV News

Solyndra develops commercial greenhouse BIPV system test site with CeRSAA in Italy

In a move that could see Solyndra expand market opportunities outside commercial rooftops, the copper-indium-gallium-(di)selenide (CIGS) thin-film firm has developed a building integrated photovoltaics (BIPV) greenhouse system that is being tested by Centro Regionale di Sperimentazione e Assistenza Agricola (CeRSAA) to validate Solyndra's agricultural credentials. The project covers an area of 400 square metres at the CeRSAA research center in Albenga, Italy. Solyndra designed and built the BIPV system, while Solar ReFeel has coordinated the research among the involved parties. Installation support and electrical contracting was provided by Enerqos Group.

The project is designed to last for 24 months to validate the crop-growth benefits of Solyndra's technology. The study will measure and evaluate the production of several crops common in the Mediterranean region when grown under the greenhouse structures with the integrated solar system.



Solyndra agricultural solar test installations.

EPIA partner with DBS for BIPV conference at Solar Decathlon Europe

The European Photovoltaics Industry Association (EPIA), supported by Design-BuildSolar, is to host a one-day conference, in the framework of the Sustainability Forum, on BIPV during the international Solar Decathlon 2010. The conference, 'Paving the way for building integrated photovoltaics,' will take place on June 23.

The BIPV conference will provide a platform for discussion between the construction and PV sectors, as well as with policy-makers. The first part of the conference will focus on the latest BIPV technologies; current and future market trends of the BIPV sector and analyzing challenges and opportunities. PV industry, members, architects, installers and other relevant actors will provide their expertise and views.

During a second session, the economic and regulatory aspects of BIPV will be analyzed and discussed. A panel discussion with representatives of the major EU photovoltaic markets will focus on best practices and lessons learnt of implementing policies for the development of BIPV in their country.

Topics will include the implementation of feed-in tariffs as well as the recently approved European Directive on Energy Performance in Buildings. Recommendations will then be drawn to Spanish policy-makers on how to better promote the use of PV in buildings while ensuring high quality, environmental sustainability and adhering to design standards.

The Solar Decathlon, held from June 17-28, attracts experts from the building and energy sectors and reaches out to a different range of audiences with the objective to raise awareness and encourage the use of solar technologies in buildings and homes.

Martifer Solar SmartPark solar carport system.

Martifer Solar completes first U.S. SmartPark carport installation

Martifer Solar has completed its first 368kW SmartPark solar carport system in the U.S. The 35,000-square-foot installation was built for the Antelope Valley Transit Authority (AVTA) in Lancaster, CA.

The carport structure consists of over 300kW of SmartPark modules, as well as a smaller roof-mounted system and was funded by the Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) grant program under the American Recovery and Reinvestment Act (ARRA).

Uni Land, EOS Energia will construct 10MW BIPV greenhouses in Italy

Uni Land has signed an agreement with EOS Energia for the construction of 10MW photovoltaic systems on greenhouses in Italy. EOS Energia will manage the design, procurement and construction of the greenhouses and will ensure that each plant is connected by the end of 2010. Uni Land has also signed an agreement with EOS for the purchase of a permit to build a ground-mounted plant, with a maximum authorized power of 0.9MW, located in the Emilia Romagna region, which is expected to cost approximately €100,000.

Uni Land installation.

Sanyo installs two BIPV solar parking lots in Setagaya, Tokyo

Sanyo Electric has completed the installation of two 'solar parking lots,' incorporating solar panels and lithium-ion battery systems, as well as providing 100 Sanyo developed electric hybrid bicycles named 'eneloop bike,' in Setagaya, Tokyo, Japan.

The power generated by the solar panels installed on the roof is stored to recharge the 100 electric hybrid bicycle batteries and illuminate the parking lot using LEDs at night. Each of the bicycle parking lots operated by the city of Setagaya at Keio Line Sakurajosui station and Tokyu Den-en Toshi Line Sakurashinmachi station feature Sanyo's HIT solar panels, which are approximately 46m², and 7.56kW, on the roof.

The 100 eneloop bike units provided at the three locations, including Odakyu Line Kyodo Station, in addition to Sakurajosui Station and Sakurashinmachi Station will be used as 'community bicycles' by a wide range of people residing in and outside Setagaya.


Source: Sanyo Electric

Sanyo solar parking lots.

The lithium-ion battery system also features AC power outlets that can be used to power external equipment during an emergency. In addition, the installed system incorporates a DC charger. This enables photovoltaic energy generated and stored in DC to be used directly and effectively without AC conversion.

SolarFrameWorks to supply BIPV roof components to Johns Manville

Johns Manville (JM) has reached an agreement with SolarFrameWorks that will see the latter supply its proprietary BIPV CoolPly solar roofing components to JM, who will market these products through its JM E^3 Company. The SolarFrameWorks product is a solution that attaches crystalline solar panels to a roofing system without the need for penetration of a roofing membrane, thus preserving the integrity of the roof system. It is claimed to allow maximum kilowatt power density with crystalline photovoltaic modules when installed as large arrays and around HVAC units and vents while maintaining high wind ratings. CoolPly is available in both thermoplastic polyolefin (TPO) and polyvinyl chloride (PVC) formats.

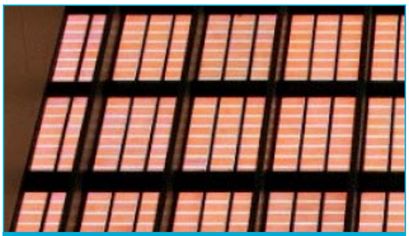
Bosch installs first Johanna Solar façade system

Bosch Solar Energy and subsidiary Johanna Solar Technology have completed the BIPV installation on the Schwager department store in the centre of Holzminden, Lower Saxony, Germany. The 21kWp façade system is the first of its kind to be installed by Bosch.

The project was focused around renovating the department store's curtain wall, which was built in the 1970s. The Johanna Solar Technology CIS solar modules are expected to generate approximately 19,000kWh of electricity annually across the 300m² of the department store's south façade.

EcoTemis partners with Cadmos for BIPV development in France

French BIPV company EcoTemis has formed a strategic partnership with Cadmos through a capital increase. Through the affiliation, the companies will build a BIPV customization facility in France, to design and manufacture versatile BIPV solutions of high architectural quality.


Source: Dyesol

Dyesol DSC module.

Pilkington North America joins Dyesol in BIPV development

Pilkington North America, based in Toledo, Ohio, will collaborate with Dyesol to develop opportunities in the BIPV market. The partnership will utilize Pilkington's TEC series of transparent conductive oxide (TCO) coated float glass and Dyesol's dye solar cell (DSC) materials and technology.

Derbigum installs 3MW combined BIPV commercial roofing systems in France for Lidl

Using its bitumen-based roof covering, which is integrated with ECD's Uni-Solar flexible a-Si thin-film laminates, Derbigum has installed approximately 3MW of BIPV commercial roofing systems at three logistics buildings for the supermarket chain Lidl in France. A 1.1MW system was installed at its Cambrai facility, a 1.1MW system in Vars, and 800kW at Les Arcs.

Product Briefings

KACO

KACO broadens Powador XP series of utility-scale solar inverters

Product Briefing Outline: KACO new energy has launched new inverter models within its XP series. The new Powador XP200-HV and Powador XP250-HV TL central inverters complement the 100 and 350kW inverters currently on the market and have output power ratings of 200 and 250kW, respectively. Two XP250 units can be integrated into a lightweight steel enclosure for the new 500kW station.

Problem: Large-scale solar inverters need to be highly efficient and reliable to meet high performance requirements of customers. The ability to offer a range of systems that better scale with a given project allows greater flexibility for project developers meeting plant expectations.

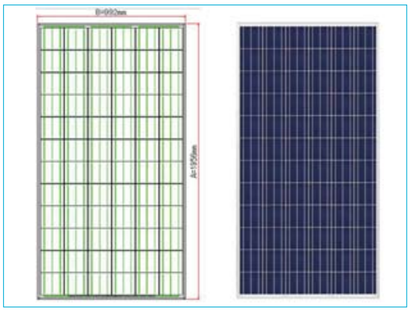
Solution: Like all of the products in this series, the new XP inverters feature full-digital controls. The intelligent control of the power electronics increases the efficiency of the power transistors. A variety of pulse width modulation techniques can be used depending on the input power. The inverters are capable of delivering reactive power and are flexible when it comes to system sizing. Powador XP200-HV comes with a transformer and Powador XP250-HV TL without. This makes the XP200 ideal for a direct feed into a low voltage grid. One or more XP250 inverters can be used in combination with a suitable transformer for input into a medium voltage grid.

Applications: Commercial and large-scale solar plants.

Platform: The Powador Series has a maximum input current of 467 or 611A with a maximum input voltage of 1,000V. The max rated efficiency of the XP200 is 97.4%, while the XP250 has a max rated efficiency of 98.2%. The MPP range is from 450 to 830V. Pre-configured, country-specific grid parameters make it easier to set up initial operation on-site.

Availability: Currently available.

Trina Solar



Trina Solar offers multicrystalline modules up to 290W for utility-scale applications

Product Briefing Outline: Trina Solar has launched its new utility-scale solar module 'TSM-PC14,' the company's most powerful module to date. The modules, scheduled for availability on the European and North American markets in the fourth quarter of 2010, have power output targets ranging from 265 to 290W.

Problem: Utility-scale PV power plants have traditionally selected some of the highest output modules to ensure the maximum ROI. However, monocrystalline modules are more expensive and often in shorter supply than multicrystalline products. There is a need for cheaper high-performing multicrystalline modules above 230W that are suited for use in large-scale projects.

Solution: A low power tolerance of +3% helps higher power output, while the 72-cell (156 x 156mm) arrangement reduces module string mismatch losses. Three bus bars significantly improve power output as well as long-term performance and reliability, while the use of highly transparent, low-iron, and tempered glass and antireflective coating increases energy yield. Equipped with high-efficiency multicrystalline cells, the TSM-PC14 is larger than conventional modules, which reduces the number of modules required for a given installation and therefore reducing overall installation costs.

Applications: A wide variety of applications ranging from commercial and industrial installations to utility-scale facilities.

Platform: All modules are designed and manufactured in China at an ISO 9001-certified factory. The anodized aluminium frame improves load resistance capabilities for heavy wind loads, while the module's composition ensures there are no problems with water freezing or warping. The panel comes with a 25-year performance guarantee of 80% power production and a TÜV-certified MC4 connector. Cell efficiencies are up to 17.03% with modules efficiencies of up to 14.95%.

Availability: European and North American markets in the fourth quarter of 2010.

Bosch Rexroth

Bosch Rexroth's slide-in module support system for thin-film modules cuts install times by 50%

Product Briefing Outline: Bosch Rexroth has developed a slide-in system for installing frameless thin-film solar modules made by Bosch Solar Energy AG. The matched combination between support and photovoltaic module is claimed to enable the modules to be installed twice as fast as they would with conventional mounting systems.

Problem: A key cost of medium- to large-scale PV projects is the installation time and the material cost of frames and mounts can significantly contribute to the overall BOS. Innovative developments in reducing installation times and material costs are required.

Solution: Speed is assured with Bosch's new system due to the reliable, easy-to-use slide-in technology, which relies on tracks instead of the usual clamps. The photovoltaic modules are simply inserted into the guide pieces and fastened instantly. The system cuts installation time in half to 15 seconds per module, meaning approximately twice as many modules can be installed using Rexroth's technology as would be completed using a conventional, four-point clamping system in the same amount of time. As installation brackets and clamps are no longer required, material costs are also reduced by about 40%.

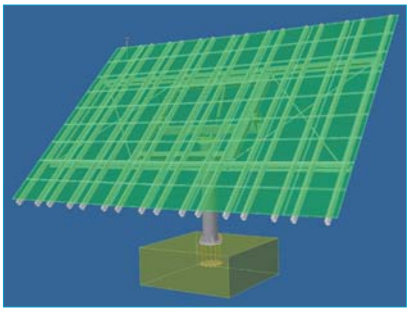
Applications: Currently applicable to Bosch Solar Energy's micromorph thin-film solar modules, but will in future be made available to framed modules, crystalline applications, and in smaller rooftop systems.

Platform: The system is built on a base frame, which features variable table lengths, bracket spacing and insert depth. With their hardened front glass, Bosch Solar Energy's micromorph thin-film solar modules can withstand mechanical loads up to 2,400Pa in this mounting system, corresponding to 350kg of weight acting on the module.

Availability: Currently available.

Product Briefings

Kemper



Kemper offers dual-axis tracking system for large-scale power plants

Product Briefing Outline: Kemper has extended its family of dual-axis tracking systems for PV modules to include the larger 'KemTRACK' 120 system, capable of handling a combined module area of 120 square metres. The construction is torsion-free, extremely robust and durable and modular in construction.

Problem: Larger and therefore more efficient tracking systems are required to operate in a wide range of applications, whether due to limited ground space or requirements to maximize output of a given ground-mounted PV project. The ability to handle high winds and snow loadings also requires a sturdy and long-lasting structure.

Solution: The KemTRACK 120 dual-axis tracking system handles more modules than the company's other systems; for example, a current yield of about 17kWp per tracker is claimed compared to 8.6kWp for its KemTRACK 60 system. The tracking system can be transported easily and very economically using standard containers. The frame construction can be welded and supplied pre-mounted, if required. The industrial drives bear the 'Made in Germany' stamp, and are maintenance free and extremely stable. Regulation of the two drives contains innovative functions and provides an increase of the current efficiency of up to 40%, according to the company. Software algorithms prevent mutual shading with sun exposure angles.

Applications: Large solar farm projects; project-specific individual constructions are also possible.

Platform: Torsion-free, hot dip galvanised steel construction, suitable for all wind and snow loads adhering to DIN 1055. Extremely high wind protection settings can be individually configured. The central control unit can accommodate modular extensions such as a surge protector or an emergency power supply using batteries.

Availability: Currently available.

Renusol

Renusol's new web configurator tool aids in planning, managing and ordering PV mounting systems

Product Briefing Outline: Renusol has developed a web-based tool for planning, managing and ordering PV mounting systems, with further applications such as managing already created projects in their entirety without time constraints. The entire planning process is easy and requires only a few mouse clicks either from a PC or on-site from a mobile device or notebook.

Problem: Customers and trading partners expect short lead-times of mounting system manufacturer, and need to be provided with exact support in the planning and calculation of a PV installation.

Solution: The intuitive program is structured according to the latest operator criteria and enables the safe planning of installations with input of the intended module type, precise presentation of the respective module orientation, as well as the creation of a detailed parts list. The user can generate both a corresponding dealer offer and a cost estimate for end customers. Each project can be saved in individual files, managed, updated online and ordered online. The entire process takes place in a password-protected customer area.

Applications: Renusol has developed the web configurator for the InterSole (in-roof) and VarioSole (on-roof) systems. Extension to the entire Renusol range of products will follow shortly.

Platform: Trading partners, engineers, architects, or planners can request personal access data from Renusol and use the web configurator free of charge. Direct access for already activated customers can be accessed at www.renusol.com/web-konfigurator.html.

Availability: Currently available.

Solon

Solon Black 220/16 modules come with service package for large-scale projects

Product Briefing Outline: Solon has developed the 'SOLON Black 220/16' monocrystalline module, which includes a service package for large-scale projects, thus providing a module that is a safe and profitable investment.

Problem: High quality and proven 'bankable' PV modules are required for large-scale projects. Guaranteed module average output capacity and efficient project timescale delivery are also key factors for successful large-scale projects.

Solution: The cost of the module includes punctual delivery directly to the project construction site. The module itself has been carefully designed for the industry branch and is manufactured using high capacity cells, 4mm tempered high-security glass, and the Solon-specific module frame with hollow-chamber profile for extra stability. The module is said to generate maximum yields using low surface areas – even in diffuse light and features high efficiency rates with output fluctuation of ±3%. Solon guarantees at least 80% of the stated minimum output power in the first 25 years of commissioning.

Applications: Large-scale roof- and ground-mounted photovoltaic systems.

Platform: The Solon Black 220/16 measures 1640 x 1000mm and consists of 60 monocrystalline cells. It has a maximum peak power of 235W – the equivalent of an efficiency level of 14.33%. The module weighs 22kg and comes with a five-year warranty. Guaranteed performance output of 95% for five years, 90% for 10 years, 87% for 15, 83% for 20 years and 80% for 25 years. Approvals and certificates include: TÜV certification for IEC 61215 Edition II, IEC 61730 (incl. Safety Class II).

Availability: Solon requires a minimum order of 500kWp, proof of the project, and a collective delivery to a single project address. Production of the new module began in April 2010.

Product Briefings

REC

REC's 'Peak Energy Module' delivers increased quality and performance

Product Briefing Outline: REC has launched its first commercial product from its integrated and highly automated cell and module manufacturing plant in Singapore. The REC Peak Energy Module delivers more power per square metre due to several design improvements. These include a more efficient cell and glass design, which result in an average increase of 9W per module.

Problem: Key requirements for large commercial rooftop and ground-mounted utility-scale PV projects are assured product quality and a reliable high power output. High quality design and manufacturing standards are vital for success in the PV industry, which is tending to lean towards fully integrated production.

Solution: The Peak Energy Module uses three bus bars and boasts improved contact between the cell and metal fingers, which improves the electrical flow. The unique glass etching process, completed in-house, uses Sunarc technology to increase energy production by 2%. The modules are easy to install with made-to-fit cables and multiple grounding points that reduce the ground wire needed in installation. Easy to lift and handle, the modules have a robust and durable design, supporting a large mechanical load (5400Pa).

Applications: Commercial rooftops through to large-scale power projects.

Platform: The modules comprise 60 REC PE multicrystalline cells with three strings of 20 cells and three bypass diodes. The glass used is high-transparency solar glass with antireflection surface treatment by Sunarc Technology. Module efficiencies range from 13% on the 215PE module through to 14.2% on the 235PE at Standard Test Conditions STC (Air Mass AM 1.5, irradiance 1000W/m², cell temperature 25°C). A 10-year limited warranty of 90% power output and a 25-year limited warranty of 80% power output are included, as is a 63-month limited product warranty.

Availability: Currently available.

Ametek Programmable Power

Ametek offers turnkey solution for testing grid-tied inverters and DC charge controllers

Product Briefing Outline: The Elgar brand TerraSAS Solar Array Simulator from Ametek Programmable Power offers a fully integrated solution for the design, development and production testing of inverters and micro-inverters for residential and industrial solar energy systems.

Problem: An essential part of inverter testing is to test the inverter using accurate simulation of the PV array response to its maximum power point tracking (MPP) function. To perform this task, the power source must accurately process the PV array's IV curve without filtering the low frequency ripple voltage produced by the inverter to track MPP. Conventional switch mode DC power sources provide slow response and therefore less accurate in testing inverters.

Solution: The TerraSAS simulates photovoltaic dynamic solar irradiance and temperature characteristics over a range of weather conditions from clear to cloudy and over a specified time interval to produce the current/voltage (IV) characteristics for the specified PV array for those conditions. The system's simulation engine can download data from the National Renewable Energy Laboratory (NREL) Solar Advisor Model database defining key parameters – open circuit voltage (V_{oc}), short circuit current (I_{sc}) and maximum power point voltage (V_{mpp}) at 25°C and 1000W/m² irradiance – so that the IV curve can be calculated according to a standard solar cell model for virtually any fill factor or solar material. Other PV panel IV curves can be entered manually, while systems with multiple panels with different characteristics resulting in 'multiple hump' IV curves can also be simulated.

Applications: Testing inverters and micro-inverters.

Platform: The modular, rack-mounted Elgar TerraSAS system offers one or more programmable DC power supplies with optimized, high-speed output response available in increments from 1 to 15kW.

Availability: Currently available.

SolarEdge

SolarEdge's PowerBoxes now support modules of up to 350Wp

Product Briefing Outline: SolarEdge has now expanded its product range to include 'PowerBoxes' embedded directly into solar modules manufactured by SolarEdge partners, for maximum simplicity of installation. The company claims to be the first to offer commercially available PV modules with embedded power optimizers.

Problem: Traditional PV installations suffer from limitations that lead to complicated design and installation, insufficient monitoring and safety, and – above all – power losses, due to panel mismatch, partial shading, sub-optimal MPP tracking, etc.

Solution: The three-fold SolarEdge architecture consists of PowerBoxes, PV inverter and monitoring portal. The PowerBoxes are DC-DC power optimizers that perform MPPT and monitoring per individual panel, and maintain a fixed DC string voltage, allowing optimal efficiency of the SolarEdge multi-string PV inverter. PowerBoxes support modules of up to 350Wp. The range of single-phase and three-phase inverter now includes inverters of 3.3-15kWp. A new iPhone monitoring application allows monitoring the PV system on the go, for easy, real-time site review even in large PV arrays. The system also offers the industry's first fully automatic solution for electrocution prevention and fire safety. Features of the SolarEdge system include: more power provision from any given PV system installation; elimination of design constraints; complete panel-level and whole-system visibility for monitoring and maintenance alerts; reduced safety hazards; anti-theft mechanisms; all while reducing the cost of energy.

Applications: Residential, commercial and utility-scale PV installations.

Platform: The SolarEdge PowerBox is based on a proprietary ASIC chip set. The web-based monitoring application alerts on underperforming modules and safety events, visually pinpointed on a site layout map and communicates across existing power lines, so no extra wiring is needed. It is specifically designed to work with power optimizers, and exhibits >97% weighted efficiency.

Availability: Currently available.

DERlab round-robin testing of photovoltaic single-phase inverters

Omar Perego, **Paolo Mora** & **Carlo Tornelli**, ERSE, Milan, Italy; **Wolfram Heckmann** & **Thomas Degner** (DERlab coordinator), IWES, Kassel, Germany

ABSTRACT

Interconnection of inverters to the electrical grid is a key issue for the widespread integration of distributed energy resources, especially when the scenario surrounding international standards is so unclear. As a pre-normative research step, a round-robin test of two small-scale photovoltaic inverters was performed by nine DERlab laboratories during 2009. The test activity was focused on the verification of individual test procedures, common interpretation of standards and requirements, and determination of problems related to the equipment and facilities involved in conducting round-robin tests. Compilation of test results and first conclusions of this activity will be presented in this paper.

DERlab consortium

The activities described in this article are a result of studies carried out by the DERlab team. DERlab is a European Project funded by the EC in the sixth Framework Programme (FP6, n. 518299), armed with the mission of constituting a Network of Excellence (NoE) of DER Laboratories for Pre-Standardization activities.

The main objective of the DERlab NoE is to support the sustainable integration of renewable energy sources (RES) and distributed energy resources (DER) in the electricity supply, by developing common requirements, quality criteria, as well as proposing test and certification procedures concerning connection, safety, operation and communication of DER components and systems. The NoE also acts as a platform for the exchange of current knowledge between the different European institutes and other groups.

"During the data collection, each laboratory highlighted problems and difficulties occurring during these inverter tests."

In order to establish a durable network of DER laboratories, the members of the DERlab Consortium, together with other important European laboratories and research centres, founded the DERlab Association (DERlab e.V.) in September 2008. The test facilities of the DERlab members (with some relevant additions) are offered, free of charge, to European researchers for activities funded by the EC in the FP7 Research Infrastructures DERri Project (Distributed Energy Resources Research Infrastructure, FP7, n. 228449).

The DERlab Consortium (see Fig. 1) has 11 members: IWES from Germany (coordinator); ARSENAL from Austria; KEMA from The Netherlands; INES-CEA from France; ERSE from Italy; LABEIN-Tecnalia from Spain; University of Manchester from UK; NTUA-ICCS from Greece; RISOE-DTU from Denmark; TU Sofia from Bulgaria; and TU Łódź from Poland.

Round-robin motivation

One of the objectives of DERlab is to support the development of European and international standards by executing exemplary research activities on specific topics and by initiating new research activities, which aim to provide the required technical information and input to the standardization bodies.

The organization's main focus is not on the single, isolated device, but on the DERs integrated in an electrical network to highlight interface conditions. As most DER electrical interfaces to the grid are realized through inverters, this paper answers the need for particular attention to be paid to the testing procedures for these kinds of devices. In order to define a field of application that can be faced, considering also the large diffusion of these devices, this investigation has been focused on single-phase photovoltaic inverters of up to 6kVA of rated power that are connected to the PV field and intended for functioning in parallel to the grid.

This activity is not intended to overlap or to substitute the work being undertaken by standardization bodies. Its purpose is to verify the applicability of the existing

Figure 1. DERlab Consortium members [1].

standards, identifying lacks, explaining difficulties and problems in test conditions and specifying testing equipment by collecting data in an inter-comparison ('round-robin') approach among DERlab members.

Appropriate and well-defined 'PV inverter testing procedures' (related to performance, grid interface and safety) have been prepared by DERlab experts as a basic prerequisite for the round-robin test. This document defines some steps and guidelines to which each laboratory must adhere in testing PV inverter characteristics. During the data collection, each laboratory highlighted problems and difficulties occurring during these inverter tests. The main purpose of such a data collection study is to collect suggestions from the various experts in the field and transfer this experience to the standards committees.

In fact, the analysis of the results and of the notes and suggestions collected during the test phase can be automatically forwarded to the relevant active standardization groups, where the engineers involved in the data collection for this paper are also directly involved in assessing and writing International and National Standards. This round robin will help in assessing, verification and modification of existing and proposed test procedures in order to fill the gaps, to harmonize, and to clarify.

Round-robin activities

The data and information for the round robin were collected during 2008 and 2009, Fig.2 shows moments of test execution; the final analysis, the definition of recommendations and the dissemination of the results are currently in progress.

In brief, a team of experts from DERlab partners has compiled a document for 'PV inverter testing procedures,' related to performance, grid interface and safety. This document has been submitted and shared among all DERlab partners, together with a template of the test reports. This document – which should not be considered a 'standard procedure to test PV inverters' because it is not produced by standard committees – defines some steps that nine DERlab laboratories have to follow to test two PV inverters within the remit of the round robin. Two inverters were circulated among these laboratories, and tested according to the indications of the procedures. The team of DERlab experts and technicians involved in the tests filled in the test reports with the results of these tests. At the end of the round robin, they reported their observations and suggestions in a questionnaire circulated in September 2009, which were then collected and analysed by a team of DERlab experts, who took on board the observations and suggestions on how to improve the test procedures in order to transfer this experience to relevant active standardization groups.

DERlab experts had the opportunity to share their experiences during the round-robin timeline. Some experts visited partner laboratories, working in collaboration with local technicians, yielding data that were collected, compared and analysed by the consortium meetings with the intention of collecting observations and improving the procedure steps.

PV inverters

The investigation focused on single-phase inverters up to 6kVA that are connected to a PV field in parallel to the grid. The two inverters that were circulated among DERlab laboratories were the Aurora Power-one PVI-3.0-OUTD-IT and the SMA SunnyBoy 4000TL, the main characteristics of which are displayed in Table 1.

Tests

The aim of the tests is to assess if the PV inverters are suitable for properly functioning in parallel to the grid and to measure the performances and characteristics of these inverters in different operative conditions. Some tests are identified as mandatory because they refer to problems related to the electrical interconnections of DER (grid compatibility and safety); the other tests are identified as optional, because they measure the performance characteristics of the inverters.

The tests performed, divided into mandatory [M] and optional [O], are listed below:

[M] – Harmonic current measurement (power quality test on grid compatibility)

Figure 2. Moment of test execution.

[M] – Anti-islanding protection detection (protection intervention test on grid connection)

[M] – DC current injection measurement (power quality test on grid compatibility)

[M] – PV leakage current protection detection (protection intervention test on safety)

[O] – Efficiency measurements (performance test; see [2]),

[O] – Measurement of MPPT (maximum power point tracker) accuracy when PV shadowing occurs (performance test).

The round-robin test was conducted to adhere to the defined test procedures (described in the DERlab 'PV inverter testing procedures' document), using the same inverters under the same test set-up and according to the same standards but with different devices, instruments and environment. The DERlab partners decided to follow the Italian standards because, as there is no EU standard, the two inverters' parameters are configured according to Italian standards.

A common understanding of the differences and remarks collected during the analytic phase of the round robin yielded refinement of the testing procedures and the elaboration of suggestions to standard committees.

The analysis of the results and considerations about the following mandatory tests are pertinent to this paper:

- Test on anti-islanding protections
- Test on harmonic current
- Test on DC current injection.

The analysis of these tests is extended to general considerations and to open questions, the outcome of which will be reported later in the paper.

Test on anti-islanding protections

The aim of the test is to evaluate the inverter's behaviour during lulls in grid connection in order to evaluate their capability for islanding prevention. In Italy, an anti-islanding protection test detects grid failures and disconnects PV generators to avoid feeding of the grid in an uncontrolled manner. Anti-islanding protection is steered by a European standard (EN-50348); however, this code

Aurora Power-one PVI-3.0-OUTD-IT

Nominal power (AC): 3,000W
Voltage range (DC): 90 – 580VCC
No. of MPPTs: 2
Protections equipments: detection of DC current injection in AC (transformerless inverter), min/max V, min/max f, df.

SMA SunnyBoy 4000TL

Nominal power (AC): 4,000W
Voltage range (DC): 125 – 440VCC
No. of MPPTs: 2
Protections equipments: detection of DC current injection in AC (transformerless inverter), min/max V, min/max f, df.

Table 1. Inverters circulated among DERlab laboratories for round-robin testing purposes.

Method of protection intervention requested by Italian grid code		Thresholds Mandatory/ optional
MIN & MAX voltage detection	0.8 x Vn (t < 0.2 s) < V < 1.2 x Vn (t < 0.1 s)	Mandatory
MIN & MAX frequency detection	49 or 49.7 Hz < f < 50.3 or 51Hz (without any requested delay)	Mandatory
Frequency deviation	df < 0.5Hz/s	If requested by the grid operator

Table 2. Method of protection intervention as defined by CEI 11-20 grid code.

contains many gaps and derogations that stipulate that each country has to provide its own grid code with different methods and values for anti-islanding protection.

Italy's MV/HV connections have to follow the specifications of CEI 0-16, the Italian standards committee, that include guidelines for LV connections and modifying the CEI 11-20 standard.

"The grid simulator must guarantee a maximum voltage THD (total harmonic distortion) less than 1%."

Although the EU standard committee is working on a common test procedure at international level (IEC 62116) for anti-islanding protection detection, the method of resonant circuit as defined by IEC 62116 is still missing the approval of CENELEC. Methods of protection intervention are implemented by the manufacturers themselves according to the national grid code.

In Italy, the CEI 11-20 grid code for LV connections requires a set of protective measures to be implemented by manufacturers in the Italian market. Table 2 shows the threshold values of voltage and frequency that cause the protection intervention and the maximum delay allowed for this intervention.

The method requested by the Italian grid code, based on minimum and maximum voltage and frequency, is intrinsically inadequate as it can fail when an equality between generated and used power occurs. Additional 'active' protections could be used to address this problem, an approach that is being investigated by the Italian National committee in the form of a new version of the CEI 11-20 grid code. Fig. 3 shows the basic circuit used by protections as requested by the Italian grid code for photovoltaic applications.

Both low and high voltage protection methods and low and high frequency protection methods have been tested during the round-robin testing procedure for this study. Further protection methods such as the rate of frequency change, impedance tests, frequency shift etc. may be used in other EU countries as stipulated by countries' grid codes, but this study's remit is limited to the two protection methods mentioned above.

Test equipment and preparation

The inverter is connected on the DC side to a PV field (or to a PV simulator) and on the AC side to an adjustable grid simulator, which allows the test operator to adjust voltage and frequency settings. The grid simulator must guarantee a maximum voltage THD (total harmonic distortion) less than 1%. A grid analyser is then positioned on the AC side, used to acquire both voltage and frequency AC signals (see Fig. 4).

Procedure

The test procedure describes the steps that should be followed to measure:

- the output limit values (AC voltage and frequency) for protection intervention;
- the time between the crossing of a frequency and voltage threshold and the intervention of the inverter anti-islanding protection.

Tests on anti-islanding protections are performed by the measurement of each threshold and the verification of the status of the disconnecting device (contactor). Furthermore, the operation delays are also measured in order to be in accordance with those results reported in Table 2.

The test method depicted in Fig. 5 shows the continuous variance of the voltage and frequency of the grid simulator. The slope of the frequency variation must be lower than the value of the rate

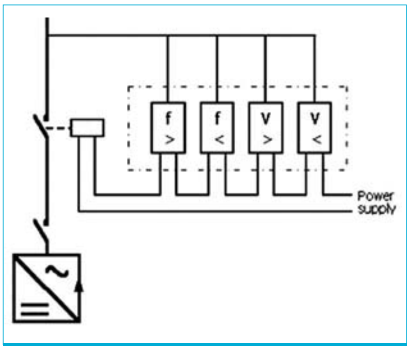


Figure 3. Basic circuit for anti-islanding protections (contactor is normally open).

of frequency change threshold (if this intervention method is implemented by the inverter manufacturer; see [3]). The test begins from the central point (nominal voltage 230V; nominal frequency 50Hz), moving towards the first target until the device trips or a safety limit is reached. This action is then repeated for each protection.

For example, in order to verify the high-voltage protection device, the voltage is slowly increased and the value that causes the trip is registered and noted as the high voltage threshold of the inverter. The initial conditions are restored, at which point an instantaneous variation of voltage is made from the same central point to a value above the measured high-voltage threshold. The time between the voltage step and the intervention of the protection is measured and noted as representing the time of high voltage protection intervention.

Results

Tables 3 and 4 summarize the results obtained in three different laboratories for threshold values and times, respectively. Both of the inverters have respected the thresholds defined by the CEI 11-20 Italian standard (limit values regarding over and under frequency time are available in Table 2).

Test on harmonic current

The aim of this test is to assess the current harmonics injection of the PV inverter into the grid using between 5% and 120% of the inverter nominal power. Several tests have been performed in compliance with the requirements of EN 61000-3-2, Annex

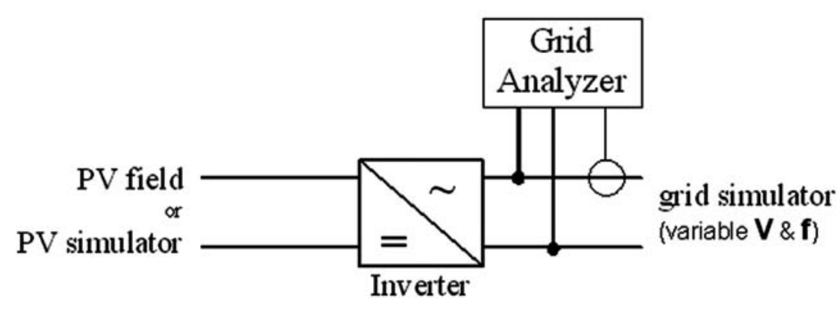


Figure 4. General architecture of anti-islanding protection measurement system.

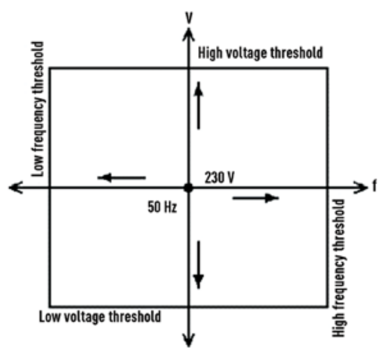


Figure 5. Grid simulator test method.

	Limit value	Lab 1	Lab 2	Lab 3
Over Voltage	276.00 V	272.20 V	273.00 V	272.82 V
Under Voltage	184.00 V	185.30 V	186.00 V	185.56 V
Over Frequency	50.30 Hz	50.28 Hz	50.28 Hz	50.27 Hz
Under Frequency	49.70 Hz	49.70 Hz	49.71 Hz	49.72 Hz

Table 3. Threshold values measured for an inverter in three different laboratories.

	Limit value	Lab 1	Lab 2	Lab 3
Over Voltage time	100 ms	90 ms	84 ms	81 ms
Under Voltage time	200 ms	180 ms	180 ms	181 ms
Over Frequency time	no intent.delay	100 ms	92 ms	91 ms
Under Frequency time	no intent.delay	90 ms	74 ms	82 ms

Table 4. Threshold times measured for an inverter in three different laboratories.

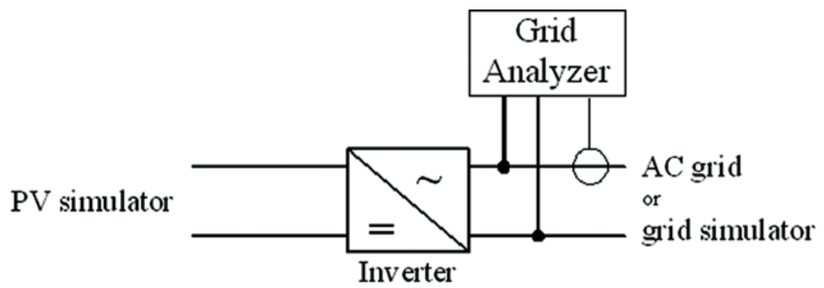


Figure 6. Harmonic current measurement configuration.

A (see [4,5]). Due to the fact that the actual voltage THD may have a strong impact on the inverters' current THD, the requirements specify the limit values for test voltage and harmonic ratios of the test voltage:

- The test voltage shall be maintained within ±2.0% and the frequency within ±0.5% of the nominal value (230V and 50Hz for single-phase supplies).
- The harmonic ratios of the test voltage (U) shall not exceed the following values with the EUT connected as in normal operation:
  - 0.9% for harmonic in order 3;
  - 0.4% for harmonic in order 5;
  - 0.3% for harmonic in order 7;
  - 0.2% for harmonic in order 9;
  - 0.2% for even harmonic in order from 2 to 10;
  - 0.2% for harmonic in order from 11 to 40.
- The peak value of the test voltage shall be within 1.40 and 1.42 times its r.m.s. value and will be reached within 87° and 93° after the zero crossing. This requirement does not apply when Class A or B equipment is tested.

Test equipment and preparation

The inverter is connected on the DC side to a PV simulator that provides the required harmonics measurements for different fixed power outputs (equal to 5%, 10%, 20%, 25%, 50%, 75%, 100% and 120% of the inverter rated power). The inverter is connected on the AC side to an adjustable grid simulator, or to an LV single-phase real grid (only if it fulfils the requirements of EN 61000-3-2, Annex A for voltage harmonics). A power analyser is then positioned on the AC side for the harmonics measurement. Fig. 6 shows the harmonic current measurement configuration.

Procedure

The test procedure describes the steps that should be followed to measure the current harmonics from 2nd to 39th. The inverter is turned on and the current harmonics are measured on the inverter output by means of a grid analyser installed on the AC output; the current THD and the current harmonics are recorded and their values are verified according to the limits expressed by the IEC 61000-3-2 (Table 5). The current THD and the current harmonics from 2nd to 39th must be recorded for values of output power equal to 5%, 10%, 20%, 25%, 50%, 75%, 100% and 120% of the inverter rated power.

Results

The testing procedure measures the amplitude of the harmonic distortion of the inverter output current, relating to different values of the power supplied. Measures have been performed for single harmonic, till the 40th one and computation has been done for the THD factor as shown in Equation 1.

Fig. 7 shows the trend of THD (%) related to the output power supplied by the same photovoltaic inverter. The consistency among the measures performed in the different laboratories is quite good; the measures' scattering increases when the power supplied by the inverter becomes lower.

In spite of the good consistency of THD measures, some differences are observed for the measures of single harmonic components related to the same inverter situation (see Fig. 8).

In order to increase the results' repeatability, a better definition of the characteristics of the measurement equipment is necessary, as is a more accurate indication of the measures' elaboration, in particular for the average computation. As a matter of fact, execution of the measures can produce a harmonic spectrum that is time dependent; for the harmonic calculation it is necessary to use a time slot large enough to represent the average level of the current harmonics. The value scattering shown in Fig. 8 can likely be produced by the use of time slots of different lengths and by application of an inadequate data average.

Test on DC current injection

The aim of this test is to detect the value of the DC current injected in the AC grid. Although the DERlab test procedure can measure the DC component, it cannot detect the protection intervention.

The Italian grid code (CEI 11-20-V1, see [6]) requires a galvanic separation between the inverter and the grid, allowing derogation for small-sized inverters. In this case the DC current injection must not exceed the threshold $I_{DC} < 0.5\% \ I_{NOM}$.

The specifications of the two inverters tested state that they are both provided with protection against DC current injection in the AC grid. However, in this

Harmonics	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}	I_{11}	I_{12}	I_{13}	$I_{n>14}$	$I_{n>15}$	THD	PWTHD
Max permissible harmonic current (I < 16 A)	1.08	2.30	0.43	1.14	0.30	0.77	0.23	0.40	0.18	0.33	0.15	0.21	0,23*8/n	0,15*15/n		

Table 5. Limit values for current harmonics.

$$THD = \sqrt{\sum_{n=2}^{N} \left(\frac{I_n}{I_1} \right)^2}$$

With:

I_1 : Amplitude of the current component at basic frequency

I_n : Amplitude of the current component at nth harmonic frequency

Equation 1.

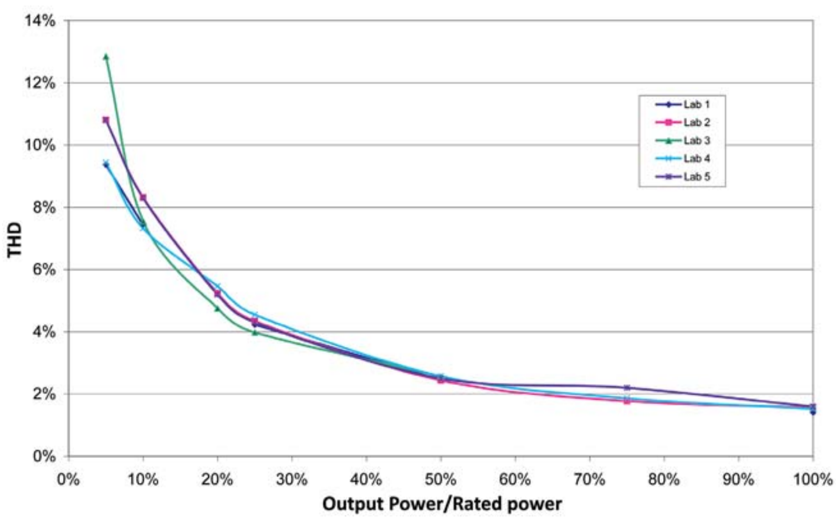


Figure 7. THD measures for the same inverter in different laboratories.

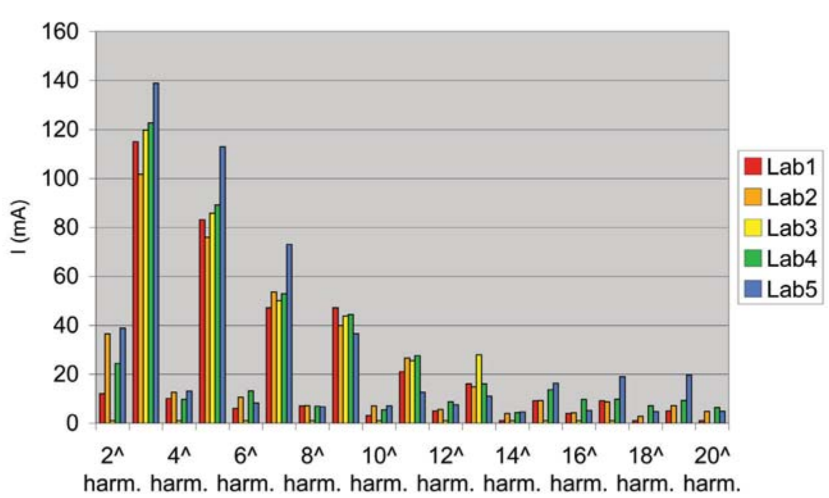


Figure 8. First 20 current harmonics measured in different laboratories (P/Pn= 50%).

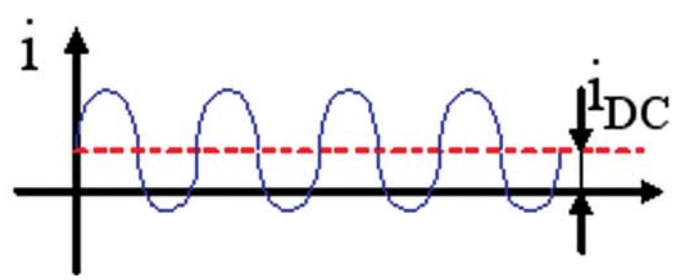


Figure 9. Representation of the DC current injection in the AC grid.

case, measurement of this intervention is not possible as the essence of the study is to investigate how to cause the protection intervention.

Test equipment and preparation

The inverter is connected on the DC side to a PV simulator that provides the required harmonics measurements for different fixed output power (equal to 5%, 10%, 20%, 25%, 50%, 75%, 100% and 120% of the inverter rated power). The inverter is connected on the AC side to an adjustable grid simulator, or to an LV single-phase real grid. A multi-meter is then positioned on the AC side for the measure of the output DC current, the configuration for which is shown in Fig. 10.

Procedure

The test procedure describes the steps required to measure the output DC current. The test is carried out for values of output power equal to 5%, 10%, 20%, 25%, 50%, 75%, 100% and 120% of the inverter rated power.

Results

DC current injection from the inverter to the grid should be avoided: indeed, the DC current component can increase losses in the nucleus of the transformer supplying the grid (and also its magnetization current and the acoustic noise level). The worst-case scenario can be garnered by adding, for each phase, the DC component values of the different generators connected to the grid. On the basis of these considerations, the CEI 11-20 standard, assumed as a reference for the round-robin test, requires, for a single generator, a DC current injection not higher than 0.5% of its nominal current. As the amplitude of these DC current components is very small in relation to the amplitude of the inverter nominal current, it can be difficult to measure (see Fig. 11).

The DC current components are injected to the grid from the same inverter, performing the measure at different levels of the output power supplied. The results are largely scattered and the measure has clear problems regarding repeatability. Fig. 12 shows a schematic of the testing configuration used. The DC current component is measured on the base of the voltage level on the shunt between the inverter and the grid (or the grid simulator).

Next, a small DC component should be measured, overlapped by a high AC current. This usually occurs when the inverter is at maximum power supply, and the measure error can be high. Furthermore, during the measure, the inverter has to be maintained in a stable condition; the PV inverters, in turn, continuously modify their working point because of the MPPT mechanism.

In order to minimize these effects, it is important to evaluate average values in a sufficiently long time slot in order to ensure that enough measurements can be collected.

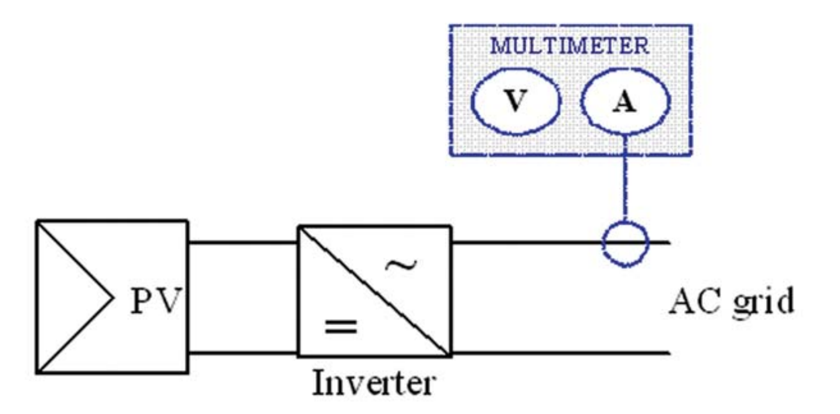


Figure 10. DC current injection measurement configuration.

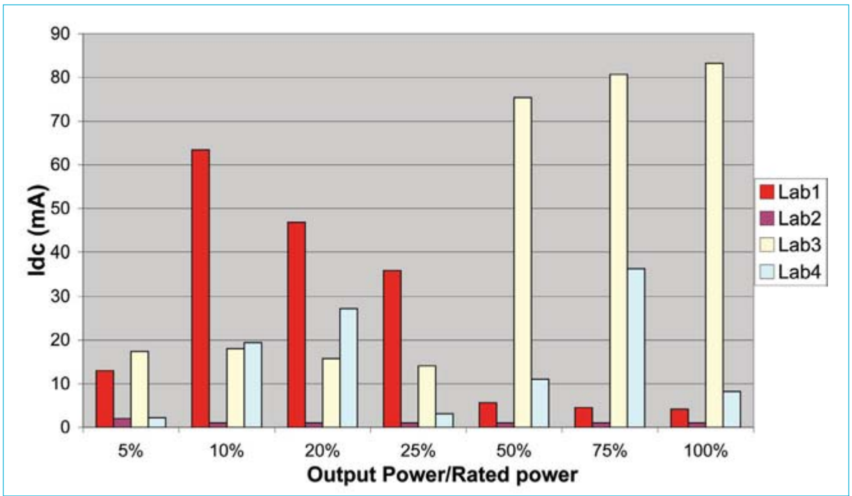


Figure 11. DC current injection measures.

Test equipments: final considerations

Testing a PV inverter that is connected to the electric network requires a DC source that can provide the due DC input to the inverter, and an AC grid – or grid simulator – that is able to supply the right voltage value and to receive the power produced by the inverter under test. However, the round-robin test brought to light some concerns in relation to these pieces of equipment, detailed in the following section.

DC supply

The DC source for the inverter tests can be a DC generator, a DC generator with a series resistance, or a photovoltaic simulator. Test procedures usually define exact values of power produced by the inverter and stable functioning conditions are required during the test. A DC generator usually cannot fulfil this requirement: in fact, the working point, defined by the MPPT, usually corresponds to the current limitation point of the generator and that produces a sudden variation. The MPPT, continuously changing the working point, interferes with the limitation control of the generator, which means that the working point cannot be stable. This factor is more relevant when the ratio between the output power and the nominal power of the inverter is low.

In order to reduce this problem and smooth the I–V curve, it is possible to use a series resistance between the generator and the DC input of the inverter. The best solution is a photovoltaic simulator that can produce the necessary photovoltaic-specific P–V curve (see Fig. 13). Attention must be paid to the characteristics of the photovoltaic simulator, as its control must be faster than the MPPT control of the inverter to be tested in order to avoid interferences and guarantee an adequate stable test condition.

The DERlab round-robin test has highlighted a problem specific to multi-string inverters (i.e. inverters connected to several photovoltaic fields). Such inverters usually have a DC-DC converter for each photovoltaic input and the outputs of these converters are linked to a common DC bus; this DC bus is connected to a DC-AC converter (see Fig. 14).

An MPPT is included in each DC-DC converter, setting up the value I_{DC} of the current required from the photovoltaic module, and consequently defining the relationship I–V of the photovoltaic module and the value of the voltage V_{DC} towards the DC–AC converter.

In practical situations, each DC input is connected to a different photovoltaic field, usually with different orientation, and the related MPPT ensures the maximum power from the photovoltaic field. For a multi-string inverter, the maximum power condition can be reached only if all the DC inputs are used and supplied with the maximum power.

Testing multi-string inverters requires clarification of the test condition related to DC inputs. Some laboratories connected a single DC generator to all the DC inputs of the inverters for data-gathering purposes. However, in order to better simulate a real use scenario, separate generators – one for each DC input – should be used. This approach avoids reciprocal interferences among the different MPPTs, which can lead to difficulties in maintaining the inverter in a stable test condition.

AC grid simulator

The grid simulator must be capable of providing a sinusoidal voltage without harmonic distortion. In addition, the simulator must be able to absorb the AC power generated by the inverter under test – without this capability, the operator will need to connect a balanced load to the output of the inverter. The load must have characteristics that are suited to a continuous connection at the maximum power value.

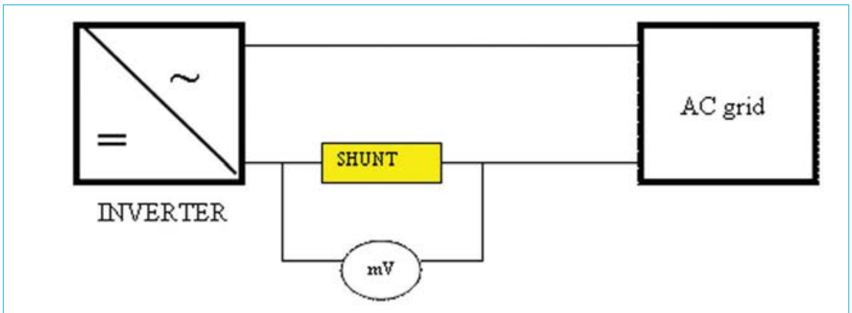


Figure 12. Testing configuration for DC current measurement.

Conclusions

The round-robin test performed throughout several laboratories of the DERlab Consortium allowed for comparison of different approaches among different testing situations, and highlighted a series of clarifications needed in order to obtain repeatable and comparable results. These experiences and the related analysis will be placed at the standard bodies' disposal, in the hope of making a contribution towards the clarification and

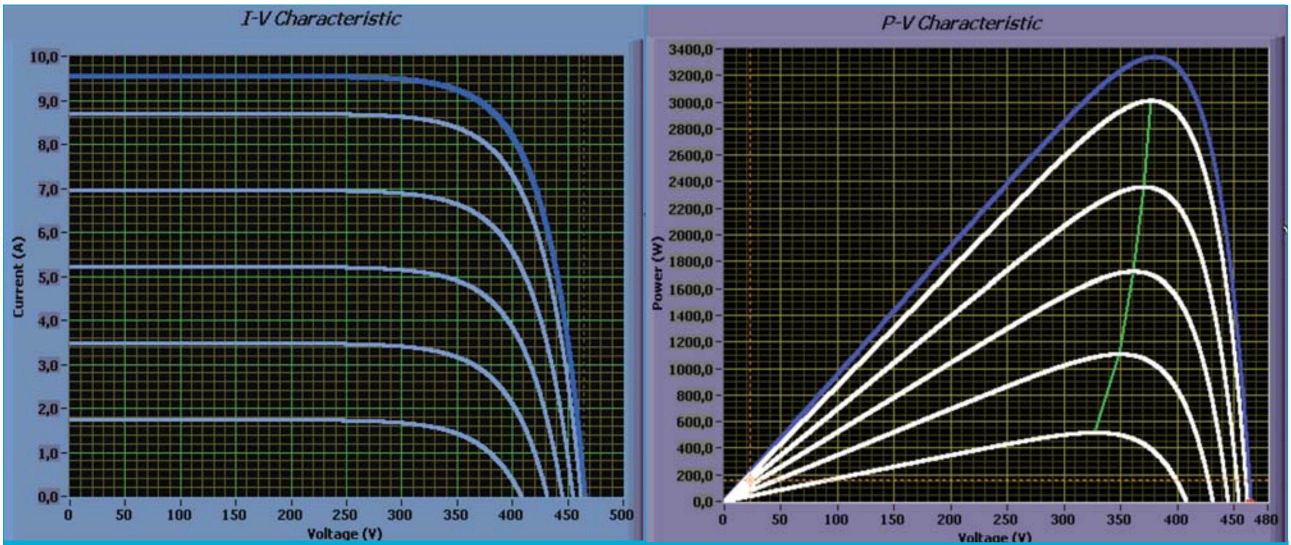


Figure 13. Photovoltaic PV curves.

the enhancement of the existing norms. The DERlab round robin approach, with the development of common testing procedures and the definition of the requirements of the testing equipment, allowed DERlab partnership to increase its common offering in this testing field.

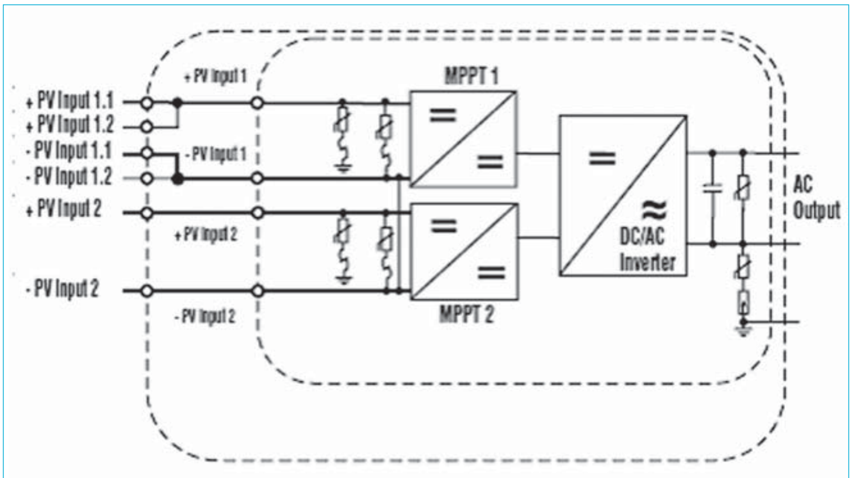


Figure 14. Usual structure of a multi-string inverter.

Acknowledgements

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About the Authors

Dr. Ing. Omar Perego (ERSE) graduated in mechanical engineering in 2000 from the Politecnico di Milano, Italy. He is involved in projects dealing with Distributed Energy Resources (DERs) related to renewable energy, poly-generation and energy efficiency development, environmental aspects and system optimization.

Dr. Ing. Paolo Mora (ERSE) graduated in electronic engineering from the University of Bologna, Italy. As ERSE leader for the DERlab Project and co-ordinator of the DERri Project, he is involved in several projects on the topics of demand side management, automation and control of electric networks and smart grids.

Dr. Ing. Carlo Tornelli graduated in electronic engineering in 1986 at the Politecnico di Milano, Italy. He is working on several projects in the areas of automation and control of microgrids and smart grids. He is also researching technologies for active networks including power electronics for distributed energy resources and information and communication technologies for the electric system.

Dr. rer. nat. Thomas Degner holds a diploma in physics and received his Ph.D. for work on the layout and control of wind diesel hybrid systems. He leads the Electricity Grids Group within the Engineering and Power Electronics R&D Division and is coordinator of DERlab and active in the CENELEC working group WG03 of TC8X. His research activities include microgrids, ancillary services, interconnection requirements, testing procedures and network protection concepts for distribution networks.

Dipl. Ing. Wolfram Heckmann graduated in 1997 from the Technical University of Karlsruhe, Germany, with a degree in electrical engineering (Dipl.-Ing.) and worked for nine years as an energy consultant. He joined the Electricity Grids Group at ISET e.V. in 2006, where his work focuses mainly on grid integration of distributed energy resources and energy management in micro-grids.

Enquiries

Power System Development Department
ERSE
Via Rubattino, 54
20134 Milan
Italy

Emails: omar.perego@erse-web.it
paolo.mora@erse-web.it
carlo.tornelli@erse-web.it
tdegner@iset.uni-kassel.de
wheckmann@iset.uni-kassel.de

Building-integrated photovoltaics: guidelines and visions for the future of BIPV

Dr. Arch. Silke Krawietz, SETA Network, Rome, Italy

ABSTRACT

Renewable energy and, specifically, the integration of photovoltaics in residential development will play an important role in the context of global sustainability and resource conservation. Just like EPIA outlines in its Solar Europe Industry Initiative (SEII) plan (2010-2012), as distributed PV and other renewable energy technologies mature, they can provide a significant share of European electricity demand. However, as their market share grows, concerns about potential impacts on the stability and operation of the electricity grid may create barriers to their future expansion. Additionally, low-cost, high-quality integration of PV in buildings and other objects poses major development challenges. The goal of the SEII is to unlock the potential for making PV a mainstream energy source, with special attention on aspects of system integration.

Introduction

In order to achieve the target of generating up to 12% of the European electricity consumption by 2020, the PV industry, together with the network operators and building sector, needs to develop economical and technical solutions that will allow a large penetration of PV at a competitive level [1].

With respect to system integration, the SEII plan shows the following key performance indicators:

- Demonstration of reliable operation of grids with high levels of PV penetration;
- Demonstration of high-quality, versatile integration of PV in buildings and infrastructural objects;
- Demonstration of large-scale use of new PV technologies;
- Availability of comprehensive PV technology, economy, market.

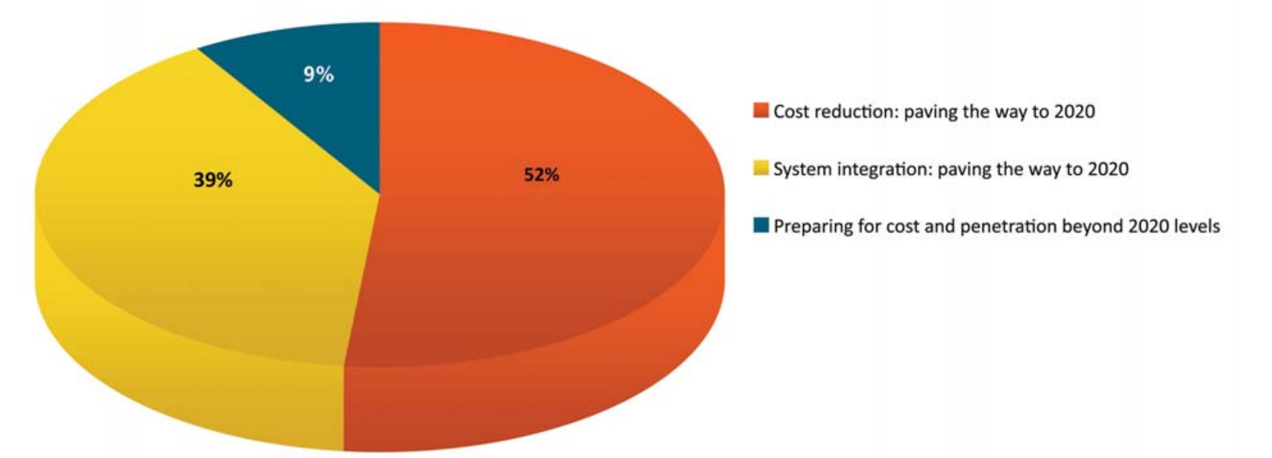
In the field of building-integrated photovoltaics (BIPV), very large-scale deployment of PV will strongly benefit from (or may even partly depend upon) the availability of multifunctional PV modules for integration solutions for buildings and infrastructural objects (sound barriers and many more). This is because turnkey system costs can be reduced by advanced integration concepts, but also because public support may be fostered or strengthened by the high aesthetic quality achievable with full integration. It is therefore imperative to develop concepts and hardware for the integration of PV [1].

Fig. 1 shows the budget distribution for R&D and demonstration projects under the SEII: 2010-2012. It should be noted that this does not include other types of investments (such as, for instance, capacity expansions or the ongoing national research on the various topics), which are not directly included under the SEII.

BIPV, using first- (wafer-based approach) or second-generation (thin-film) photovoltaics, is already offering enormous possibilities for architects and engineers to integrate this cutting-edge technology into their buildings and to make BIPV a part of their overall architectural concepts. Nevertheless, there are still many unexplored possibilities and challenges, as BIPV is not yet integrated in every new or refurbished building. This will, however, hopefully be the case in the near future, keeping in mind the European Energy Performance of Buildings Directive (EPBD), which was recast in 2009, and other policy movements that promote the use of renewable energies in buildings.

> "PV building products should not only produce electricity, but also be able to fulfill other functions."

The integration of photovoltaics in buildings is a key to the future of PV technology. A BIPV system will be integrated successfully if it is incorporated into the building fabric with good design and structure and with a sustainable energy concept. The building envelope has become a more complex and multifunctional element, with increasing façade performance expectations. With new technological developments, radical changes to the design of façades and roofs can be realized. While designing



Courtesy of EPIA, p. 18.

Figure 1. Budget distribution for R&D and demonstration projects by categories under the SEII: 2010-2012.

the building exterior we need to be aware that the use of PV as part of the envelope is important.

This presents only one aspect of various building envelope performance characteristics which need to be considered in the planning stage. To accomplish all these building performance expectations, PV building products should not only produce electricity, but also be able to fulfill other functions. Photovoltaic integration is becoming a design element for buildings. PV modules in a building can have several functions such as providing weather protection, heat insulation, sun and noise protection, as well as assisting with the modulation of daylight [2].

Instead of conventional façades and roof elements, the use of photovoltaic modules could be described as constructive integration. The modules thus replace components of the building envelope and roof. In the broadest sense an integrated PV into the façade is and can be an architectural visual enhancement, in accordance with the eligible BIPV solutions for the FiT in various countries.

"In planning a BIPV system, the orientation of the selected building surfaces for PV must be taken into account."

How is it possible to achieve a successful integration of photovoltaics into buildings? Which criteria and critical factors should be taken into consideration early on in the planning stages and then in the overall architectural concept itself?

By following some critical principles and various aspects of BIPV that must be considered by architects and planners in order to achieve a maximum yearly energy output of the system, a successful BIPV will be capable of achieving the maximum possible energy output for the installed PV system as well as a pleasant aesthetic result.

The factors to be considered are:

- Inclination and orientation of the BIPV system;
- Rear ventilation; and
- Shadowing and different orientations.

Inclination and orientation of BIPV systems

Both the inclination and orientation of a solar cell surface influences the yield. The ideally positioned PV system corresponds in its inclination approximately to the degree of latitude of the location, and is orientated to the south.

A south-orientated vertical BIPV system can still achieve 70% of the best possible yield. It achieves good performance even when the sun is low in the sky (for example in the morning, the evening and mostly in winter). In the summer, the conditions are not as favourable for a high energy yield result.

A vertical system, which is orientated towards the east or west, can reach up to 50 to 60% of the maximum energy yield and has good performance in the morning and evening respectively.

A vertical façade, which is oriented towards the north in Europe, rarely receives any direct sunlight, with the exception of indirect sunlight for brief periods in the summer, early in the morning or late in the evening. Nevertheless, it achieves 20 to 30% of the best possible yield due to diffuse light scattered across the sky, especially in cloudy weather.

To achieve acceptable yields, it is advisable but not essential that the system is oriented towards to the south. Electricity is often required most on summer afternoons due the air conditioning load in the building. A system oriented more to the west than the east could be the best choice in this case.

In planning a BIPV system, the orientation of the selected building surfaces for PV must be taken into account to a certain extent. Although the planning criteria should not be purely yield-oriented, it is nevertheless important to include the requirements of these electrotechnical components in the design considerations.

The orientation of the module surface, when located in a southerly orientation with an inclination of approximately 35 degrees towards the horizontal in Central Europe, enables maximum solar yields to be achieved over the entire year. However, the architect or planner retains substantial flexibility. Deviations from southeast to southwest involve only small losses of yield. Even in the case of vertical installation, with a southerly orientation, it is possible to achieve almost 3/4ths of the solar irradiance compared to an optimal orientation.

Rear ventilation

In addition to the alignment and possible shadowing of the PV surface, the electrical efficiency of the photovoltaic modules significantly influences the yearly energy yield. This decreases as the modules become warmer. The architect/planner can exert influence on their structural integration. Sufficient rear ventilation should therefore be guaranteed, weighing it against other construction and design decision-making criteria. The module cooling may also be combined with controlled waste heat recovery.

Shadowing and different orientations

Solar cells are combined into a module and connected in a series to obtain higher module voltages. Within the particular string of cells, like in series-connected batteries, it is known that the 'weakest' cell determines the total electricity output in the module. This kind of weakening of the cell can be caused, for example, by (partial) shadowing. In this case, the electricity reduction does not occur linearly to the shadowed module surface, but acts disproportionately towards it.

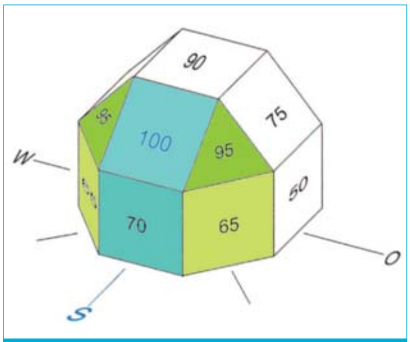


Figure 2. Influence of alignment (orientation and inclination) on the annual insolation quantity in Central Europe [3].

This also applies to the interconnection of the modules in the generator array, because in order to achieve the normal system voltages, multiple modules are connected in series to form a so-called generator string. The generator array can then – according to the desired system voltage – be expanded with several parallel connected strings. The electrical power output of such a string is determined by the weakest module. To minimize the progression due to unavoidable partial shadowing, a weakened module can be 'circumvented' by using so-called bypass diodes between the cell connections. The above-described effect also occurs if the modules in a string have different orientations. Here the amount of electricity is determined by the least favourably-orientated module. However, this problem can be counteracted by the appropriate interconnection of the generator array in strings that are as short as possible.

The decisive factor for the maximum energy yield of a photovoltaic system, in addition to the orientation, is the absence of shadowing on the generator surface because even minor shadowing of individual modules may result in substantial reductions in the energy yield.

Therefore, the module surface should be planned in such a way that it remains shadow-free as much as possible, at least during the summer season. The initial indications can be obtained, for example, with the aid of solar altitude diagrams. More detailed information can be obtained from alternate or other simulation programs.

"The decisive factor for the maximum energy yield of a photovoltaic system, is the absence of shadowing on the generator surface."

Particular attention should be given to the surrounding buildings. Even plants around the building may eventually cause shading and thus have an adverse effect

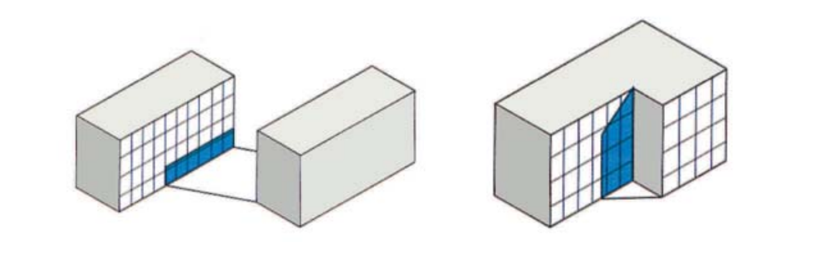


Figure 3. Shadows cast by surrounding buildings (left) and the geometry of the building in question (right) need to be taken into account during the design phase [3].

on the performance of the modules. This applies in particular to newly-planted green spaces, which are often designed by external planners. It is advisable to establish guidelines that can guarantee a shadow-free module surface.

Even the possibility of shadows cast by the building itself should be considered. This can be caused both by the building geometry itself and also by details of the constructions' deep cover strips, suspended elements or moving parts – all of which risk casting unfavourable shadows (see Fig. 4).

All of these elements must be considered in the early planning stages of a building, in order to achieve the maximum energy output of the PV system [3].

Outlook into the future

In the future there will be overlapping areas between architecture and the field of photovoltaics and therefore it is important for the sake of future collaboration that architects develop a knowledge of BIPV. This will be increasingly important for future collaboration between architects, PV specialists/experts and PV companies.

Consequently new integration possibilities can be found in an interdisciplinary collaboration among the various branches, as there are still many unexplored possibilities in the field of BIPV. This is a continuing challenge for the architects of today and tomorrow.

Innovation and R&D is necessary for a more widespread use of BIPV and for the development of new products. A strong interdisciplinary collaboration between PV and building component manufactures, architects and engineers is essential. The collaboration between these areas might lead the way new designs of BIPV modules, with more flexibility in shape, colour and dimension. Better performance and higher PV efficiency, together with more variability of BIPV products, is expected.

The future of BIPV can only be designed and developed with common efforts in the direction of a BIPV future and the multiple use of façades, roofs and building components.

PV technology has seen a huge increase in the last decade and more is expected to come, especially in Europe. BIPV will play an even more important role in the future.

As the EPIA report SEII suggests in "System Integration Paving the Way 2020", the development of new multifunctional PV-based products, research infrastructure, test facilities, and test procedures for building-integrated PV products in order to make innovations faster and easier are becoming ever more important.

As well as optimization of the energy output and value in a complex environment, shadowing, and demand-side management options must be considered in order to get the best value in PV production [1].

Every building in 2030 that is designed, constructed and monitored will have cutting-edge BIPV technology. Architects of today and tomorrow have to keep pace with the development of building technologies and stronger policy regulations in the framework of climate change and sustainable development. Amelioration and application of PV is a key to the future.

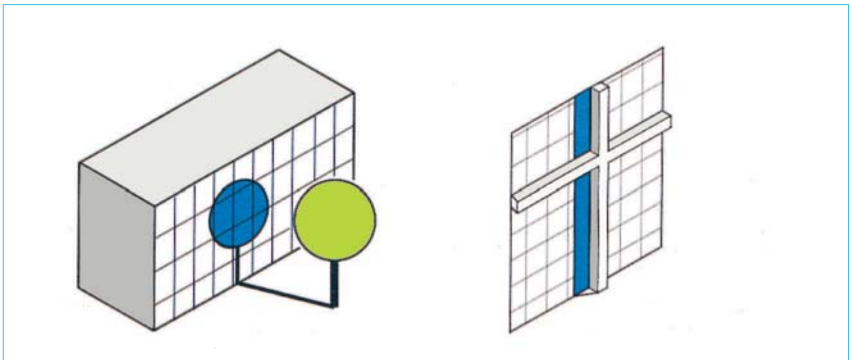


Figure 4. Plants (left) and deep cover strips (right) are among the elements that can cause shadowing on a building and reduce the BIPV system's efficiency [3].

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About the Author

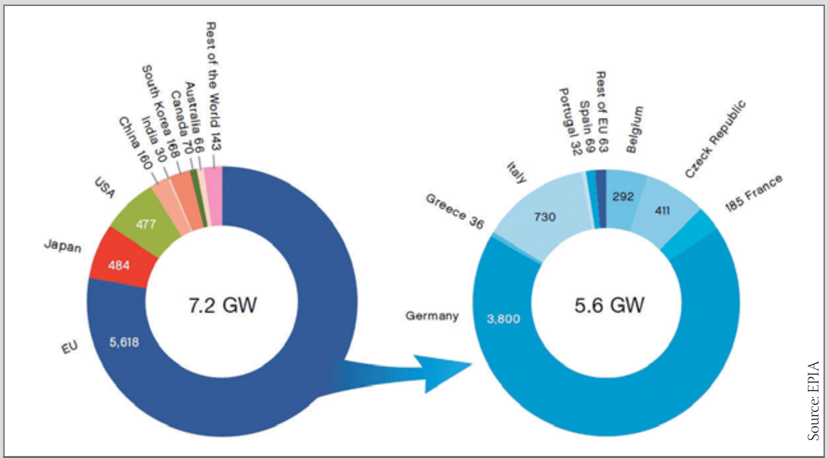
Prof. Dr. Silke Krawietz is CEO and Scientific Director of the SETA Network, an organization that is active in the field of Sustainability, Energy, Technology and Architecture and offers services for BIPV projects, information, and consultancy. She is collaborating with EURAC, Bolzano, in the Institute for Renewable Energy, as well as UNEP, Paris in the Sustainable Building and Construction Initiative (SBCI) as a member of the European PV Technology Platform. Dr. Krawietz has been Interim Professor at the Faculty of Architecture at the University of Catania, Italy for the past five years and she has worked on many BIPV projects with international bodies and European universities. An expert in Jeremy Rifkin's team, she holds a Ph.D. in BIPV from the Faculty of Architecture, University of Darmstadt/Germany.

Enquiries

Tel: +39 06 35491557
Email: seta@gmx.net
silke.krawietz@eurac.edu
Web: www. seta-network.com

Market Watch

EPIA revises solar market growth for 2009: global installs reached 7.2GW



World and European PV markets in 2009 (MW).

Preliminary 2009 market figures issued in March 2010 by the European Photovoltaic Industry Association (EPIA) showed that installations had increased by 6.4GW. However, newly revised final figures show that installations increased to at least 7.2GW in 2009. The PV market therefore grew by almost 15% in 2009 compared to 2008 and the total cumulative power installed in the world increased by 45% to 22.9 GW.

Not surprisingly, the German market was a key catalyst for growth last year, which increased from 2GW in 2008 to around 3.8GW installed in 2009, representing more than 52% of the world PV market. Revised figures from Italy also helped push 2009 installed figures to nearly 1GW more than the preliminary figures issued in March. Installations in Italy reached 720MW, up significantly from 338MW in 2008.

Other European countries also experienced good growth in 2009. The Czech Republic and Belgium saw installations of 411MW and 292MW, respectively. France followed with 185MW installed in 2009, with an additional 100MW installed but not yet connected to the grid, according to EPIA.

The market also developed significantly outside Europe with 484MW installed in Japan and 477MW (including 40MW of off-grid applications) in the U.S. However, the EPIA forecast for new emerging markets such as the UK may be overly conservative. The trade association noted that it expected the UK market to reach between 20 and 40MW in 2010 on a 'moderate' analysis. Market research firm iSuppli Corp is currently estimating that installations could reach 100MW in the UK in 2010.

The strong growth is set to continue in 2010. Despite concerns over the impact the German feed-in tariff reductions will have, Germany is still expected to retain its number one position with up to 4.5GW installed this year. Overall, installations could reach 12.7GW, a 76% increase over 2009.

2010 Market Forecast

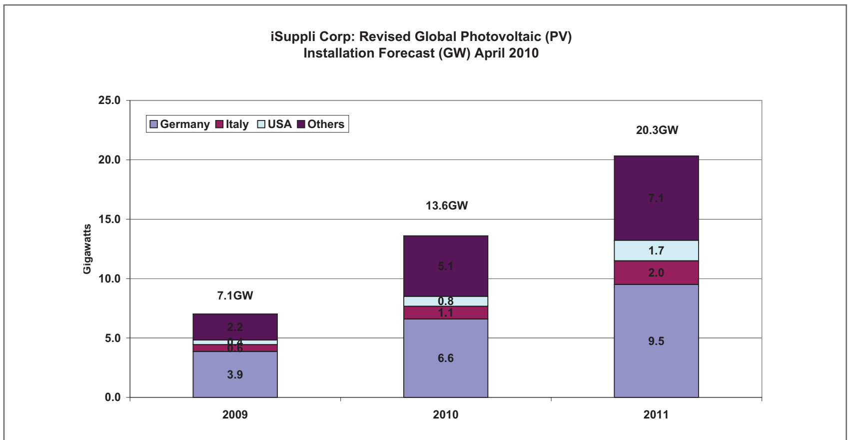
iSuppli bets big on global solar installations forecast for 2010 reaching 13.6GW

iSuppli now projects solar installations will reach 13.6GW this year, an increase of 93.6% compared to its estimates of installations reaching 7.0GW in 2009. The market research firm had previously forecast PV installations to reach 8.3GW, up 64% from 2009.

The market research firm cited that the massive change in its forecast was due to a significant surge in demand in Germany, combined with expected plunging prices, making solar increasingly attractive.

According to iSuppli, PV installations in the second and fourth quarters will be key periods for robust growth, in part due to the poor winter conditions in Europe. The rush to beat feed-in tariff changes in Germany will drive growth.

The period after the midyear changes to the German tariff system will lead to further plummeting prices last seen in 2009, when market demand in the first half of the year was weak and overcapacity was at its height.



iSuppli Corp: revised Global PV installation forecast (GW).

In another bullish prediction, the market researcher believes that the significant capacity expansions being implemented by c-Si module producers will not be enough to avert potential supply constraints in 2011. The rationale that iSuppli gives is that global PV installations will rise to 20.3GW in 2011, nearly triple the 7.0GW in 2009.

Unless additional expansions take place, crystalline-silicon modules could encounter constraints in 2011. iSuppli forecasts that utilization rates for c-Si module production facilities will climb to more than 90% in 2010. Furthermore, many Tier 1 suppliers of c-Si modules and cells will be sold out. Tier 2 and Tier 3 module suppliers are seeing business pick up, as they strive to supply Germany with the modules it needs.

Despite the short-term supply challenges, the outlook for global PV installations remains bright.

IMS Research says solar installations could reach 10GW in 2010

Having forecasted that global PV installations would actually grow in 2009, IMS Research now expects global installation could reach 10GW in 2010, despite changes to the German feed-in tariff. Strong demand is coming from many different countries, according to the research firm.

"An incredible 1.5GW of new capacity was installed in Germany in December," noted Ash Sharma, PV Research Director at IMS Research. "This was earlier predicted by IMS Research which measured inverter shipments at 3.5GW in Q4'09, and also predicted that the global PV market grew by 25% to exceed 7GW."

IMS Research feels very proud of itself for highlighting that it was one of only a small number of research firms that had forecasted growth for 2009 and that such growth would be in the 20% plus range.

Almost 7.5GW of new PV capacity was added worldwide in 2009, according to latest confirmed results from IMS Research.

World PV Module Supplier Rankings
MW Shipments

	Company Name	Change 08-09
1	First Solar, Inc.	2
2	Suntech Power Holdings Co Ltd.	-1
3	Sharp Electronic Corporation	-1
4	Yingli Green Energy Hodling Co Ltd	-
5	Trina Solar Limited	2
6	Sunpower Corporation	-
7	Kyocera Corporation	-2
8	Canadian Solar Inc.	1
9	SolarWorld AG	1
10	Sanyo Electric Co. Ltd	-2

Full Market Share Tables available in IMS Research's Annual and Quarterly World Market for PV Cells & Modules Reports

Source: IMS Research May-10

IMS Research:
PV Market Analysis (2010).

Barclays Capital analyst raises 2010 global solar installation forecast to 11GW, Germany to 5.8GW

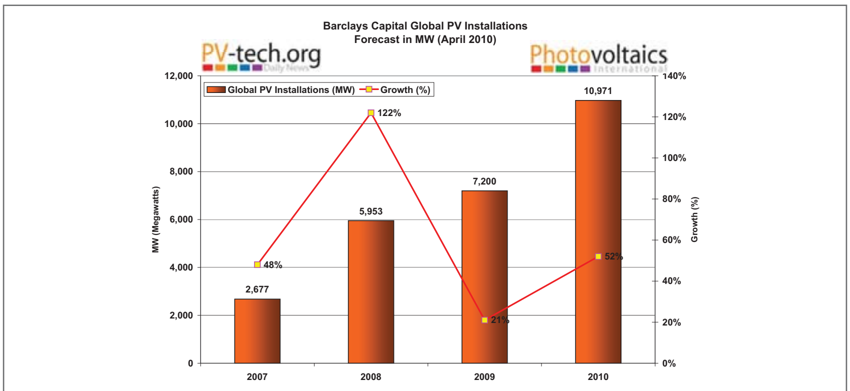
Industry demand checks and recent German PV installation figures have seen Barclays Capital analyst, Vishal Shah raise his forecast for global solar installations for 2010. In a research note to investment clients, Shah expects installations to reach approximately 11GW this year. He also noted that PV installations reached 7.2GW in 2009, an increase of 21% over 2008, when installations reached 5.95GW.

German installations are now expected to reach approximately 5.8GW in 2010, up from 3.8GW in 2009. However, Shah expects that first-half-year installations in the country will reach 3.8GW alone and 2GW installed in the second-half of 2010, suggesting that the expected feed-in tariff changes will impact installations but not result in a collapse in the German market.

Indeed, Shah is expecting that the fall-off in demand in Germany can be offset by shipments strength from other markets such as Japan, Italy, France, the U.S. China, Canada, Czech Republic and other European markets.

In particular, the Canadian market is expected to increase sequentially through at least the first three quarters of the year, with a forecast for the year of installations reaching 317MW, an increase of 273% compared to 85MW projected for 2009.

The French market also remains strong, forecasting PV installations to increase 169% in 2010 to 497MW. Shah also noted that the Italian market is once again picking up and could result in installations reaching over 1GW this year. Preliminary official figures in Italy put installations at 582MW in 2009.



Barclays Capital: global PV installations forecast (2010).

2009 Market Trends

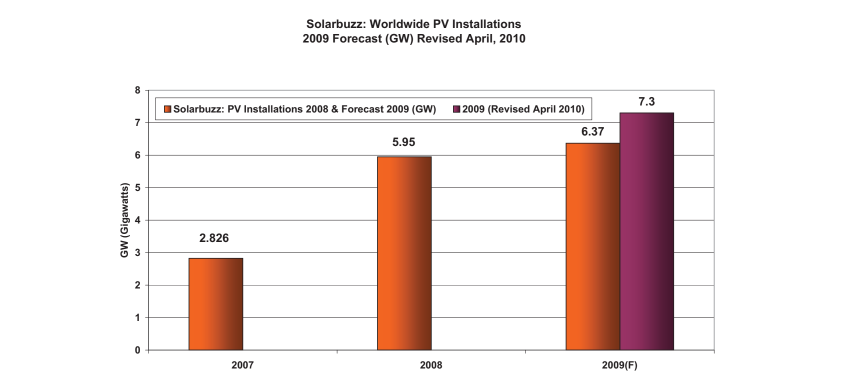
Global PV market climbed 20% to 7.3GW in 2009, says Solarbuzz

The massive late surge in solar module installations in Germany in 2009 has meant that the global PV market increased 20% over 2008, according to revised figures from Solarbuzz. Installations reached 7.3GW last year an increase of 0.87GW on its previous market forecast.

As the German market closes in on a 4GW figure for 2009, running well ahead of the 2.5-3.5 GW per annum path specified in the currently proposed amendment to the Germany's Renewable Energy Act (EEG), further tariff cuts could be on the cards.

"The current EEG policy amendment is based on a target market range that will be overshot by a large margin in 2010, so the Government may yet choose to cut back tariffs mid-year even more aggressively than currently planned", said Craig Stevens, president of Solarbuzz, a division of The NPD Group. "Even without such revision, the PV industry will need to plan on a major re-balancing of global supply and demand in both mid-2010 and the start of 2011, worse than occurred from the policy adjustment in Spain in 2008."

The market research firm said that Germany now accounted for 63% of global demand in fourth quarter of 2009, a record high. At 3.73GW, it was more than seven times larger than in the first quarter of 2009, following massive growth in European demand through the year. Solarbuzz had only recently said that PV installations reached 6.43GW in 2009, representing an increase of 6% over the previous year.



Solarbuzz: Worldwide PV installations 2009 forecast (GW).

Official: solar installs in Germany reach 3.8GW in 2009

The German Federal Network Agency has released preliminary photovoltaic (PV) installations in the country for 2009, which highlight the significant growth that took place between October and December 2009. In total, 3.8GW was installed in 2009, a 60% increase over 2008, of which 2.3GW was installed between October and December.

"According to the figures we have done in the past year, a significant build up of solar systems. The installed capacity has increased from 6.0 gigawatts in 2008 to 9.8 gigawatts in 2009," noted Matthias Kurth, President of the Federal Network Agency, in a statement.

Figures released for the year through to September, 2009 showed that installations had reached 1.5GW. Based on the Federal Network Agency data, installations in December reached 1,45GW alone.

PV installation figures in Italy reached 720.3MW in 2009

According to updated figures from GSE, PV installations in Italy for 2009 have risen to 720.3MW, up from revised figures released in January 2010 of 374MW. Installations connected to the grid in 2008 amounted to 338MW. Recently, Barclays Capital had forecasted that PV installations in Italy could reach 2GW in 2010 as grid parity had been reached.

Reuters reported that Italy's Economic Development Minister revealed that Italy gets 20% of its energy output from renewable sources, though demand for electricity fell in 2009, due to the economic recession.

SEIA releases 2009 U.S. Solar Industry Year in Review report

After what was a trying year in economies all over the world, the Solar Energy Industries Association has released its 2009 U.S. Solar Industry Year in Review report, finding that the U.S. solar industry posted strong numbers and showed significant growth. Overall, the United States ranked 4th in new solar electric capacity worldwide with industry growth totaling nearly $4 billion – a 36% improvement.

The US solar electric capacity increased by 37% due mainly to a constantly increasing demand for PV arrays in residential and utility-scale settings. The increased demand and industry growth generated 17,000 new jobs from coast to coast. The U.S. now has 46,000 workers in the solar industry.

PV installations that are grid-tied grew 38% with PV module production climbing 7% from 2008 figures. Residential grid-tied solar installations doubled from 78MW to 156MW, while non-residential grid-tied PV installations inclined 2% less than 2008. The total utility-scale channel reached 17GW while a collective U.S. CSP capacity reached 432MW.

California was the leader in solar electric capacity with 220MW followed by New Jersey at 57MW and Florida at 36MW.

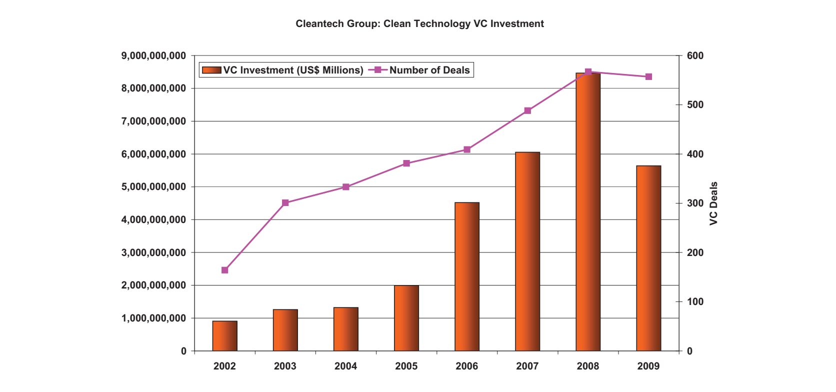
News

General Market News

McKinsey study finds electricity from renewable energy is a feasible goal by 2050

McKinsey recently concluded a feasibility study to determine if electricity from 100% renewable resources was possible. The study determined that by 2050, not only is it feasible, but countries like Germany are leading the way to making it possible. The study, published by the European Climate Foundation was commissioned to examine the possibility of the EU achieving 80% greenhouse gas reduction by 2050 compared to 1990 levels. The study concluded that along with renewable energy being 100% feasible, it was also a reliable and economically sound energy decision.

Germany currently has one of the biggest renewable energies markets in the world with 2009 showing a 16.1% increase in the total share of electricity from renewable resources. Germany also saw its PV installations surpass 3.8GW last year, making it responsible for more than half of the world's solar market for the year. With only 2% of Germany's suitable rooftops covered with a PV system, the country has plenty of opportunity to expand its international lead in the solar renewable energy market.



Cleantech Group: Clean technology VC investments (2002-2009).

Solar VC funding wanes in 1Q 2010

Having been the major beneficiary of venture capital investments over recent years, solar funding could be on the wane if the fall in funding for the first quarter of 2010 develops into a trend going forward. According to the latest findings issued by the Cleantech Group and Deloitte, transportation topped the category list for the first time with US$704 million invested in 27 deals. The solar sector only attracted US$322 million in 27 deals. Clean technology in general attracted VC investments totalling US$1.9 billion across 180 companies in the first quarter of 2010.

In 2009, VC investments in solar reached US$1.2 billion, 21% of all funding; however, transportation (including electric vehicles, advanced batteries, fuel cells) was close behind with US$1.1 billion in funding.

"The bounce back in venture investment from lows in early 2009 has continued, with the first three months of 2010 representing the strongest start to a year we have ever recorded," said Sheeraz Haji, president of Cleantech Group. "Key to the growth has been increasing interest in a broader range of cleantech themes, such as smart mobility and resource efficiency, which are now taking over from the historically dominant renewable energy sector."

On a regional basis, North America accounted for 81% of total investments in the quarter, a three-year high for the region, according to the report. Europe and Israel accounted for 14%, China 4%, and India 1%.

In the solar sector, investments of note in the quarter included: SpectraWatt, which raised US$41.4 million; Petra Solar raising US$40 million; and Enphase Energy, which also raised US$40 million.

Cleantech venture investment was up 29% from the previous quarter and up 83% from the same period a year ago. The number of deals recorded in the quarter was a new record, slightly higher than the previous record of 165 deals achieved in the fourth quarter of 2009.

Gartner highlights its 'Cool Vendor' solar start-ups

In its Cool Vendors in Solar Energy, 2010 report, Gartner highlights some of the solar energy start-ups that it believes are developing technologies and innovations that will likely have a strong impact on the adoption of solar energy. Companies included in the review include Applied Quantum Technology, BrightView Systems, Confluence Solar, Innovalight and Solexant.

Gartner noted that innovation remains strong in the PV industry, although venture funding is somewhat limited in comparison with two or three years ago. A key hurdle for start-ups is to overcome the lack of project finance for solar installation projects as finance requirements have turned to the 'bankability' of projects, which dictate the use of previously used and known vendors and products.

According to the market research firm, vendors in the Cool Vendors report are developing innovations that have the potential to dramatically lower the cost of PV solar energy, if they can surmount the bankability barrier. This has become a key focus of start-ups since the collapse in average selling prices that occurred during 2009.

CSI data analysis: April 2010 application rate is staggering; Asian modules dominating

By **Mark Bachman**, Auriga USA

Applications into the California Solar Initiative (CSI) were 151MW in April 2010, a record month that saw growth of 134% over the previous record of applications set in March 2010. Despite the declining subsidy programs in California, demand is robust. We attribute a large part of this momentum to the influx of low-priced Chinese and Japanese modules as key enablers to making solar solutions more affordable across all of the end-markets. Lower average selling prices (ASP) appear to be winning market share, rather than arguments about superior branding, aesthetics, and high-performance solutions. We also believe that the California market is an acceptable proxy for total U.S. demand.

Trina Solar has entered the market, and solar contractors have booked over 24MW in April 2010, a positive affirmation of our recommendation to own the stock. We also find that SunPower is lagging behind the industry growth rate for first four months of 2010; SunPower is up 58% YTD over 2009 while the market is up 95%. This supports our contention that SunPower is losing market share in the U.S., and we reiterate our thesis for margin compression in SunPower's business model.

We issued a mid-month analysis on April 22 and reported that applications were running 91% ahead of the pace set in 2009; total applications in 2010 are now 252MW versus the 87MW in the same period in 2009, resulting in a growth rate of 190% YTD. The 2010 count also compares very favourably with the 265MW of applications for all of 2009. Our analysis shows that 2010 applications already account for 95% of total applications submitted in the previous year. April 2010 set a new monthly record of 151MW of applications, a 134% growth rate over the 65MW of applications received in March 2010. We note this is back-to-back months of record solar applications; November 2009 is the third-highest month on record with 37MW.

Similar to our mid-month report, low ASP modules from Asian manufacturers are dominating the application base. Suntech has 18% share of 2010 applications and has already achieved 135% of its total MWs from 2009. After a slow start to the year, Sharp has rebounded in April and comprises 14% share of 2010 applications. We note that in addition to SunPower, Sharp is also lagging behind the market growth rate of 95% so far in 2010. Applications using Trina Solar modules have one exceptional month on record, but it is too early to call this a trend, in our view.

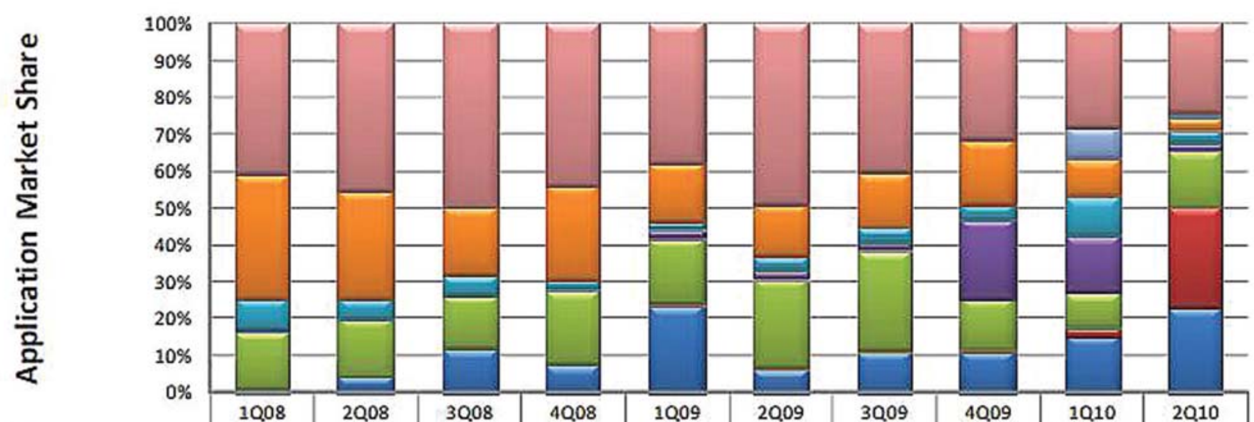
Low ASPs are driving market share shifts to Chinese and Japanese module suppliers. Market share shifts are favouring low-priced modules from the likes of Suntech, Sharp, Trina Solar, Yingli and Kyocera.

SunPower has edged ahead slightly with over 8MW of applications in the government sector during the last 10 days of the month. Notably, the applications were from SunPower's own systems group and not generated by third-party installers. Recent checks into our installer contacts continue to suggest that SunPower's high-performance modules are priced at a 10% to 30% premium. Our contacts noted that Suntech, BP Solar, Sharp, and Kyocera modules are priced more competitively, and somewhat surprisingly, Evergreen modules (ESLR, NR) were noted to be priced more competitively as well.

Applications in the commercial sector are dominated by the Asian module manufacturers; this is also where modules from Trina Solar have made a surprising entrance. Applications in the government sector saw a late surge of projects using SunPower modules. The 8.6MW of applications in April were all generated internally, which piques our interest as to whether third-party installers can be as successful with SunPower modules as the year progresses. Our recent channels have us leaning away from success.

Residential is the lagging sector as the commercial and government sectors are the primary end-market drivers for solar applications. The residential market is up meaningfully YTD in 2010, but is growing slower than the commercial market.

News



	1Q08	2Q08	3Q08	4Q08	1Q09	2Q09	3Q09	4Q09	1Q10	2Q10
Other	41%	45%	50%	44%	38%	49%	40%	31%	28%	24%
DelSolar	0%	0%	0%	0%	0%	0%	0%	0%	9%	2%
SunPower	34%	29%	18%	26%	16%	14%	15%	18%	10%	3%
Kyocera Solar	9%	6%	6%	3%	2%	4%	4%	4%	11%	4%
Yingli Green Energy	0%	0%	0%	0%	2%	2%	2%	22%	16%	2%
Sharp	16%	16%	15%	20%	18%	24%	27%	14%	10%	15%
Trina Solar	0%	0%	0%	0%	1%	0%	0%	1%	2%	28%
Suntech Power	1%	4%	12%	7%	23%	6%	11%	11%	15%	23%

Source: California Solar Initiative, Auriga USA.

CSI data analysis for April 2010.

The impact of the revised French FiT

Richard Loyen & **Sylvain Roland**, Enerplan, La Ciotat, France

ABSTRACT

The French Ministry for the Environment, Ecology, Sustainable Development and Sea (MEEDDM) officially published a new decree concerning photovoltaic electricity generation and feed-in tariffs (FiT) on January 12th 2010. This was followed by a second decree, published on March 16th 2010, which contained some additional information and revisions to the first. This paper outlines the effects the revisions will have on France's solar industry and provides guidelines for future developments in the country.

Presentation of the new feed-in-tariff

For the government, the main goal of the revised FiT was to stop speculation on the photovoltaic market, while also providing a new framework for the development of this market. The new FiT is now effective until the end of 2012, which effectively means that this particular FiT scheme will remain unchanged until 2013. From this date onwards, and assuming there is no change in the meantime, the FiT should normally decrease by 10% each year. The new decree has fixed three types of FiT based on building integration criteria (see Table 1).

BIPV systems

Building-integrated PV systems up to 250kWp benefit from a tariff of €0.58 or €0.50, depending on the intended use of the building in question. The government has also provided the following new definition of the term 'building integrated':

- The PV system must follow the roof angle of a wind- and waterproof building (four sides closed)
- PV modules (or thin-film modules) must provide the waterproofing for the building
- Removal of the modules or films could not be performed without damaging the waterproofing ability of the building.

This definition also includes architectural PV systems with features such as windows, balconies or flat roof balustrades and sidings or shading over windows. The €0.58 level is only applicable in the case of an installation on new and existing houses or apartment buildings. It is also applicable on education and health buildings that have been in existence for more than two years. The €0.50 rate is valid for BIPV systems on other types of buildings that have stood for more than two years.

Simplified BIPV systems

PV systems above 3kWp that include simplified building integration are eligible for an FiT of €0.42. Simplified BIPV systems refer to installations that comply with the following requirements:

- PV system is parallel to the roof
- PV system (in its entirety) replaces components which provide wind- and waterproofing to the building
- PV system (in its entirety) ensures wind- and waterproof qualities.

From 2011, this €0.42 FiT will also be applicable to systems under 3kWp that adhere to the following conditions:

- System is installed on the roof and follows the roof angle of a wind- and waterproof building (four sides closed) that provides protection to people, animals, goods and activities

Figure 1. BIPV installed on an industrial roof.

<table>
<tr><th colspan="5">BIPV systems up to 250kWp</th></tr>
<tr><td colspan="2"></td><td>On new and existing houses or apartment buildings</td><td>On education and health buildings (in existence for more than two years)</td><td>On other types of buildings (in existence for more than two years)</td></tr>
<tr><td>2010 (transition phase)</td><td>• PV system is parallel to roof angle
• PV system replaces components of wind- and waterproofing
• PV system ensures wind- and waterproof qualities</td><td rowspan="2">€0.58</td><td rowspan="2">€0.58</td><td rowspan="2">€0.50</td></tr>
<tr><td>2011</td><td>• PV system has to follow the roof angle of a wind- and waterproof building (four sides closed)
• PV modules (or thin-film modules) provide waterproofing of the building
• Removal of the modules or films could not be performed without damaging the waterproofing ability of the building
• Tariff also valid for architectural PV systems with features such as windows, balconies or flat roof balustrades and sidings or shading over windows</td></tr>
<tr><th colspan="5">Simplified BIPV systems > 3kWp</th></tr>
<tr><td colspan="2"></td><td colspan="3">Every type of building that provides protection to people, animals, goods and activities</td></tr>
<tr><td></td><td>• PV system is parallel to the roof
• PV system (in its entirety) replaces components which provide wind- and waterproofing to the building
• PV system (in its entirety) ensures wind- and waterproof qualities
• Tariff also valid for architectural PV systems with features such as windows, balconies or flat roof balustrades and sidings or shading over windows</td><td colspan="3" rowspan="2">€0.42</td></tr>
<tr><td>From 2011, systems under 3kWp will be eligible if they comply with specific conditions</td><td>• Installed on the roof and has to follow the roof angle of a wind-and waterproof building (four sides closed), that provides protection to people, animals, goods and activities
• PV system (in its entirety) should replace roof and waterproofing components
• PV system (in its entirety) has to in itself ensure that the building is waterproof</td></tr>
<tr><th colspan="5">Non-BIPV installations, including ground-mounted installations</th></tr>
<tr><td></td><td>Corsica and overseas territories</td><td colspan="3">€0.40</td></tr>
<tr><td></td><td>Mainland installation < 250kWp</td><td colspan="3">€0.314</td></tr>
<tr><td></td><td>Mainland installation > 250kWp*</td><td colspan="3">€0.314</td></tr>
</table>

* Regionalized ratio from 1 to 1.2, depending on geography and insolation levels.

Table 1. Summary of France's new feed-in tariff conditions.

- The PV system (in its entirety) should replace roof and waterproofing components
- The PV system (in its entirety) has to in itself ensure that the building is waterproof.

Non-BIPV installations

All other kinds of installations, including ground-mounted installations and solar thermal concentrated power systems below 250kWp, are eligible to a €0.314 tariff in mainland France. For systems above 250kWp, the tariff becomes regionalized, taking into account the insolation of the implantation site. This ratio will range from 1 in the south of France to 1.2 in the north of mainland France.

In the overseas territories, there is only one tariff level for all other kinds of installations, including ground-mounted installations and solar thermal concentrated power systems, which is set at €0.40 (no power distinction applies in these cases).

Despite such evolutions on the concept of BIPV, the decree also refers to the increase of production caps for PV installations. In mainland France, these caps are fixed at 1,500 hours or 2,200 hours if the panels are installed on solar tracking systems; for Corsica and overseas territories, they are fixed at 1,800 hours or 2,600 hours if the panels are on solar tracking systems.

Finally, the last significant change, which has been in force since November 2009, refers to the removal of the license for PV production for installations under 250Wp ('certificat d'obligation d'achat'). The decree of January 2010 set the obligation that installers must attest that they have realized the installation in compliance with norms and laws.

Consequences for the PV market

Now that the FiT modification is complete, the details contained therein are becoming clearer. Throughout the months of negotiation with administrative bodies, players within the photovoltaics market learned that they, as the source of practical information, had to supply credible proposals to avoid market overheating, and that further FiT modifications should be expected. The professionals involved

Figure 2. BIPV installed on a glass roof.

Market Watch

in the provision of data needed to avoid speculation behaviours on the market, which could potentially threaten the FiT scheme and, crucially, the government's trust of PV players.

This topic of avoiding market speculation behaviours is now clearly shared by government and members of the PV industry, people who are working on technical innovations, creating jobs, and having a long-term vision for and effect on the market. Many of these actors are active in Enerplan, the French professional association for solar energy.

Before analyzing the consequences of the new tariff's layout, it is interesting to take a look back at the French PV market's development in 2009. On the one hand, the country's cumulated market based on installations connected to the grid is 268MW. On the other hand, the 2009 annual market based on installations sold during the year was around 250MW; this discrepancy between the numbers is mainly a result of the waiting time on the part of installers for grid-connection.

Evaluation of the maturity of the French market requires the comparison of these data with those of Germany, which saw the market reach 8,500MW in 2009, with grid parity foreseen within the next five years. Compared to Germany's current situation, France's new FiT legislation introduced a bonus for non-BIPV installations above 250kW, which will most likely act as a catalyst for development of ground-mounted and medium- to large-scale roof installations, thus revising France's installed power capacity upwards.

In November 2009, the government also published new rules concerning urbanism authorization for this kind of installation in anticipation of more favourable FiT guidelines for ground-mounted installations. Ground-mounted installations are now subject to an environmental impact study.

Moreover, these new conditions for BIPV are seen as technical challenges for the majority of PV manufacturers. In order to be eligible for BIPV conditions, manufacturers must now design innovative integration systems and submit them to an evaluation committee, while the installers must also provide training in these new products and installation methods.

“Ground-mounted installations are now subject to an environmental impact study.”

However, it is all too easy to gloss over the responsibilities of the BIPV installer amid these FiT discussions. Indeed, new BIPV conditions lead to greater responsibilities in areas such as insurance on the part of the installer. By requiring the installer to attest their realization of the installation in accordance with norms and laws, the new FiT clarifies their responsibility in respect to the installation. In a further attempt to drive this point home, since the end of March 2010, every PV installation has to be reported to the CONSUEL (inspection office specialized in electric security).

Every player of the PV sector should now be aware and work in line with insurance obligations (10 years' insurance, special insurance requirements for buildings that are open to the general public, etc.). They also need to be aware of responsibilities linked to installation performances; regardless of the nature of the responsibility (penal, financial...), BIPV does not have space for amateurs, speculators or opportunists. The PV market is not a jungle – it is a strategic technology and should be viewed as a component of building energy efficiency.

In the coming months and years, the French PV market has to be developed in such a way as to ensure quick maturation. With this objective in mind, Enerplan and other professional bodies – including installers and other players in the electricity sector – have launched a 'PV and building think-tank' in order to make this sector more durable. The aim is to prepare professional members of the PV and building industries for future legislation changes and market evolutions.

“The French PV market has to be developed in such a way as to ensure quick maturation.”

The ultimate goal of this initiative is to give industry members a sense of responsibility for the market, and to ensure that every member plays his or her part in this durable market.

About the Authors

Richard Loyen is Head of Enerplan and has been involved, as co-ordinator or partner, in many Europe-funded projects (DG TREN, Thermie, ALTENER, OPET, SOLARGE, European Solar Days, among others) in the renewable energies field since 1995. He has held the role of Head of the French Solar Professional Association since 1999, and has conducted many studies related to solar energy policies and benchmarking, among others. He is also heavily involved in 'Plan Soleil', the dissemination and promotion program of French solar thermal equipment in the building sector, and in co-ordination on industrial and professional actor actions with Ademe.

Sylvain Roland has been Project Manager at Enerplan since 2008. He has a degree in business intelligence and is in charge of Enerplan's participation in the European project 'PV Legal'. Sylvain has conducted various market forecast studies and is responsible for the organization's market analysis.

Enquiries

ENERPLAN – Association professionnelle de l'énergie solaire
Le Forum bât. B-515
Avenue de la Tramontane
Zone Athelia IV
13600 LA CIOTAT
France
Tel: +33 4 42 32 43 20
Email: contact@enerplan.asso.fr

Expectations for the UK solar market

Emma Hughes, News & Features Editor, *Photovoltaics International*

ABSTRACT

On April 1st 2010, the UK government's Department of Energy and Climate Change (DECC) officially launched its renewable energy policy. The document includes the Carbon Reduction Commitment Energy Efficiency Scheme (CRC EES), designed to improve public and private sector organizations' energy efficiency; and the generous feed-in tariff (FiT) incentive, which pays 41.3p/kWh of solar photovoltaic energy generated. This article will look at the expectations for the UK solar photovoltaics market following the government's policy launch. The paper will focus on the impact of the UK's late arrival to the renewable energy market; why the FiT is so incremental for successful growth; what the expectations are for the development of the UK solar PV market as well as an investigation into whether the UK is really ready for this level of change.

Introduction

Householders who install small-scale solar panel systems in the UK are now eligible to receive up to £1,000 a year – tax-free for 25 years – for the electricity they generate under the new government Clean Energy Cashback scheme, known more widely as the feed-in tariff. Government figures reveal that any UK resident who installs a typical 2.5kW PV system at their existing residence will initially be paid 41.3p per kWh generated [1]. Former Energy and Climate Change Secretary Ed Miliband outlined that such a set-up would result in a reward of up to £900 in the first year on top of a £140-a-year saving on energy bills (UK elections have taken place since this paper was penned).

This policy was long awaited in the UK, as its residents became more aware of neighbouring European countries' renewable energy success. However, the optimistic figures released by the government have been met with a great deal of uncertainty coupled with a severe lack of education in the sector. It remains to be seen just how successful the UK solar photovoltaics market will be, considering its infancy.

The UK feed-in tariff

The generous financial incentive that is the UK feed-in tariff has set the market off to a good start. Its 41.3p/kWh rate is high enough to really push the investment in solar energy in the country. But who is really going to benefit from this incentive? The initial costs – an average installation spend of £8,000-£12,000 – are simply too high for the average citizen to afford.

The £8,000-£12,000 payout secures the customer full installation – including the site assessment, the modules, the inverter and the installer's charge, yet this is still a large sum to pay out upfront. The varying issues and concerns surrounding this aspect of the market will be discussed later.

The Department of Energy and Climate Change (DECC) claims that this initial cost is justified by the rate of return on investment (ROI), which it claims is 5-8% on a well-sited 2.5kW installation [2]. It also claims that a UK solar generator could earn up to £1,000 a year, meaning that their initial costs would be earned back in a maximum of 12 years. Considering that a solar system usually has a lifetime of 25 years, the owner then earns up to £1,000 a year for an extra 13 years, marking an estimated profit of £13,000.

Size matters

Since releasing the FiT policy guidelines, the DECC has faced the question of who can actually afford to install solar power systems, as the high expense of installation prevents solar from being available to the masses. A spokesperson at the DECC was quick to assure us that low-interest finance options will soon be available to cover these costs: "There are already signs that the finance market is looking to develop products in this area so that future FiT revenues can be used to pay off upfront loans."

UK installer Solarcentury has reported a fourfold increase in sales enquiries since the FiT was initially announced in February. Thus, supposing the funds are available, the UK residential market looks set for moderate growth. But there is a problem. In the case of solar installations, size does indeed matter. Many UK residents' homes may not have a well-positioned south-facing roof; furthermore, in the event that a resident does have such a roof, it may not be large enough to house the 2.5kW system required for the full ROI. In this case, they will not earn the full payback, and may even lose out on their investment altogether.

Taking this into account, it looks as though the residential market will see success, but it may take a while to get going. However, one aspect of the solar market that looks set to experience immediate growth is the farming sector. Given the large building sizes on most farms in the country, UK farmers are almost guaranteed to receive the ROI that has been quoted in all of the DECC documents. There is already evidence that the solar farmland market is beginning to pick up.

Courtesy of Solarcentury.com

Figure 1. C21e and C21t tiles installed on South Yorkshire Housing Association houses in Rotherham, England.

Jonathan Scurlock, Chief Adviser, Renewable Energy and Climate Change at the National Farmers' Union, sees the potential for this market: "For many farmers and landowners, it now makes environmental and financial sense to consider installing solar PV on farm buildings." Scurlock agrees that farm buildings present a perfect opportunity for the installation of PV, and that it is most likely that the FiT will indeed drive the expected uptake.

"Introduction of feed-in tariffs has resulted in a flood of interest in on-farm generation from farmers and technology providers, and substantial growth in an infant UK industry can be expected over the next five years," he says. However, while Scurlock has already seen a great amount of interest from farmers in PV, he also admits that there is a lack of education in connection with the policy, explaining, "Some details of guidance are still lacking for applicants to the scheme."

Courtesy of Solarcentury.com

Figure 2. C21e solar electric roof tiles on a building in Sturgess Farm, southwest England.

Following the leader

Residential and farm building figures are reminiscent of the solar success of solar market-leader Germany. The early indications for the UK market – highlighting a fairly successful residential market and an even more successful farm building installation rate – draw parallels with the fully established German market. Dr Henning Wicht, iSuppli's Senior Director and Principal Solar Analyst, says that 40% of the PV installations in Germany are residential and two-thirds of the 50% commercial rooftop installations in the country are on farm buildings. Wicht predicts that the UK market will mirror the success in Germany due to this striking similarity.

Supply and demand

Modules

At time of writing, just over a month after the government's passing of the UK FiT rates, there is an unfortunate shortage of top brand solar equipment. In the case of solar photovoltaic modules, there are two options: cheaper, less efficient modules, or over-inflated high efficiency modules. However, the choice of which product to use usually lies with the installer rather than the customer. If the installer arrives with low-cost, low efficiency modules, such as the 170W Yingli modules offered by one installer in the UK, the system is not likely to be any bigger than 1.2kW based on the average size of UK residents' roofs. The customer will then have a system installed which, again, is not likely to ever earn them back the £8,000-£10,000 they will have paid out initially. Yet if the installer opts for the expensive high efficiency modules, such as BP Solar's range, or the Sanyo HIT module, one can expect to pay the very high-end price for the whole installation, costing £12,000 and approximately £6/W. This, according to iSuppli, is 50% more than customers in Germany pay for exactly the same products.

Inverters

In the UK, at the moment there is really only one inverter option available – the Fronius inverter. Fronius is not a market leader, yet it is charging a premium price for its inverters for use in the UK. Typically, a Fronius inverter will cost anywhere between £1,170 and £17,100 for systems ranging from 1,300Wp to 40kWp. Considering that this price is included in the initial installation expenditure, it is quite reasonable.

There are, however, two other factors at play here. Firstly, the conversion efficiency loss of Fronius inverters is approximately 4-5%. If we compare this inverter with one of the market leaders, such as SMA's Sunny Boy range, one notices that the price and conversion efficiency loss are not necessarily in synch. The Sunny Boy has a conversion efficiency loss of 2%, making it far more efficient than the Fronius model. The pricing of the SMA inverters (which are certified for use in the UK but not currently available) is around £800-£1,700. In comparison, the SMA option seems preferable, being cheaper as well as more efficient, but UK customers are being railroaded into buying the less attractive option, as there is currently nothing else available on the UK market.

Secondly, inverters have an average expected lifetime of 10 years. This is reflected in the product warranty, which on average is between five and 10 years. Based on the 25-year average life expectancy of PV modules, the customer could potentially be faced with having to replace the system inverter twice, costing well into the thousands of pounds on top of the initial £8,000-£12,000 already spent. Such a scenario has to be considered when calculating the ROI, potentially extending the time it takes to earn back the initial expense. This becomes all the more aggravating when one considers the prices across Europe in countries such as Germany and Italy, which are significantly lower in comparison to the pound sterling.

Due to the current lack of knowledge on these products in the UK, most installers and customers will be unaware of this price comparison.

When the price is right

It is necessary at this stage to consider why the products available in the UK are so limited, and why the prices of these products are so inflated in comparison to the more successful European markets.

Many European PV leaders, including France, Italy and most significantly Germany, will experience cuts to their FiT

Courtesy of Sundog Energy Ltd.

Figure 3. Integrated solar PV on a new build domestic home in south Scotland.

rates in 2010. For Germany, the cuts will take effect from July 1st, meaning that the market at present is booming as projects are installed while the incentives are high. The UK market is being further impacted as global inverter and module suppliers try to meet demand for their products as a result of this market boom.

On one hand, the UK has launched its financial incentives at the worst possible time, as the German market hits its peak and installations are plentiful. High quality products can be sold at low prices, as the demand is certain. For the UK, distributors are still unsure of the market's stability, and so will charge the maximum for their products, and only supply what is not needed throughout Europe.

On the other hand, this could be a positive start for the UK market. Since the UK is only one month into benefiting from financial incentives for the installation of solar PV, a rush to install at this point is not expected. As the July 1st deadline approaches for Germany, it can be predicted that installations in Europe will slow down, quite possibly by a significant amount. As this decrease starts to take effect, the manufacturers – and, of course, the installers – working in Germany will begin to turn their focus onto the UK market. By this point, the country should be more aware of the FiT incentives available, and indeed more educated in the workings of the technology needed in the UK in order to promote success.

Light at the end of the tunnel

Even with some uncertainty surrounding the UK solar market, expectations for its success are high. Ash Sharma, Research Director and Report Analyst at IMS Research, predicts that the UK's feed-in tariff will significantly accelerate the market. "Quite simply, the UK PV market will not grow to any substantial volume without large subsidies. The low insolation levels and high PV system prices would prevent any major uptake in the UK," said Sharma.

He foresees that the UK could see 40-60MW of installed PV in 2010, in comparison with the 5MW installed in 2009 when there was no FiT available. "From a demand point of view, I think UK consumers and investors are generally quite savvy and the FiT will be viewed very favourably. Many in the country invest heavily in property and the average age of a house-buyer in the UK is much lower than countries like Germany – [those in the UK] like investing money in property and adding PV systems will be an extension to this."

Courtesy of Sundog Energy Ltd.

Figure 4. Integrated solar PV retrofit on a home near York, England.

> "Even with some uncertainty surrounding the UK solar market, expectations for its success are high."

Although Sharma is optimistic about the growth of the UK market, predicting that 150MW of installations is achievable by 2011, he does recognize that the lack of inverters available could slow its progress. But despite this potential pitfall, IMS Research's widespread study of other markets makes him confident that the UK's solar growth will soon accelerate as he has seen the evidence of how the dynamics can change rapidly once full government support is given. "All indications in the medium term are positive: the FiT is reasonably generous and supports systems up to 5MW. And although the UK is not the sunniest country in Europe, it does have a reasonable amount of free roof-space and an appetite for investment," he said.

Independent solar expert Michael Pitcher from BFC Solutions, an associate consultancy, also acknowledges the potential of the UK solar market. "Countries like Germany and Belgium have embraced PV and are already reaping the rewards, but solar panels perform very well in the British climate so there's no reason why the UK shouldn't also harness the benefits of solar energy," he said.

Energy companies such as npower and E.ON have also begun to show optimism for the future of the solar photovoltaics market. By May 1st, one month after the FiT took effect, npower was already seeing an 80% increase in customer interest in solar energy. Louisa Gilchrist, solar expert for npower, said, "It's fantastic to see feed-in tariffs generating so much interest with homeowners and the scheme should be applauded for energizing the solar industry in the UK."

E.ON has also released positive feedback from customers in connection with the use of solar energy; however, the company also recognizes that many UK customers need assistance when choosing to install a PV system, due to the lack of knowledge on the products, installers and information available. As a result, E.ON launched the SolarSavers scheme, which provides a one-stop-shop service for installing and generating solar power.

Andrew Barrow at E.ON said, "As one of the leading power and gas providers in the world and the UK, we can provide customers with the quality assurance for solar energy systems. Now that the UK is working to cut its CO_2 emissions down, we think it is important to offer residents the opportunity to be a part of this themselves."

Ignorance is not bliss

All things considered, there is still this recurring theme of education, or indeed the lack thereof. At present, there is a severe gap in awareness of the subsidies available, of what products should be used and how they should be installed. The lack of education does not lie solely with the customer, but also with the installers. This is something that will have to change dramatically before the market is able to progress into a noteworthy league. Sharma reinforces this point: "This will be one of the key restraints for the UK market. A great deal of education will be needed to allow the market to develop. It is also likely that a number of integrators from Europe will set up subsidiaries in the UK to target this market."

The migration of experienced European PV companies is highly likely as the majority of installers currently working in the UK are not PV specialists. While this is not a criticism of the UK installers, as the market was not nearly large enough to warrant UK-based specialized installers before the introduction of the FiT, it will be a great benefit to the market if experienced PV companies begin to move into the country, setting up subsidiaries in order to accelerate the uptake.

Conclusion

The UK photovoltaics market certainly has some obstacles to overcome before it matures. While the country was late in receiving its FiT policy, this incentive is now set to drive the market forward in 2010. Its generous payback, combined with further government financial support, will significantly increase the amount of PV uptake in the UK. While there is a lack of product availability in the country, there are positive signs of improvement, as European suppliers start to focus on the UK's growing market, and foreign installers begin work in the country. Industry professionals predict a drop in product cost and an increase in product availability, and also foresee that an emphasis on customer as well as company education will occur within the coming months. The significant parallels with market-leader Germany only reinforce the experts' predication that the UK solar market is set for success.

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Comparative analysis: Chevron's Project Brightfield puts thin-film PV to the test

Nothing says oil-refinery site remediation like a photovoltaic installation. Chevron, though more known for harvesting energy from carbon than from photons, has activated what it calls Project Brightfield. This intriguing multimillion-dollar PV panel test bed sits on a repurposed site near Bakersfield that once hosted a long-decommissioned petroleum processing facility.

Seven emerging module technologies — with a total ground-mounted capacity of 740kW — have been deployed in a multiyear program designed to benchmark the new panels' performance against a standard crystalline-silicon array while also measuring their capabilities in the varied meteorological conditions in the south-central California location.

The PV participants span technologies and geographies. CIGS producer MiaSolé, CdTe upstart Abound Solar, and silicon-nanoink developer Innovalight hail from the States; Sharp (which also provides the c-Si control array) with its tandem-junction a-Si, and Solar Frontier (ex-Showa Shell Solar) with its CIS represent Japan. Schüco's CIS and Solibro's CIGS play for Team Germany.

Jerry Lomax, Chevron Technology Ventures' VP of emerging energy, recounted how the selection process went down.

"We interviewed and reviewed about 180 solar companies from around the planet for their best emerging solar technologies. We narrowed that list down to about 20 vendors who had new emerging technologies in their pipelines coming forward for commercialization.

"We began to meet and talk with their engineers, their scientists, their manufacturing people, to understand why they thought that the new product that they were planning to bring out was going to be a better solar product in the next generation, with better efficiency and lower cost, that would meet the durability requirements of a 25-year life. "We designed a project so we could put those seven emerging panels in a side-by-side test for about three years, and we negotiated purchase agreements with the vendors, and as part of that, we agreed to share the operational data for their panels with them as well as the operational data for the control panels."


Photo courtesy of Chevron

A weather station also keeps track of the elements and atmospherics, adding to the data stream of benefits for participants.

In other words, the testing ground provides these up-and-coming technologies with a way of compare themselves against a proven 'state-of-the-shelf' crystalline system and to see how they perform in a climate that has wide temperature swings, high winds, strong irradiance, dust storms, and the infamous Tule fog — a potential treasure trove of real-world performance and comparative data.

The seven test arrays range from the equivalent of a small residential system — about 2kW — to more than 200kW, or about the size of a middling-large commercial installation, according to Lomax.

"They are not evenly distributed," he explained. "Some of the vendors wanted a bigger footprint in the test, to use a bigger set of panels. Some of them couldn't yet produce enough of their brand-new panels in the time-frame we wanted to install them, so they gave us a smaller percentage of the field."

Sharp, the company against which the others are measuring themselves, told me that the crystalline-silicon 'control' array is made up of 28 216W polycrystalline modules (about 6kW installed) — the size of a large residential system.

Sharp also has some tandem-junction thin-film modules being tested — about 1,800 of its IEC-certified 121W panels (conversion efficiency of 8.5%), equalling an array rating of 217kW or so.

MiaSolé announced that it has approximately 200kW of its 10.5%-efficient CIGS panels deployed at the test site, which is also the company's first commercial-scale project in California.

Abound Solar also cites Brightfield as its first commercial installation in the Golden State. The company's Mark Chen said that roughly 3,000 of its CdTe modules are there, comprising about 190kW of power-generating capacity.

The smallest Brightfield array belongs to Innovalight, which has a dozen of its >18% efficient (tops in the field) silicon-ink-enabled crystalline modules racked up.

Sharp's Paul Wormser said: "Having a chance to work on a project with Chevron is always a benefit. They're really good people, they really know what they're doing. They have a long-term view of their business and how solar relates to it."

"We have tested our thin film for decades, but we have not tested thin film side-by-side with crystalline in a Bakersfield environment," he continued. "While we know our product, we know how it behaves, being able to literally measure it moment by moment in that kind of an environment helps reinforce what we already know, and puts it in an environment that a lot of the market in the U.S. cares about, climate-wise."

Balance-of-system components are also getting put through their paces at Brightfield acres.

"Part of our objective with installing the site with an array of thin films was also to test and get more experience with what we felt were the leading racking systems, mounting hardware, and a range of inverters," explained Lomax. Chevron put in four different racking systems, more than half a dozen mounting systems within those racks, and seven different inverters.

Chevron Energy Solutions played an instrumental role at Brightfield, according to Lomax, not only in helping the team select the best performing, easiest to use, most rugged BOS gear, but as the general contractors for the project. CES will also "have the inside track on the [data from the panels'] performance."

Chevron didn't set up the test bed just because of a healthy curiosity about which of these PV panels will earn performance bragging rights: The company plans to build up its own solar energy-generating capacity on other repurposable company sites, noted Lomax.

In addition to sending some sun-juice to PG&E's grid, Chevron is "using the power for our oil fields, which are colocated adjacent to this location. It will help us get comfortable with the concept. In the future, we can scale this, make it a more common approach to lowering the cost structure of our traditional oil and gas [facilities], improving the sustainability and carbon footprint."

There's a concept bridging the browntech-greentech divide: megawatts of solar panels, including the best of the Brightfield Seven, helping to power oil fields and refineries.

This column is a revised version of a blog that originally appeared on PV-Tech.org.

Tom Cheyney is North American Editor for the *Photovoltaics International* journal and writes news and blogs for PV-Tech.org.