Fifth Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS

SunEdison: methods for yield monitoring of commercial-scale solar installations

BP Solar unveils a new method of EVA encapsulant cross-link density measurement

ZSW: CIGS characterization and monitoring technologies

IMEC tackles inline processing of thinner c-Si wafers

Q-Cells: fab scaling insights from the Malaysia fab

SolarWorld grants a first look at its new U.S. facilities

Third Quarter 2009 www.pv-tech.org


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Publisher's foreword

The photovoltaic marketplace is experiencing rapid declines in average selling prices of modules as a result of the global recession. Manufacturers and installers are being challenged to dramatically reduce operational costs to remain competitive. Some of the weaker players are starting to drop out of the industry while those with more robust business models are refocusing efforts on technology and processes that can reduce costs and increase yields.

As we put the finishing touches to the journal prior to printing, we are seeing reports of economic growth during Q209 in some key PV markets including Germany (0.5%), France (0.5%) and Japan (0.9%). Whether or not these results are sustainable and just how long it will take for growth to impact the PV industry will undoubtedly be hot topics at this year's EUPVSEC in Hamburg.

This topic will be at the forefront of people's minds as they meet in Hamburg at the upcoming EU PVSEC to assess new technological developments in the solar industry. This time of year also sees *Photovoltaics International* celebrating its first anniversary. Accordingly we have produced the biggest issue yet with over 200 pages, 15 of which contain 43 individual and independent reviews of some of the latest tools and resources available for the PV supply chain.

We learn best from doing, and so within this edition you will find many practical real-world papers to help you assess your own company's supply chain in the PV industry.

A member of our own editorial advisory board, Gerhard Rauter, COO of **Q-Cells**, teams up with **M+W Zander** to provide (p.14) a comprehensive benchmark of two operational facilities. The paper goes on to present a case study of the new Q-Cells cell manufacturing facility in Malaysia. We also bring you the first look inside the new **SolarWorld** facilties in the USA (p.30).

Before anyone heard the name Sunfab, the technology experts at **Applied Materials** were working with FPD manufacturers to improve process efficiencies. In a first for *Photovoltaics International*, we present a paper with case studies from the FPD industry (p.35) that looks at ways to reduce glass scrap by up to 95% using APC (Automated Process Control) methodologies.

As 25-year module warranties require durable encapsulation solutions, EVA is a popular and accepted method but poses some measurement challenges. **BP Solar** presents (p. 150) a new method for measuring cross-link density. This paper is followed up by a roundtable discussion on the nature of solar lamination (p.160).

The industry has transitioned over the past five years from watts to kilowatt-hours. Measuring system output accurately for the purposes of feed-in tariffs, renewable credits and other performance-based rebate systems is paramount. **SunEdison** helps us understand these dynamics with a survey of 70MWp worth of installations across the USA and Germany (p.173).

Be sure to check out all the winners in our special feature covering the **International Solar Technology Awards** (p.92) and take your time reading through the 19 technical papers in this issue. We are always looking for feedback, so if you are in Hamburg in September feel free to come and visit some of the team at booth B2G/37.

See you in Hamburg!

Sincerely,

David Owen
Photovoltaics International

Photovoltaics International

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Front cover shows wire web of a multi-wire saw (foreground) with cut wafers (background). Picture courtesy of Fraunhofer Institut für Solare Energiesysteme (ISE), Freiburg, Germany.

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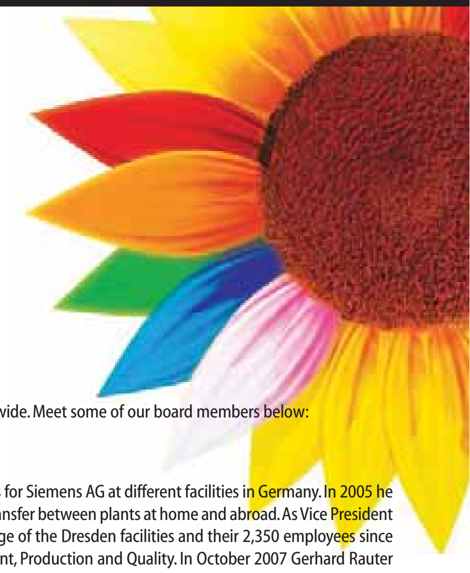

Photovoltaics International's primary focus is on assessing existing and new technologies for "real-world" manufacturing solutions. The aim is to help engineers, managers and investors to understand the potential of equipment, materials, processes and services that can help the PV industry achieve grid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

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

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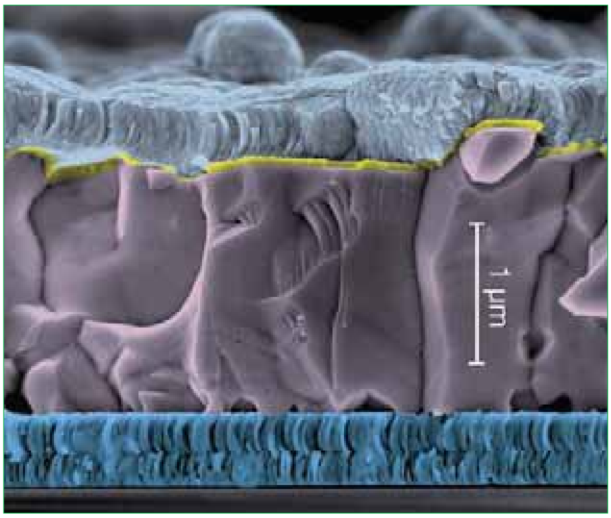
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Fab and Facilities

Evergreen Solar signs contract manufacturing agreement with Jiawei Solar, Wuhan government

Evergreen Solar has finalized its agreements with Jiawei Solarchina and the Wuhan Government's Hubei Science & Technology Investment (HSTIC).

As part of this agreement Evergreen Solar will manufacture String Ribbon wafers using its Quad furnaces at a leased facility being built by Jiawei in Wuhan, China on Jiawei's campus. Jiawei will convert the wafers into Evergreen branded panels on a contract-manufacturing basis.

An investment of US$17 million in cash and equipment in the Wuhan String Ribbon operation will be made by Evergreen, while HSTIC will provide Evergreen Solar with US$33 million of 7.5% financing, which it must repay no later than July 2014. Jiawei will make a similar investment for its cell and panel operations with the support of HSTIC.

The contruction of the factory has begun while the cell and panel production is scheduled to commence in 2010; initial capacity for the project will be approximately 100MW and will then be increased to 500MW by 2012.

Evergreen Solar and Dynamic Green Energy, Jiawei's parent company, have agreed to exchange warrants representing 1% of their outstanding shares. These warrants will have a five-year term and may be exercised for 20% of the warrant shares for each incremental 95MW of production capacity achieved.

"Our String Ribbon wafer technology, combined with Jiawei's low-cost manufacturing capabilities, should enable our products to stand out distinctly among customers seeking both value and dependability for their solar energy solutions," commented Richard M. Feldt, Chairman, President and CEO.

"As we reach the 25MW quarterly capacity by the end of 2010, we expect total manufacturing costs of our String Ribbon panels produced in China to be in the range of US$1.40 per watt to US$1.50 per watt, with both companies working aggressively to further improve technological performance as well as reduce manufacturing costs. Our mutual goal is to drive conversion efficiency and manufacturing performance so that panels are produced at the US$1.00 per watt level by no later than 2012."

Capacity News Focus

SMA Solar opens CO_2-neutral inverter factory; takes capacity to 4GW

SMA Solar has inaugurated its new 18,000 square meter solar inverter factory, which takes its annual production capacity to 4GW. The facility is also claimed to be the first of its kind to be CO_2 neutral. The electricity and heat demand is covered by renewable

SMA Solar's new solar inverter factory.

energy sources that include a 1.1MW integrated PV system and a combined heat and power plant fueled with bio-gas generates CO_2-neutral electricity. The company obtains additional power for the facility from other renewable sources.

Günther Cramer, Chief Executive Officer of SMA Solar Technology AG, said, "With our CO_2-neutral inverter production we even go one step further. Today we can show that an advanced production on industrial level can be done with a minimal environmental footprint. As the worldwide leading producer of solar inverters we now intend to initiate a trend towards CO_2-neutral factories."

SMA Solar also said that the process steps for production in the new facility have been completely redesigned in terms of efficiency. All production lines have been designed for maximum product production flexibility in 'just-in-time' procedures, negating warehouse requirements.

Efficiency measures throughout the facility in include the use of natural lighting and intelligent ventilation as well as the use of storage units for heating and cooling.

SVTC and Roth & Rau announce increased capacity at Silicon Valley plant

SVTC Technologies, a provider of technology development and commercialization services to semiconductor clients and Roth & Rau, a Germany-based solar equipment manufacturer, have announced a renewal and expansion of their partnership, establishing a 30MW photovoltaic development and manufacturing center located in California's Silicon Valley.

The Silicon Valley Photovoltaic Development Center has increased capacity since the original plans; the manufacturing line will now have a capacity of 30MW as opposed to the former 5MW benchmark. SVTC and Roth & Rau decided that this was an important move if they were going to meet the greater demand from solar development companies.

The 30MW Development Center will offer a full range of manufacturing equipment and services to companies engaged in the development and production of solar cells.

The Center is scheduled to be operational by 2010 and will offer a full range of low-cost development solutions along with the 30MW solar cell production line. The manufacturing line will consist of state-of-the-art Roth & Rau equipment and will also include tools from other world-class solar equipment suppliers.

First Solar to build and operate 100MW CdTe thin film plant in France for EDF

First Solar will build and operate a 100MW plus capacity CdTe thin-film plant in France for EDF Energies Nouvelles. The two companies will share the capital and start-up costs, while EDF will take all production volumes for a 10-year period. First Solar has manufacturing operations in the U.S., Germany, Malaysia and France.

The new 100MW-plus plant will require an initial capital investment of more than €90 million with full production to start in 2011. EDF Energies Nouvelles raised €500 million last year to finance its photovoltaic development ambitions, targeting 500MWp in PV installations by 2012. EDF has used First Solar's thin film modules on several projects. The plant will include a facility for recycling solar panels, France's first and the only such plant in Europe outside of Germany. At full production the entire facility is expected to employ approximately 300 people.

HelioSphera inaugurates state-of-the-art plant in Tripoli

HelioSphera, formerly Next Solar, has officially launched its 27,000m^2 state-of-the-art plant with a production area of 17,000m^2 and a fully automated cleanroom of 1,500m^2. The factory, which specializes in producing thin-film photovoltaic panels using Oerlikon's Micromorph technology, has an annual capacity of 60MW and is located in Tripoli.

SVTC Technologies facility.

HelioSphera production facility.

Back in March it was announced that a €185 million investment subsidized by €29.879.500, which is one of the largest private investments in Greece of the past decade, was included in the Developmental Bill that was voted into law by the plenary of the Greek Parliament. The plant is said to be the largest of its kind in Europe.

The Minister of Economy and Finance Yannis Papathanasiou inaugurated the plant; it also received a blessing from Bishop of Mantineia and Kynoureia Alexandros.

Also present on the day were the Under Secretary of National Education and Religious Affairs, Andreas Lykourentzos, the General Secretary of the Peloponnese Nikolaos Aggelopoulos, the Prefect of Arcadia Dimitrios Konstantopoulos, the Mayor of Tripoli Alexandros Kotsianis and members of the local political leadership.

HelioSphera is also planning a customers' event in its Tripoli premises in October to celebrate the first commercialization of its products.

Aerojet and Solar Power announce 3.5MW solar system at Sacramento site

Aerojet, a GenCorp company, and Solar Power, Inc. announced they have agreed to collaborate and build a 3.5MW solar system at Aerojet's Sacramento, California facility in the Sacramento Municipal Utility District (SMUD). This is the first solar system Aerojet has installed and it is a significant part of the company's environmental and sustainability initiatives. The solar facility will provide over 20% of the power to a number of Aerojet's projects and with a system life expectancy of 25 years, the cumulative environmental offsets for a system of this scope are significant.

The solar array will be ground mounted utilizing a single-axis tracking system, a design element that allows each panel to follow the course of the sun throughout the day. The solar array will consist of approximately 18,000 SPI 200W modules atop 12 tracking arrays, covering an area of over 20 acres.

"During the RFP process we competed with most of the major U.S. solar firms for this project. We are very proud to have been selected and we look forward to working with the Aerojet and SMUD teams throughout the project's execution," said Steve Kircher, CEO of Solar Power, Inc. "The system will serve Aerojet and our community; it will be installed by people from our region and will help to improve our environment." Installation and connection of the 3.5MW system should be completed in November 2009.

Bielefeld a+f GmbH lands €40 million solar deal

Gildemeister group's Bielefeld a+f GmbH has completed a major deal worth a total of €41.1 million. This deal will certainly strengthen Gildemeister's presence on the Italian solar market, making it a strong competitor for others in this field.

Apulia will be host to nine solar parks with an output of up to 1MW each; installation is expected in the coming months. This area of Italy is considered ideal for the use of PV technology, making this latest order an important move in the Italian solar market.

Implementing the international market strategy means that a+f can draw upon the global comprehensive Gildemeister sales and service network.

Gildemeister has already installed solar plants with total output of up to now 51MW in several locations globally including Germany, Spain, Italy, Greece and South Korea.

Other News Focus

Chinese consortium sets up new solar panel sales hub in US

A consortium of 30 Chinese solar panel companies, collectively known as Centron Solar, has announced that it will be setting up a new sales hub in the Oregon, United States. Centron Solar brings with it 10 high-level managers as well as ambitious plans to expand to around 250 new employees in a year. The consortium sees an untapped module market in the US.

BP Solar announces lower greenhouse gas emissions since installing EASI technology

BP Solar International has cut its greenhouse gas emissions and electricity costs through use of energy saving technologies engineered and manufactured by Energy Automation Systems (EASI), installed back in 2006/7. Brelsford also noticed that his facility's energy bills fell 8%, based on a 6MW site after EASI technologies were installed. More than 500 people are employed in the facility, which operates 24 hours a day, seven days a week.

"We began calculating the greenhouse gas reductions for our customers in 2008," said Joe Merlo, Energy Automation Systems' CEO said. "The formula involves determining the types of fuel used to power their operations and calculating both the cost savings in kilowatt hours and the greenhouse gas reductions based on those lower numbers."

Moser Baer's solar energy company waiting on build in Chennai

Moser Baer Photovoltaic (MBPV), a subsidiary of the optics and technology company Moser Baer India, has postponed its October plans to set up a manufacturing facility. Originally, MBPV was to build an Rs 2,000 core facility to manufacture silicon PV film modules on a 120 acre site near Chennai. The company blames the process of choosing equipment partners and similar negotiations for the delay but provided no information on the financing of the project.

SolarCell News Focus

Centrosolar Group pulls out of solar cell manufacturing joint venture

The joint venture between Centrosolar Group and Qimonda, known as Itarion Solar, has announced that it has filed for insolvency.

The negotiations for the Itarion Solar venture were cancelled following the insolvency of Qimonda in January 2009. Originally, a consortium of Portuguese industrial companies, banks and investment funds had been put together to take on Qimonda's interest in the venture, yet Centrosolar came to the conclusion that the direction taken by the negotiations now ruled out the success of the project.

Solutions to this problem had been previously discussed, yet Centrosolar says it had foreseen considerable risk involved as well as a much greater involvement in the operating side of business to be taken on, on Centrosolar's part. The management resources required would therefore have represented a major distraction from the company's own core business.

Centrosolar says that it needs to write off its investment in Itarion with a current book value of €10.1 million; further to this, Itarion carries net financial debt of approximately €16.5 million, for which both Qimonda and Centrosolar are liable.

An agreement has been reached with the lending banks to repay this amount in instalments up until mid-2011; this arrangement will enable the company to continue expanding its core business' including system integration for PV roof systems, as well as the manufacture and sale of solar key components such as antireflective glass and mounting systems.

Polysilicon News Focus

Formosa Chemicals & Fibre to set up poly-si factory in Taiwan

Taiwan-based Formosa Chemicals & Fibre Corp., a petrochemical production company, has announced that it will invest US$1.03 billion to set up a solar-grade poly-Si factory in central Taiwan, according to a Chinese-language Economic Daily News (EDN) report.

The factory will eventually have an annual capacity of 8000 metric tons. First-phase establishment of 4000 metric tons is expected to be to be completed in 2012.

Formosa Chemicals & Fiber was established in 1965 to meet the rising demand in fiber and plastic products in Taiwan. Since then, the company, primarily engaged in petrochemical production, has expanded into an industry giant, dealing with specialty chemicals, plastics, textiles, nylon, engineering, and construction of industrial parks throughout the country. Formosa also generates electricity and provides water treatment services.

EU Commission approves subsidies for ersol's crystalline-silicon PV factory in Arnstadt

Bosch unit ersol Solar Energy has received the anticipated approval of EU Commission subsidies toward its investments in the crystalline-silicon PV sector. Since Thuringia and the Federal Republic of Germany had already accepted this support subject to the approval of the commission, ersol says the grants will cover more than 10% of the overall funding of €530 million to be invested in expanding the company's manufacturing site in Arnstadt.

The expansion, which will also be financed with Bosch Group loans and internal ersol funds, will increase the nominal solar cell production capacity to 630 MWp over the next few years, as well as establish a dedicated PV moduling facility.

Production at ersol's Arnstadt site is scheduled to begin in the first part of 2010.

The company also has a micromorph-silicon thin-film PV joint development venture with Schott Solar.

Wacker Schott Solar commissions silicon crystallization factory, begins tool installations

Wacker Schott Solar has commissioned a new plant, which will be used to produce solar-grade polysilicon crystals. Construction took nine months at the site in Jena, Germany, and production tools are being installed in stages on the 13,500-m2 factory floor. Overall capacity is expected to reach 275 MW by the end of 2009. The roof of the new structure also features a 300-KW solar power system.

The company, a joint venture between Schott Solar and Wacker Chemie, says that it intends to gradually expand its manufacturing capacity to 1 GW by 2012. Planned investments of more than €300 million in the Jena facility are likely to create at least 700 new jobs. The new plant will employ ingot crystallization technology that melts hyperpure silicon in crucibles and casts multicrystalline silicon ingots using directional solidification.

Patrick Markschläger and Axel Schmidt, Wacker Schott Solar's two managing directors, said they were pleased with the new plant's rapid completion: "We built the factory in record time and are now starting to install its equipment. It's particularly worth noting that production continued without interruption throughout the construction period."

The roof of the new building also features what is being called the largest PV array in Thuringia. The 300-KW system's modules were made and supplied by Schott Solar, and the installation is operated by PV Meins.

Hemlock Semiconductor begins operation of 8500-mt polysilicon plant in Michigan

Hemlock Semiconductor Group has begun operation of a new 8500-metric-ton polysilicon production facility several months ahead of schedule. The plant, located in Hemlock, MI, is the first phase of a planned US$1 billion expansion at the site.

The company says the second phase of this capacity expansion will start to become operational in 2010 and, together with the initial phase, will increase the total annual capacity onsite to approximately 36,000 metric tons.

Excavation has already begun on the site of Hemlock's new polysilicon manufacturing facility in Clarksville, TN, according to the company. Construction will soon begin on plant, which is scheduled to come online in 2012.

Hemlock has announced investments totaling more than $4 billion over the past five years, moves that will expand the company's capacity by nearly 10 times while creating more than 1500 new jobs.

"The new capacity from our latest expansion is a critical milestone to ensure our customers' confidence that they will have the silicon feedstock needed for the semiconductor and fast-growing solar energy industries," said Rick Doornbos, Hemlock's president/CEO. "It takes a tremendous team effort to be able to deliver an expansion of this magnitude ahead of schedule, and we're very proud of our team for making it happen."

"Despite the economic recession, the long-term outlook for the solar market remains strong," he continued. "Our demonstrated capabilities to deliver recent capacity expansions on or ahead of schedule and our more than 40 years of technical and manufacturing experience puts Hemlock Semiconductor in a strong position to help our customers succeed in an industry that continues to show promise and growth."

Sumco to close silicon plant in Ohio

Sumco Phoenix Corporation is to close its silicon wafer manufacturing plant in Maineville, Ohio, USA due to the weaker than expected demand and semiconductor industry's move to larger wafer sizes. The Ohio plant also makes solar silicon ingots, which will also be affected by the closure. Consolidating its operations, Sumco said that production would shift to its other plants in the U.S. and overseas.

"This was a very hard, yet necessary conclusion to reach for the continued survival of our business," commented Shigetoshi Shibuya, SUMCO Phoenix Corporation President and Chief Executive Officer. "The employees at Maineville have tried valiantly for some time to make this work, and we are extremely grateful to them; however, our operations there

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Tool Order News Focus

Umicore selects Eyelit's MES suite for germanium wafer production

Eyelit has shipped one of its integrated manufacturing execution software (MES) suites to materials technology company Umicore for production of germanium wafers at its Olen, Belgium-based Electro-Optic Materials Business Unit. The company intends to roll out the system to Quapaw, Oklahoma in the second half of this year.

Together with its distribution partner SYSTEMA, Eyelit has shipped its MES suites to CaliSolar, Nemotek and SiCrystal GmbH since December 2008. The companies announced a partnership in June 2008 that stated that SYSTEMA would provide local European support, consulting services and be a distributor of Eyelit's innovative product suite. Eyelit's suite provides integration to SAP as well as a scalable solution for equipment management and product traceability, from raw material feedstock through to germanium ingot growth and wafer production.

Schott Solar opens second CSP receiver production line in Albuquerque

Schott Solar announced that it is starting production on a second CSP receiver line in Albuquerque, New Mexico. Schott Solar's 200,000 square foot facility is the first new solar manufacturing facility to open since the enactment of the American Recovery and Reinvestment Act, which provides incentives for the growth of solar manufacturing.

The facility was an investment of over US$100 million from the Schott Solar group, but will be the first manufacturing site in the world to produce both receivers for CSP and photovoltaic modules side by side. With the launch of the second production line, the facility can produce enough receivers to meet the demands of up to 400MW of CSP power plants per year.

New SEMI standard offers framework to unify PV manufacturing equipment communication interface

SEMI has published a new technical standard that offers a framework to unify equipment communication interfaces in the solar photovoltaics manufacturing sector. The trade association says that the standard, PV2-0709, better known as "PV2," marks a significant industry milestone, since it defines a unified equipment communication interface for PV production systems.

The standard should provide multiple benefits to the PV industry including shorter ramp-up times, increased functionality, simplified requirement specifications, and increased potential cost savings for manufacturers, according to SEMI.

PV2 "was developed by the European Equipment Interface Specification Task Force (EIS TF) to reduce the effort equipment suppliers have to spend to develop and maintain a variety of equipment communication interfaces, and establish the foundation for deploying advanced factory management and control software systems," the trade group says.

Matthias Meier, who works for the Fraunhofer Institute for Manufacturing Engineering and Automation and was a key leader in the development of the new standard, notes that "tasks such as equipment efficiency monitoring, maintenance management, scheduling, dispatching, work-in-progress tracking, yield optimization, and process monitoring and control are either fully automated or at least strongly supported by shop-floor IT systems that depend on being able to communicate with production equipment.

Solar panel maker Sunworks gets deal on its power

The New York State Power Authority has awarded 5MW of hydropower to Sunworks Solar, a small solar panel manufacturer planning to build a plant in Western New York. Sunworks will receive a 25% discount. Company officials said they have not yet selected a site, nor have they come up with a construction timetable though work could start spring 2010 at the earliest.

The NY Power Authority has also allocated 40MW to Globe Metals, also involved in the production of solar power. That company is refurbishing a Niagara Falls plant to produce metallurgical-grade silicon for solar panels.

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have been severely impacted by both the unexpected nosedive of the global economy and changes within the industry itself over the past year."

Approximately 360 workers will be affected by the closure, which is expected to be completed by June, 2010. Sumco had bought the plant in 1989. It has no current plans to sell the plant or surrounding real estate, the company said.

centrotherm photovoltaics sees second turnkey polysilicon plant operational

Shaanxi Tianhong Silicon Industrial Corporation in Xian City, China has successfully started polysilicon production at its 1,250MT plant, according to turnkey plant provider centrotherm photovoltaics. The plant was planned and developed by centrotherm SiTec, a subsidiary of centrotherm formed out of centrotherm's acquisition of SolMic and from its former subsidiary centrotherm SiQ. This is the second turnkey plant the company has successfully completed.

"The realization of this project allows us to show that we can supply the complete process on a single source basis, all the way from designing and planning, through the provision and installation of the key equipment, and on to the start of operations," commented Dr. Albrecht Mozer, CEO and CTO of centrotherm SiTec. "With this second success in Asia, centrotherm photovoltaics is underscoring its expertise in the silicon production area, and affirming the potential of this business area.

Shaanxi is targeting both semiconductor and solar markets with its polysilicon.

Sphere Renewable Energy's Buckeye Silicon unit to build solar polysilicon plant in Ohio

During a ceremony held Monday to sign a memorandum of understanding, officials of California-based Sphere Renewable Energy Corp. (SREC) said the company will develop a wholly owned solar materials manufacturing subsidiary, Buckeye Silicon (BeSi), in Toledo, OH. The venture's initial polycrystalline-silicon production module will be located at the University of Toledo's Center for Renewable Energy.

The poly made by BeSi will be sold predominantly to PV producers in North America and Europe, according to SREC, which recently has entered into a joint venture with strategic East Asian investors to begin using its proprietary process to mass-produce crystalline silicon for the solar market.

SREC said its approach involves a light industrial, modular process which requires much less space and energy than a traditional polycrystalline-silicon production facility and that its development is more efficient. The commonly used approach has involved massive chemical infrastructure facilitation, similar to an oil refinery, with many of the related concerns that refineries experience. The company claims that its process does not have the environmental problems that other polycrystalline silicon manufacturer's experience.

The financial terms of the deal, the timelines for the construction and production ramp, technical details of the manufacturing process, and the projected manufacturing capacity of the new facility were not disclosed.

Location Briefings

Bayern Innovativ – Bavaria

Photo: Gehrlicher Solar AG.

Location: Situated in Nürnberg in Southern Germany, the company Bayern Innovativ GmbH conceives and organises cooperation platforms for business and science, in order to initiate innovations in small and medium enterprises. The "Corporation for Innovation and Knowledge Transfer" brings together companies and institutes thematically focused on regional, national and international levels of enterprise.

Introduction: The networks within Bayern Innovativ GmbH today comprise around 50,000 companies and 500 scientific institutes from over 50 countries. Within the framework of the Bavarian "Cluster Initiative", Bayern Innovativ was commissioned with the management of five clusters back in 2006: Automotive, Logistics, Medicine Technology, New Materials and Energy Technology. Two active partners in the Cluster network are Energiezentrum Guggenmos and Gehrlicher Solar AG.

Infrastructure:

- The "Energy Center of Renewable Energies – Energiezentrum Guggenmos" in Warmisried, Bavaria, is a unique building featuring renewable energy technology. With a 30kWp PV power plant on the roof of the rotating building, the building's rotation also powers a mill for biofuels.
- In June 2009, Gehrlicher Solar AG connected one of Bavaria's biggest open land power plants. The power plant in Helmeringen near Augsburg has 135,648 solar modules from First Solar on an area of 300,000 square meters with an electrical power of 10MW peak. The power plant uses thin-film technology and provides power for 4,000 households.

Key features/incentives: Regarding energy efficiency and renewable energy sources, Bavaria is one of the top regions in Germany. The primary energy consumption of renewable energies is already amounting around 8.0%: 2.2% of which is provided by hydropower and 4.4% from biomass. The other 1.6% is supplied from photovoltaic, biogas, biofuel and geothermal energy and pellets. Bavaria today produces nearly half of the solar power generated in Germany, and the region is seeing an increase in the uptake of photovoltaic applications as a source of energy. The country has competence in planning and installing grid-connected solar power plants on roofs and on open land. Eleven universities and 15 technical colleges as well as the headquarters of the Fraunhofer and Max-Planck Institutes are situated in Bavaria.

Key tenants

China Sunergy, Wacker Chemie, Siemens Solar, Schott Solar, Fraunhofer Institute, Max-Planck Institute.

Florida

Location: Located in the Southeastern corner of the United States, Florida is the 8th largest economy in the western hemisphere, and the 20th largest economy in the world. The state's excellent location and multimodal infrastructure make it an ideal location for many U.S. and international businesses looking for worldwide connectivity and abundant market opportunities.

Introduction: Florida is an emerging solar market and business location with strong solar availability, growing energy demand and broad industry.

Infrastructure: Florida has a large potential PV supply chain, drawing on existing industry and research assets in materials, semiconductors, photonics, electronics, etc. The state's research universities, producers of PV module and systems components, solar thermal equipment, and environmentally conscious utilities are key:

- Florida universities, including the University of South Florida (Tampa), University of Florida (Gainesville), University of Central Florida (Orlando), and Florida State University (Tallahassee) conduct groundbreaking research in thin and thick films, PV and hybrid systems, tandem solar cells using organic and inorganic materials, optical designs for efficiency improvement, testing activities, including the development of CIGSS thin film cells, PEC cells and tri-biological coatings and the use of solar-thermal tri-generation systems.
- Florida Power & Light Company, a subsidiary of the FPL Group, is set to complete construction on the DeSoto Next Generation Solar Energy Center, the largest PV plant in the United States. DeSoto is one of three solar facilities that FPL is building in Florida, totaling 110 megawatts of renewable energy generation.
- Other Florida utilities are working on seven additional solar facilities in the state.

Key features/incentives: Florida averages about 240 days of year-round sunshine and receives 85% of the maximum solar resource available in the U.S., making it suitable for a range of solar technologies. Clean energy incentives and tax exemptions are available to companies looking to produce renewable energy sources or to integrate renewable energy into their production process. Additional incentives based on job creation and capital investment may also be available.

Key tenants

Advanced Solar Photonics, FPL Group, Petra Solar, Progress Energy, SOL, Inc., Sunovia Energy Technologies.

What they say: "Florida's Governor Charlie Crist is committed to a green energy future. There is strong government support at both the state and local levels for energy efficiency and clean energy economic growth in Florida.

Governor for Florida, **Charlie Crist**.

Scaling challenges for photovoltaic manufacturing facilities

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ABSTRACT

The photovoltaic market is currently experiencing a rapid decline in the average selling price per module, resulting in a new era of challenges to reduce the investment and operational costs of manufacturing facilities. Subsequently, PV modules are rapidly gaining acceptance for industrial applications in the renewable energies sector. The PV industry will therefore need to progress toward high volume production of the established process technologies to meet future demand after the current inventory base has been installed. This paper addresses the potential impact of process technology, manufacturing and automation considerations, as well as the appropriate building concepts for large-scale crystalline silicon cell manufacturing. The other inherent advantages and considerations regarding fabs with a capacity approaching one gigawatt peak are also evaluated and discussed based on comparisons between two actual production facilities.

Introduction

The PV module market is in a state of oversupply. Much of the excessive inventory, estimated at close to 3GWp in total (Fig. 1), will be installed while the existing manufacturing base starts to ramp up to the available production capacity. Nevertheless, investments in new manufacturing facilities may occur due to other factors such as emerging PV technologies or changes in national incentives, including tax breaks, subsidies or feed-in tariffs for the generation of power from renewable energy sources. The technology split between silicon-based and thin film (CdTe, a-Si/µ-Si and CIGS) is forecasted to develop from 80% to 20% by 2012.

Therefore, a continued downward trend in the average selling price (ASP) per module is visible, which is expected to increase demand and renew growth in the mid-term.

Renewed market demand for new PV modules is forecasted to grow at a compound annual growth rate (CAGR) of between 20 and 30% over the next few years. In addition to improvements in module efficiency through technological progress and increased manufacturing throughput, photovoltaic manufacturers will also need to reduce the investment and operational costs of their buildings and facilities as a second contributor to reducing the manufacturing cost per watt peak. Both are key factors in attaining grid parity as early as possible.

Process technology outlook

The first focus area to reduce manufacturing cost is still the development of alternative PV technologies and the optimization of existing processes, thereby

Process	Gases, Chemicals & Materials	Layer	Elements in Layer	Elements in Cell
		Current Status		
N/A	N/A	Doped Si wafer	Si, B	Si, B, P, N
Doping, dry	$POCl_3$	Active layer doping	P	Ag, Al
Doping, wet	H_3PO_4	Active layer doping	P	
SiN_x – CVD	SiH_4, NH_3	ARC Si_3N_4	Si, N	
SiN_x – Sputter	Targets	ARC Si_3N_4	Si, N	
Metallization	Ag – Paste	Front contact	Ag	
Metallization	Ag / Al – Paste	Back contact	Ag, Al	
Metallization	Al – Paste	Back area	Al	
Base-Metallization	Current Process: Ag, Ni			
		Future Trends		
Antireflective Coating		ARC SiO_2	Si, O	O, Ti,
Antireflective Coating		ARC TiO_2	Ti, O	Mg, Ni, Sb,
Metallization	AlMg / Al – Paste	Contacts	Al, Mg	Cu
Metallization	AlMg / NiSb – Paste	Contacts	Al, Mg, Ni, Sb	
Metallization	Cu – Paste	Contacts	Cu	
		Future Processes		
P-Doping	In-line technology combined with SEP			Cu, Sn
Selective Emitter Process	In-line technology			
Ag-LIP Process	In-line metallization			
Base-Metallization		Cu-Sn		
Nano-Technology				

Table 1. Current and future elements used for wafer-based PV cell manufacturing.

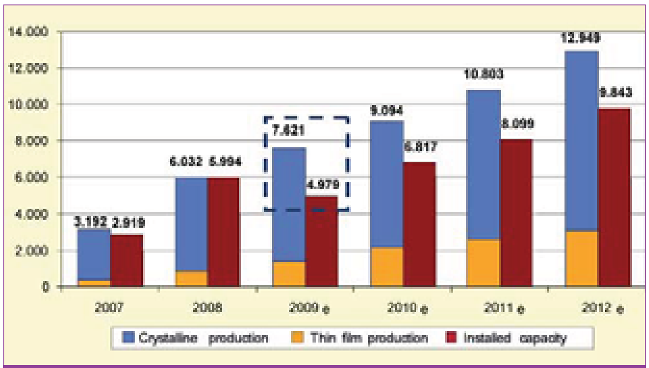

Figure 1. Forecasted gap between global module production capacity and demand [1].

improving average cell and module efficiency and/or simplifying the manufacturing process. Table 1 summarizes the most commonly used elements for wafer-based PV module production in the Periodic table and provides an outlook of elements that are currently being evaluated for new silicon-based process technologies, such as alternative metallization processes by substituting other less expensive metals for silver.

Process technology-driven improvements inevitably impact the design and operation of a manufacturing facility. For instance, with the introduction of new processing materials, alternative process material storage, handling, supply and disposal concepts may need to be implemented.

> "Economies of scale are primarily achieved through the dilution of fixed costs that are independent of production capacity, as well as through the improved utilization of building areas, facility systems, process equipment and automation."

The challenges of large-scale manufacturing

Besides the development of new PV technologies and processes, large-scale manufacturing facilities are recognized as part of the second strategy to reduce the overall cost of manufacturing. The economies of scale are primarily achieved through the dilution of fixed costs that are independent of production capacity, as well as through the improved utilization of building areas, facility systems, process equipment and automation. The key factors include:

- Increased productivity of process equipment
- Higher space utilization of manufacturing and support areas
- Increased ratio of manufacturing area to total building area
- Alternative building concepts, including logistics
- Alternative facility system technologies
- Administration, operations and maintenance staff
- Redundancy of facility system plant equipment
- Advanced engineering and design systems
- Large volume utility supply and disposal contracts (power, water and waste)
- Large volume contracts for consumables and spare parts.

Benchmarking case study

A number of these key factors were examined by benchmarking two multi-crystalline silicon-cell manufacturing facilities of differing capacities. Both are actual projects that have been performed by M+W Zander as the General Contractor (Design/Build or EPC) for

	Design Manufacturing Capacity	Building Concept	Facility Concept	Total Gross Building Area (m^2)
Project 1	100MWp	Single-level manufacturing	Facilities integrated in fab building	10,000
Project 2	600MWp	Multi-level manufacturing	Separate central utility building	38,000

Table 2. Key features of M+W Zander reference projects.

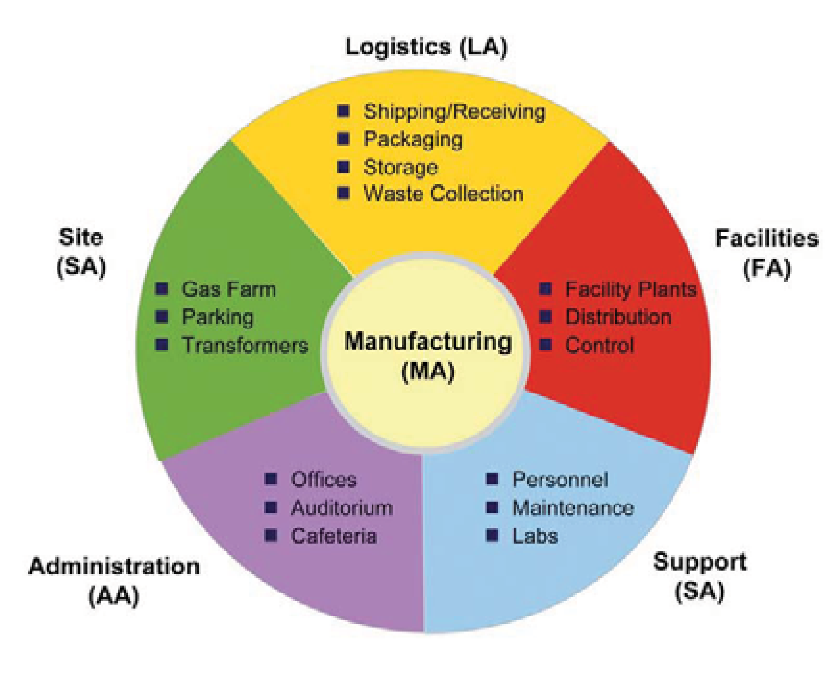

Figure 2. M+W Zander area classification system for PV manufacturing facilities.

the site infrastructure, buildings, facility systems and process tool hook-up. Table 2 outlines the key features of these two projects.

The results of the comparison are discussed by factor in the following sections. For confidentiality reasons, all project-related numbers provided in this article are normalized to arbitrary units where the value for Project 1 (100MWp) was set to 1.

A functional categorization system of the total gross building area is required in order to evaluate the Key Performance Indicators (KPIs) between the projects. Fig. 2 illustrates the building area classification system that was utilized during this investigation.

Productivity considerations

PV cell manufacturing equipment is typically grouped into partial or fully automated production lines of between 80 to 100MWp per line. The automation concepts provide batch or single-substrate transfer and buffering capability between the output loader of a process tool and the input loader of the subsequent equipment. Each line requires a certain level of 'catch-up' manufacturing capacity at the bottleneck tool in order to achieve the average design throughput of the line in the event of unscheduled downtimes. Therefore, other tools may not be fully utilized due to differences in throughput.

In contrast to the 100MWp manufacturing facility, which consists of a single production line as well as all support and facility plant functions, the 600MWp complex within a dedicated manufacturing building can accommodate multiple production lines that are typically installed in linear or U-shape arrangements. To illustrate the comparison, Fig. 3 depicts the linear layout of six individual process lines compared with the integrated 'Smart Farm' approach.

Through improved capacity sharing and implementation of the appropriate automated material handling and manufacturing execution systems, the utilization of process equipment within each dedicated farm can be improved, thereby reducing the overall process equipment count. The decrease in total process tool count in Fig. 2 is 20%, with a corresponding effect on investment and operation costs not only for the process equipment, but also for the required building spaces (manufacturing and support areas) and the facility systems. Another noticeable decrease is the amount of personnel required for operations and maintenance. It should be noted that the Smart Farm concept can also be implemented in a phased capacity ramp strategy.

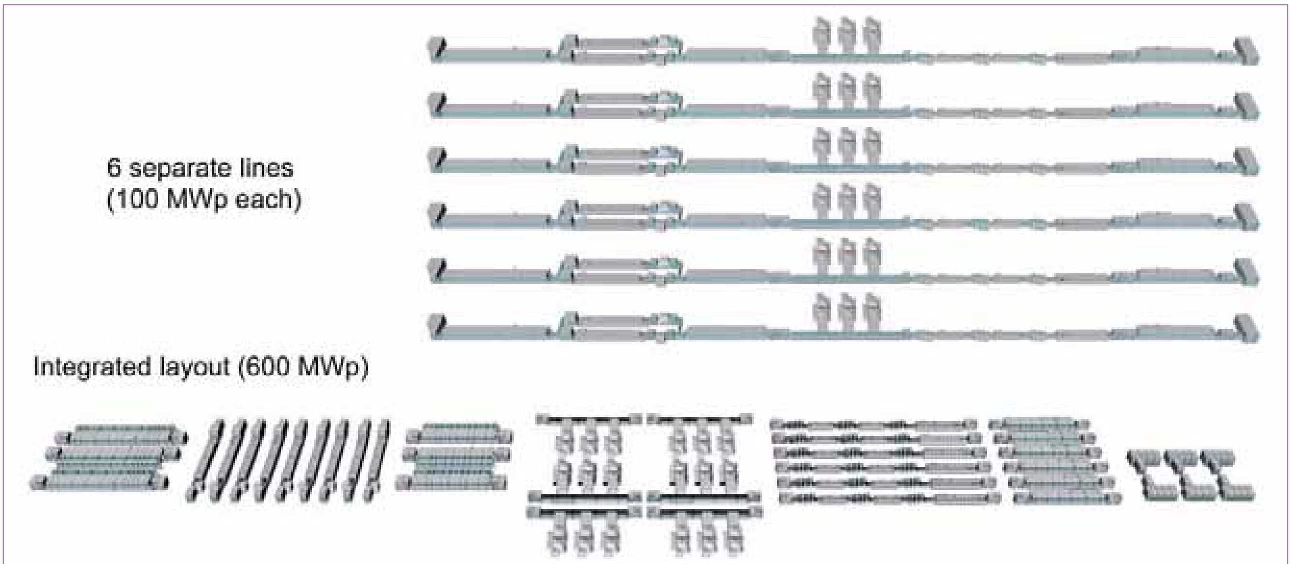

Figure 3. The Smart Farm concept – improving overall equipment utilization through capacity sharing [2].

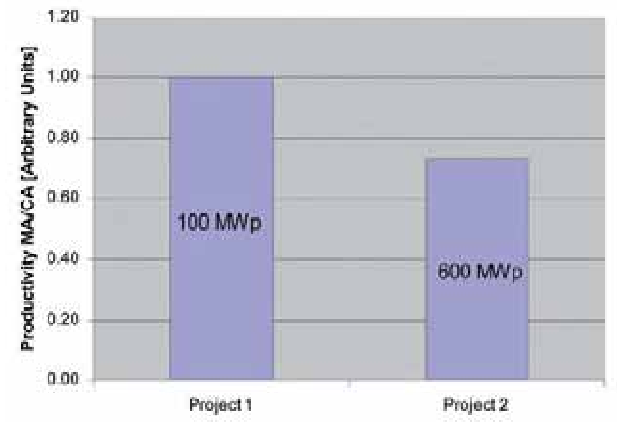

Figure 4. Manufacturing area productivity improvement per capacity in MWp.

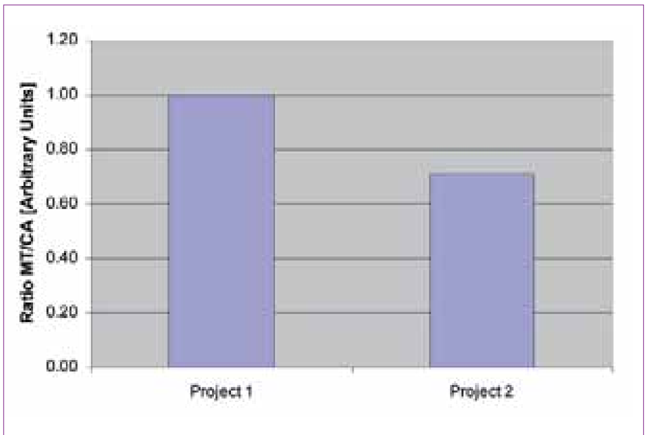

Figure 5. Ratio of tool count vs. manufacturing capacity.

In the selected projects, the productivity enhancement was first determined by evaluating the manufacturing area productivity, a KPI that is calculated by dividing the manufacturing area by the manufacturing capacity. The calculation yields an improvement of 27% in Project 2 (Fig. 4).

The resulting increase in manufacturing area productivity is primarily driven by the reduced process tool count due to the higher overall equipment utilization of Project 2's process equipment set. Additionally, the more efficient utilization of gross manufacturing area between equipment for maintenance, tool move-in and personnel access improves the packing density of the process equipment.

Fig. 5 addresses the KPI Process Tool Productivity, which is determined by dividing the total number of major (value-adding) process equipment by the overall manufacturing capacity.

A reduction of 29% was observed during the evaluation of the reference projects, which again verifies the potential to reduce the overall capital expenditure (CAPEX) for process equipment and the associated facility systems and manufacturing support areas. This benefit may be partially offset by increased investments required for more advanced automated material handling and MES (Manufacturing Execution System) systems.

Redundant plant equipment

Redundant facility plant equipment is installed to ensure that facility system capacity is available around the clock, i.e., even during maintenance or an unplanned shutdown of operational units. A common strategy is to utilize an "n+1" philosophy for all manufacturing-critical systems, but site-specific factors in different countries and regions, such as the reliability of the local electrical power grid, may affect this in order to ensure a sufficiently stable redundancy concept. Table 3 summarizes the redundancy approach for selected large facility plant equipment.

The philosophy selected by the user in Project 1 was to accept a degree of degradation of the HVAC (heating, ventilation and air

	Make-Up Air	Exhaust Fans	Chillers	Transformers
Project 1 (100MWp)	2 + 0 (100%)	2 + 1 (150%)	2 + 1 (150%)	2 + 0 (100%)
Project 2 (600MWp)	4 + 1 (125%)	3 + 1 (133%)	5 + 1 (120%)	2 + 0 (100%)

Table 3. Comparison of the redundancy approach for selected facility plant equipment.

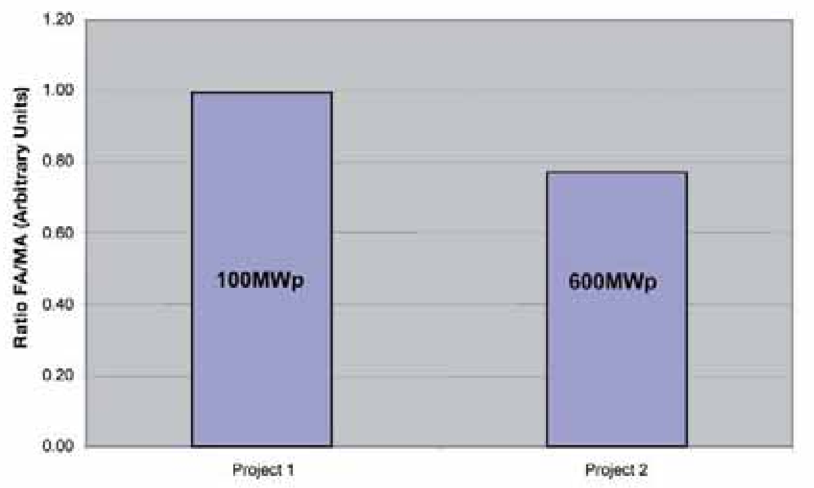

Figure 6. Ratio of facility area to manufacturing area.

conditioning) system with respect to heat removal and temperature stability in the manufacturing area. In most other cases, the percentage contribution of redundant capacity is higher in comparison to Project 2 (600MWp). These differences influence the overall CAPEX of these facility systems on a per MWp basis, thereby favouring the large-scale facility.

The overall effect of reduced redundancy, as well as the installation of larger plant equipment units can be determined by calculating the ratio between the facility area that is required to support the entire PV production complex and the manufacturing area. A lower ratio indicates a lower overall investment per manufacturing capacity by saving building floor space for these functions. An evaluation of the reference projects yielded a reduction of 22.5%, as illustrated in Fig. 6.

> "Process-critical systems drive environmental protection requirements, such as process exhaust systems, gas and chemical storage and waste water treatment."

Alternative building concepts

Photovoltaic manufacturing facilities are purpose-built around the process technology and equipment to be utilized. This affects the specifications pertaining to height development, structural loading, logistics, fire protection zoning, emergency egress concept etc. The process-critical systems drive environmental protection requirements, such as process exhaust systems, gas and chemical storage and waste water treatment.

Fig. 7 depicts the migration of the building concept for cell production facilities. Whereas a 100MWp fab typically consists of a single-storey building with all functions integrated within the building, large-scale manufacturing facilities are often constructed vertically with multiple levels in a similar fashion to flat panel display or semiconductor manufacturing fabricators. This building accommodates the production equipment, selected support functions and the process critical supply systems such as process chemicals, specialty gases, production make-up air handlers and exhaust treatment.

Selected systems such as electrical power supply, chilled and hot water generation, ultra pure water generation, wastewater treatment etc. are centralized and located in a dedicated Central Utility Building (CUB), which may ultimately be shared with a second adjacent fab. The same approach often applies to other site functions, such as an on-site energy supply centre or a logistics building for storage of raw materials or shipping of the final product.

Overall area scaling advantages

The area overhead ratio (also known as the building efficiency factor) is defined as the ratio between the total gross building area and the manufacturing area (Fig. 8). This is a typical KPI for determining the overall efficiency of a building concept.

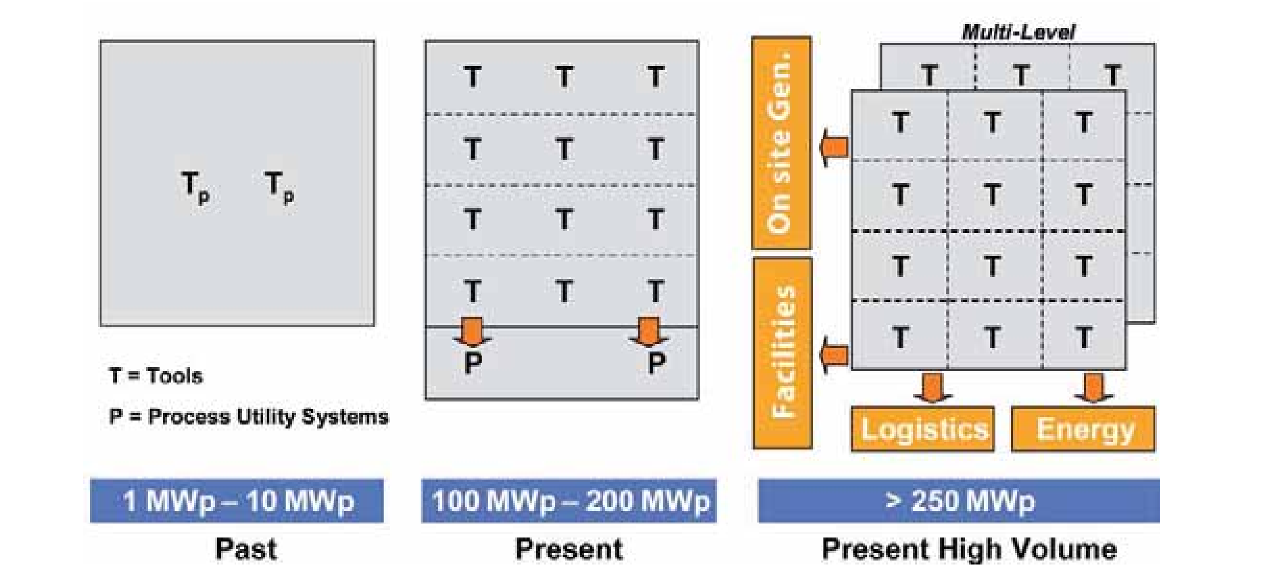

Figure 7. Migration of PV manufacturing building concepts.

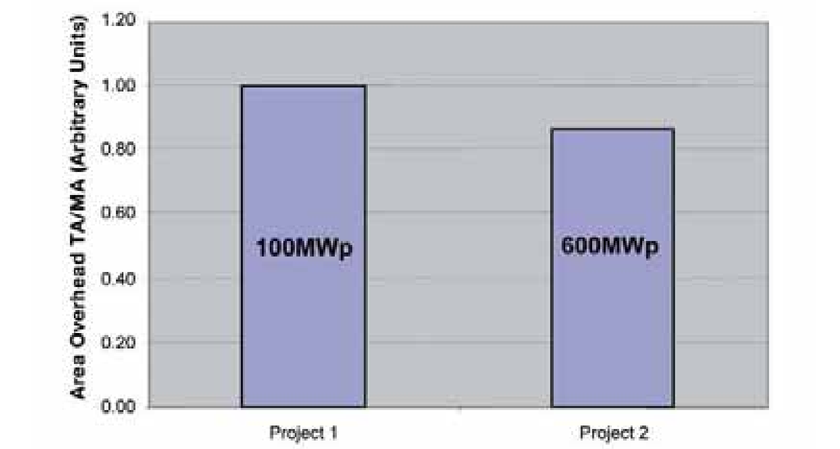

Figure 8. Area overhead ratio comparison.

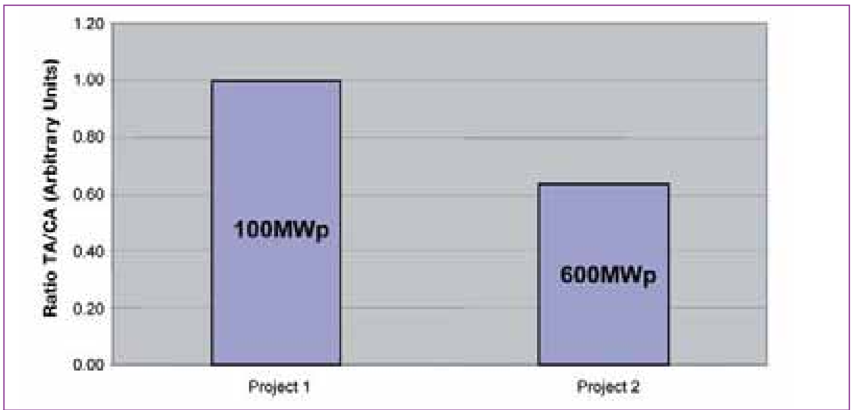

Figure 9. Total gross building area by manufacturing capacity.

A reduction of 13% in the area overhead ratio was observed, which directly reduces the construction cost of the buildings. The reduction is mainly driven by the dilution of administration functions, logistics areas, as well as the higher area efficiency of large facility plant equipment as discussed in the previous section.

A second KPI was calculated to determine the overall reduction in investment for the building and associated facility systems, namely the ratio between the total gross building area and the manufacturing capacity, illustrated in Fig. 9. This KPI is simultaneously influenced by the improvement of the area overhead ratio as well as the manufacturing area productivity.

In this comparison, the required building area per manufacturing capacity was reduced by 36.5%, thereby demonstrating the significant potential to reduce CAPEX for construction of the buildings and the associated facility systems through the migration from medium- to high-volume manufacturing.

Alternative facility system technologies

Large-scale manufacturing facilities also present the opportunity to consider alternative facility system concepts in order to further enhance the energy and environmental efficiency of the overall complex. The implementation of measures such as heat recovery systems is generally

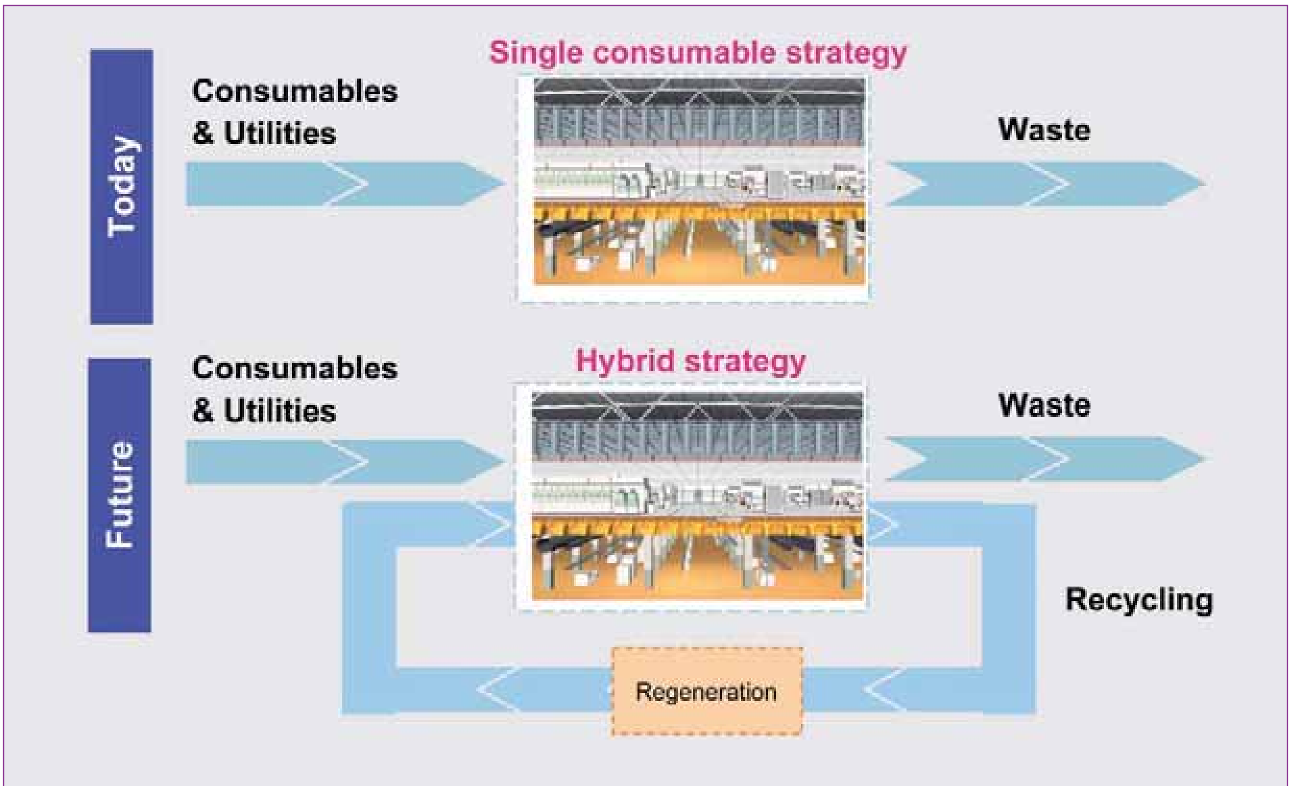

Figure 10. Waste reduction potential – material recycling.

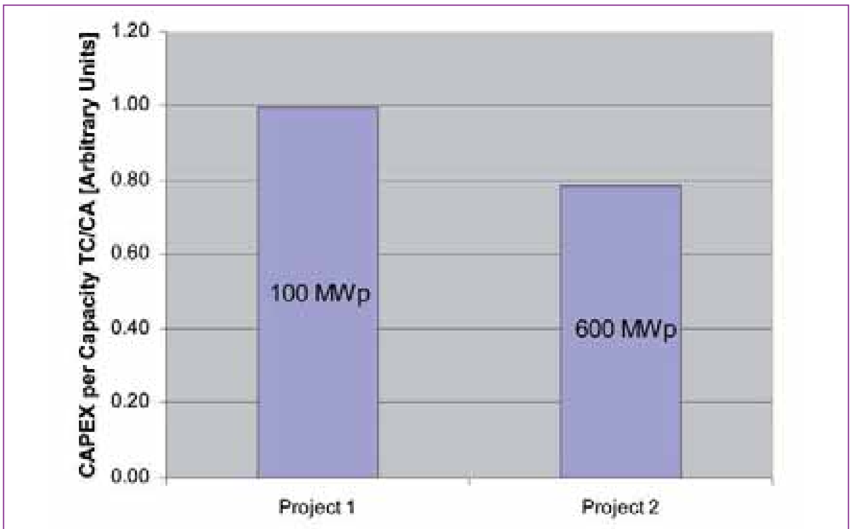

Figure 11. CAPEX per manufacturing capacity for building and facilities.

not viable in smaller manufacturing facilities due to the high specific investment cost on a per MWp basis.

As an example, dual temperature process cooling water (PCW) systems are under evaluation for very large manufacturing facilities. A single system in small factories is designed at the lowest temperature set point required by the process equipment set, although most of the equipment can operate at higher temperature level. A dual temperature PCW system can be designed and optimized according to the actual demand of the equipment, thereby saving cooling capacity and the associated electrical power, which can compensate for the higher initial investment in a secondary system.

The overall electrical demand of a large manufacturing facility complex can favour implementation of a tri-generation power

Figure 12. Architectural impression of the Q-Cells PV manufacturing complex in Malaysia.

plant. Such energy supply centres can simultaneously provide stable electrical power, hot water, as well as chilled water to the campus, and may also be owned and operated by a third party. Compared to conventional power plants, tri-generation plants substantially reduce the primary energy demand of manufacturing facilities. They normally operate with high efficiency gas motors, which further contribute to the overall reduction of the CO_2 footprint of the manufactured product by between 30 to 50% compared to conventional power supply concepts.

Large-scale manufacturing facilities not only promote the implementation of energy-saving measures, but also support waste reduction and material recycling technologies. Such measures often become mandatory in order to minimize the handling and storage volume of hazardous process materials such as HF or other chemicals, which not only reduce manufacturing cost, as shown in the schematic in Fig. 10, but also improve the industry's image regarding environmental compatibility and protection.

On-site bulk gas generation (e.g. hydrogen or fluoride) can be implemented, resulting in lower overall handling and operational costs for gas generation and transport compared to regular shipment of tankers and trailers. For specialty gases, bundle or trailer solutions become feasible compared to bottled systems, thereby reducing gas costs and enhancing handling safety. Furthermore, separate gas shelters can be implemented in lieu of dedicated gas rooms inside a building, thereby reducing the requirements for safety systems.

For ultra pure water (UPW), DIW supply and other process supply systems, savings are primarily driven by the increased system size and higher overall utilization and can be centralized in the CUB building to serve multiple fabs. Secondly, with a linear arrangement of the manufacturing lines (Smart Farm concept), the specific distribution system costs and space requirements are lowered. Particularly for wastewater treatment systems, the Smart Farm concept facilitates the segregation of wastewater flows, thereby enabling the implementation of dedicated treatment methods. Water recycling technologies become more economically viable with increased size of the manufacturing facility, especially if such facilities are located in areas with a limited source of raw water.

In many of the aforementioned opportunities, precise determination of the utility consumption data of all process equipment is essential to enable correct sizing of each facility system and hence minimize CAPEX, which requires improved co-ordination between the process technology team, facility engineering group and the process equipment vendors.

Overall building and facility investment (CAPEX)

In order to evaluate the opportunities of large-scale PV cell manufacturing facilities, the overall CAPEX per manufacturing capacity for the buildings and facilities of the benchmarked projects was evaluated. This comparison includes the investment for site development, building structure, architectural interiors, the mechanical, electrical and process utility systems as well as the electrical control and life safety systems. Normalized values were applied to account for exchange rate differences, local climate and site-specific requirements (such as foundations). A reduction of 21.3% of the normalized CAPEX was determined (Fig. 11). The overall CAPEX reduction would be higher when taking the lower number of process equipment into account, which results from implementation of layout concepts, such as the Smart Farm approach, into account.

As described previously, the major contribution to CAPEX savings is the reduction of required building area by increased area efficiency (production and facilities), lower facility system capacities due to the smaller process equipment set, as well as by the diluted overhead functions (administration, support and logistics). These savings are greater than the additional investment in the sustainability of the complex. Furthermore, the operational expenditure (OPEX) is also substantially decreased through an improved redundancy strategy and higher utilization of less production equipment and the corresponding facility systems.

Figure 13. Side view of the Q-Cells cell manufacturing building in Malaysia.

Figure 14. Overhead utility connections to process equipment in the manufacturing area.

Figure 15. View of the Central Utilities Building (CUB).

Case study: large-scale cell manufacturing facility

One example of a large-scale manufacturing facility is Q-Cells' new cell production building in Malaysia. It constitutes the first phase of a planned gigawatt production complex with various technologies in the future. The location was a greenfield site with no available infrastructure. In order to achieve a fast-track schedule approach, design standardization was critical for all building systems and mechanical, electrical and process systems with a high level of flexibility for future requirements.

Figure 12 illustrates the overall complex, which consists of multiple cell manufacturing buildings, a central logistics building and site functions including a bulk gas yard and energy supply. A particular feature of the design is an interconnecting ('spine') building to enable inter-building material and personnel flow as well as utility distribution.

The Cell Manufacturing building, shown in Fig. 13, is a triple-storey complex consisting of two levels to accommodate the cell production lines, and a ground floor for logistics and building-specific facility systems such as electrical distribution, HVAC and process systems. The Spine building features a similar height development with co-planar floors on all three levels. This concept allows multiple usage of the building, where the major functions on the ground floor (material flow and inter-building facility connections) can be separated from personnel flow on the upper levels. It also contains a large data centre, gowning rooms and office space to support the first cell building.

The Logistics building is a single-storey unit adapted to the requirements of a warehouse. This includes dedicated HVAC and electrical distribution systems as well as the appropriate building height and building column grid spacing for the installation of fully automated high-bay storage systems.

The Central Utilities Building (CUB) supplies the cell building with chilled water, make-up water for the UPW plant and electrical power distribution. The CUB also houses the necessary expansion space of these systems for future manufacturing facilities (Fig. 15).

Centralized site functions for multiple buildings include the primary electrical

Feature	Definition KPI	Ratio	Project 1	Project 2
Capacity (MWp)		CA	100	600
Process Tool Utilization	Major Tools by Capacity	MT/CA	1.00	0.71
Basebuild Investment	CAPEX for Buildings & Facilities by Capacity	TC/CA	1.00	0.79
Area Overhead Ratio	Total Building Area by Manufacturing Area	TA/MA	1.00	0.87
Facilities Overhead	Facilities Area by Manufacturing Area	FA/MA	1.00	0.77
Manufacturing Productivity	Manufacturing Area by Capacity	MA/CA	1.00	0.73
Overall Productivity	Total Building Area by Capacity	TA/CA	1.00	0.64

Table 4. Overview of the Key Performance Indicator (KPI) comparison.

substation, fire protection tanks and pump house, FMCS/Fire Alarm Centre and a wastewater treatment plant.

Construction of the Cell building and associated functions was completed in less than eight months, commencing with the foundations and ending in Ready for Equipment (RFE). The first process line was fully installed, started up and qualified within three months. Production of the first cells commenced in 2Q09 and commercially available cells are scheduled for shipment in 4Q09.

Considerations

Although significant CAPEX and OPEX saving opportunities have been demonstrated with the migration from medium- to large-scale manufacturing facilities, other factors need to be considered when developing a business case, such as the increased upfront investment in buildings and facilities, especially if the ramp schedule between pilot and full mass production is prolonged. In the case of a high volume manufacturing complex, a non-scheduled production shutdown will have a severe impact on overall manufacturing capacity, even for the larger cell manufacturing companies.

Furthermore, the selection criteria for the location of a large-scale production site, such as the adequate availability of water and power utilities, become more stringent. With respect to facility design, the high availability criteria for a broad range of facility systems has become mandatory, thereby driving considerations such as robust design, sufficient system redundancy, and high quality of key system components.

The size of a single factory or site may be limited by asset protection considerations, the insurer's requirement and local safety and environmental codes and regulations. As an example of the latter, the consumption of some hazardous process materials has also resulted in comprehensive evaluation of recycling technologies.

Due to the higher initial investment for large-scale manufacturing facilities, a sustainable design of the complex is a critical factor in order to cope with future process and manufacturing technology development and avoid premature obsolescence of the factory. Appropriate design strategies and solutions can be transferred from other industries such as semiconductor or flat panel displays where a high level of volatility of process, product and technology development can be observed.

Conclusions

Despite current market conditions, the PV industry is maturing at a rapid pace in terms of large-scale manufacturing of its mainstream technologies that will drive the reduction in manufactured cost per Watt peak in order to attain grid parity in many regions and countries.

It has been demonstrated what level of economies of scale can be achieved through implementation of cell production buildings with a manufacturing capacity of 600MWp. The major contributors to these savings are the reduced investment in process equipment through higher utilization, as well as a reduction in all building areas and facility system capacities.

Improvements in economies of scale calculated during the benchmarking evaluation of the selected fabs in this paper are summarized in Table 4. The Basebuild Investment KPI quantifies the overall reduction in normalized investment for the building and facilities from a CAPEX perspective by over 21%. The larger saving in the number of process equipment, generated by the improvement in their overall productivity, would further improve the overall CAPEX productivity KPI.

Additional benefits of a large-scale facility include its ability to facilitate further reductions in manufacturing cost per Watt, and to improve environmental compliance. Additionally, alternative facility system and building design approaches, including low CO_2 discharge energy supply concepts and enhanced waste collection and recycling technologies are possible.

When evaluating the business case for a large-scale facility, certain considerations should also be discussed and clarified.

The key criteria for the successful design and execution of a large-scale cell manufacturing facility on a fast track schedule include:

- Production space flexibility.
- Centralized plant with modular design/expansion.
- Accurate determination of current utility consumption data of the process equipment and allowance for future process development requirements.
- Standardized construction methods.
- Increasing production environment requirements for future technology nodes with higher efficiencies.
- Commercial procurement strategy for large-scale multiple fab sites.

Acknowledgements

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Gerhard Rauter has been a member of the Q-Cells SE Executive Board since 2007. He is responsible for the core operating business of producing and developing crystalline solar cells. From 1979 he worked in managerial positions for Siemens AG, and 20 years later, in 1999, he started working for Infineon Technologies AG, where he became Vice President Operation & Production in 2005.

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Hartmut Schneider is deputy manager of M+W Zander's Global Technology Services Group and is responsible for industrial engineering activities. This includes a range of services to define the fab concept, the process equipment layout of the cleanroom, support areas, utility requirements and the automation concept as well as to consult on operational and process-related design issues. He joined the company in 1991 and has a degree in physics from the University of Stuttgart, Germany.

Martin Beigl is Managing Director of M+W Zander's European Division. He has an extensive background in the design of all types of mechanical and utility systems for advanced technology facilities, as well as specialized experience in the design and construction management of cleanroom systems, including HVAC systems, environmental control, cleanroom layouts, air management and particle control. He joined the company in 1985 and received his engineering degree in mechanical engineering from the Fachhochschule Esslingen, Germany.

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From Arco Solar to the gigawatt age: past, present, and future of photovoltaic manufacturing reside in SolarWorld USA's facilities

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ABSTRACT

SolarWorld USA's two main manufacturing facilities in Camarillo, CA, and Hillsboro, OR, represent the past, present, and future of crystalline-silicon solar photovoltaic manufacturing in the United States. The Southern California site, which sits in a small industrial park across from a verdant expanse of strawberry fields, was home to one of the world's first (and at one time the largest) solar factories in the late 1970s, a historic campus that has changed corporate hands several times, from Arco Solar to Siemens Solar (1990) to Shell Solar (2001) and finally to SolarWorld (2006) over the three decades since its inception. This article provides a look inside the factory doors.

The Arco epoch was an especially noteworthy one in the early go-go days of the industry. The firm, a division of petrochemical giant Arco and led by PV pioneer Bill Yerkes, became the world's number-one solar company. It was the first to make more than 1MW of modules in a year, the first to commission a 1MW grid-tied power plant, the first to get UL listings for solar panels, and the first to offer UL-listed junction boxes. A gallery of heritage modules in a lobby at Camarillo bears witness to the unique legacy of the production site – from the skinny, two-cell-wide 15-, 20-, and 30-watt antiques through the increasingly sophisticated Siemens and Shell models to the high-power 72-cell units produced at the plant today.

This was once a place where just about every step in the photovoltaic production value chain was done (and in some cases invented) – from pulling ingots to making wafers to designing and building process equipment to conducting R&D to manufacturing cells and panels. Although the Camarillo factory now pumps out SolarWorld's monocrystalline-silicon modules mostly for the North American market on a new automated 100MW capacity line, the site has been a hotbed of thin-film PV development at various times, including a multimegawatt copper-indium-selenide (CIS) pilot line during the Siemens and Shell eras (technology that lives on in the Avancis venture in Germany).

The Oregon location, set on 97 acres not far from the fabled Intel digs in the suburbs of Portland, was once a Komatsu Semiconductor silicon ingot and wafer-making plant that, due to one of the inevitable down-cycles in the semiconductor business, lay idle and was never fully equipped, let alone ramped up to production. SolarWorld bought it in 2007 and has since poured hundreds of millions of dollars into tearing out floors and ceilings, knocking down walls, and otherwise retrofitting the facility.

The company is finishing a new 210,000 sq ft logistics and production building, which will turn the site into a vertically integrated, 21st century solar PV fab complex that will reach a nameplate

Photo: SolarWorld

Solar cells run through a highly integrated, closely monitored process flow.

capacity of 500MW by 2011 – the largest of its kind in North America. There's enough land on the Oregon site to build another factory of a similar or larger scale, though SolarWorld has made no definitive plans to do so.

Following the production flow

At one end of the Hillsboro factory, operators load charges of virgin and recrystallized scrap polysilicon into one of the dozens of crystal furnaces. The materials are then spun-melted and formed into single crystals and pulled into ingots, after which they are transported to a cropping and squaring area. The two-metre-long rectangular loaves of processed silicon are then taken to the cutting area, where they are sliced into ~200µm-thick wafers by a phalanx of whooshing wiresaws collectively containing spools of thousands of kilometers of diamond wire, most of which must be replaced after being used for a single cut.

The 156-mm wafers' surfaces are further prepped, cleaned, and inspected before they are either kicked back for additional reprocessing or binned and then placed in cassettes to move into the cacophonous cell-processing area, where the silicon squares are processed, screen-printed, and cleaned before becoming high-efficiency mono cells. After yet another round of thorough quality control checks, the bluish cells are shipped to Camarillo to be placed into modules.

There, the glass is prepped and the cells are linked 12 to a string, 6 strings to a module, and the units are laminated, backsheeted, j-boxed, and framed into glass PV panels, each flash-tested for its power output capabilities. The finished Sunmodules go through a final manual inspection and, if they pass muster, are then stacked according to wattage and finally loaded 40 or so at a time into sturdy shipping boxes.


Photo: Tom Cheyney

Gordon Brinser, VP of operations for SolarWorld USA's production facilities.

Acting as tour guide for my springtime visits to the Hillsboro and Camarillo factory floors, Gordon Brinser steered a fine line between filling in details about certain production flows or tool layouts and begging off on any further discussions of the secret-sauce elements that the German-owned company believes give it an edge on the competition. "How to integrate [the tools] and how to use [them] in a fully continuous line is where our intellectual property comes in," he told me.

As vice president of operations for SolarWorld USA, his responsibilities extend to both facilities (as well as the company's Vancouver, WA silicon plant). Brinser is a veteran silicon ops guy, having helped set up and run factories for Wacker Siltronic and Sumco in the Pacific Northwest and Singapore, but he's a relative newcomer to the solar manufacturing business, with about a year and a half on the SolarWorld job. With the plants running around the clock, seven days a week, at close to or at full capacity, Brinser has his hands full.

Meeting the challenges of the facility retrofit

Brinser has done facility retrofits and green-field construction projects during his career and readily admits that both approaches have their advantages and disadvantages. During our walk-through of the Hillsboro production area, we came upon an unusual tool-meets-factory layout quirk, where the back end of a texturizing wet bench fit snugly through the bottom of the inverted vee of a large girder – a "structural component" that wasn't on the architectural blueprints provided by Komatsu.

"That's one of the things about using a preexisting building", he explained. "You lay out the map and say this is where all our tools need

Photo: Tom Cheyney

SolarWorld USA's Hillsboro site, where ingots, wafers, and cells are produced.

to go and you start doing the construction. Because everything's done so quickly and in parallel, all of a sudden when you're in the middle of taking down walls and the layouts don't quite clearly show all the structural components of the building, and you open it up and say, 'oh shoot' – what do you do? Luckily, with the equipment, we had to move it a foot or two, so at least it didn't come down right in the middle of the tool. This was a surprise to us that these structural components were here – on the drawing, none of the girders were there."

"The thing with retrofitting an existing facility is, it's much faster, since a lot of the components are already there inside, so some of the long lead times are gone," he continued. "You already have the shell, so you don't have any weather issues to mess with schedules. You're under cover the whole time.

"[But] there are surprises that weren't completely documented. You have to live

Photo: Tom Cheyney

SolarWorld USA's Camarillo location, where module assembly takes place.

Photo: SolarWorld

A forest of crystal growers melt down the polysilicon and turn it into ingots.

under the constraints of this acid system, or a chemical delivery system may be in one part of the building but you need [it] someplace else, so it's not quite perfectly laid out the way you want it. I think we've made a very good balance of what we need and what was here, and at the end of the day, it's a state-of-the-art facility," he said.

Balancing automation costs, seeking better tools

Although SolarWorld touts both the Hillsboro and Camarillo plants as "fully automated," the reality on the shop floors is something different. Most of the lines are indeed populated by handling robots that whip wafers, cells, glass plate, and modules around with precise ease or conveyors continuously rolling steady streams of wafers/cells inexorably along the flow of production, yet a handful of processes still require the human elements of keen eyes, taut muscle, and technical savvy.

An example in Hillsboro is the wire-saw room, where ingots are still lifted and largely mounted manually onto the tools before being sliced into wafers, an area where Brinser admits he would like to see a higher level of automation. In the wafer cleaning area, after a batch of properly prepared substrates are placed inside the handling cassettes, a technician comes along and hauls the "boats" off the end of the machine. "It's a cost-benefit balance, in terms of automation," the VP said.

Down south in Camarillo next to the module line's cell-stringing equipment, we observed an inspector as she carefully examined damaged cells. "We 100% inspect visually," explained Brinser. "We have some stations here, because of mechanical handling, where operators take out the broken cells. She'll do a minisurgery, take it out, clean it up, and repair it. Any broken cells are sent back to Germany to be stripped down."

"Stringing is still very mechanical," he continued. "Lamination has been highly automated, and stringing's highly automated too, but with stringing there is still a lot of physical contact with the cell. Every time you touch it, you risk cracking it or chipping it. So for moduling, you put all this money in to get this nice cell and now you gotta handle it again. Advances for different stringing technologies would be very beneficial."

Another area where Brinser seeks better solutions from the suppliers is in the heart of the cell-fabrication area, where he'd like to see something done about the enormous footprint of the screen-printing systems (they take up about half of the floor space there) as well as improvements in the throughput and process capability of the equipment.

"Longer term, there's a lot of opportunity here in this process for more speed, better uniformity," he noted. "The less shading you can put on a cell, the more efficiency you'll get. Look how much footprint this thing takes up," pointing at a dozens-of-metres-long system. "When we talk about how to make the process a lot cheaper, how can you do this all in one single process step? How can you get twice as much or three times as much capacity out of this floor space?" He wondered aloud about some way of double-stacking the tools and reminded me that big footprint tools also carry a larger price tag in terms of their greater use of electricity, chemicals, and other not-so-fixed costs.

"Any place we can eliminate a process step, eliminate complexity – like going inline instead of batch – that's great," he said. "Volume for us is what's key. At the end of the day, it's about reaching grid parity," noting the company's ambitious roadmap to drive 10% out of its manufacturing costs each year.

SolarWorld works closely with its vendors, big and small. Some suppliers are more sophisticated because of years of experience working with (and being beaten up by) semiconductor manufacturers, while others come from the less-demanding specs of the machine-shop realm. "We're working very diligently with our suppliers to improve the quality," said Brinser. "You'd be surprised at some of the conversations we have with them. We start talking about capability and it's a foreign topic to them."

But the company is not just looking at its current needs from the upstream supply chain. "We look at best of breed for every single operation and say, 'what's the best today and are they going to get us to what we need in the future?'" he explained. "For the wiresaws we just went through a whole new analysis for our second expansion here, and we reevaluated all the manufacturers."

Photo: SolarWorld

A high level of automation greatly increases the capacity of the moduling line.

Pushing forward on the production ramp

The results of that reevaluation are bearing fruit, as additional wafering tools have been delivered to Hillsboro and will be making their first cuts by the end of August, according to Brinser. New silicon-ingot cropping and squaring gear has also arrived and will be part of a newly dedicated area adjacent to the crystal pulling room. Facility drop-downs are also in place, so "by the end of the third quarter, we should have all the major tools in their proper location," he said.

By October, tools will also start populating the new 210,000 sq ft building being built behind the current facility in Hillsboro, with operational capability coming online not long afterwards, explained Ben Santarris, a former business editor at the Oregonian who joined the company as its public affairs manager. The new addition, which will be split more or less evenly between logistics and production uses, will be dedicated in early October as part of the site's first anniversary celebration.

Brinser revealed that the new manufacturing space will be used for additional module assembly lines, "which will allow us to quickly add capacity, as needed." This move will make the Hillsboro campus a de facto vertically integrated facility and give the company even more flexibility to meet the demands of what could become the fastest-growing solar PV marketplace over the next decade.

The benefits of such soup-to-nuts integration are critical to SolarWorld's gameplan for success. "Being vertically integrated, you can align those quality parameters pretty tightly," Brinser said. "You can drive that quality real easily back all the way down the line to the source of where the quality problem exists, and you can fix it there. There's no hidden factor."

About the Author

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Supply chain management in the PV industry

Rainer Krause & **Udo Kleemann**, IBM Deutschland, Mainz, Germany

ABSTRACT

Efficient management of the PV supply chain can save a company money, both directly by reducing material and component cost, and indirectly by improving lead time, inventory optimization and quality throughout the entire value chain. So-called static supply chains compare poorly to their dynamic counterparts that see cost reduction and quality as well as material availability improvements. What follows is a proposal of improving the supply chain using methods like integration, data exchange and collaboration that can also help to improve entire E2E flows through re-structuring and outsourcing from one level to another.

Motivation

As succinctly put by Linda Cantwell, an IBM executive in the ISC organization, "It's very exciting to see how the challenges of today's global marketplace are bringing increasingly sharp focus to how supply chain business processes – operated as an integrated whole – bring strategic competitive advantage to the enterprise. The more complex the business model becomes, the faster supply chain excellence is recognized as a critical competitive tool and solution. Whether trying to determine how best to accelerate delivery of value to one's clients or where in the world is the optimal location in which to operate, supply chain emerges as a critical discipline which can bring direct and truly sustainable business performance improvement."

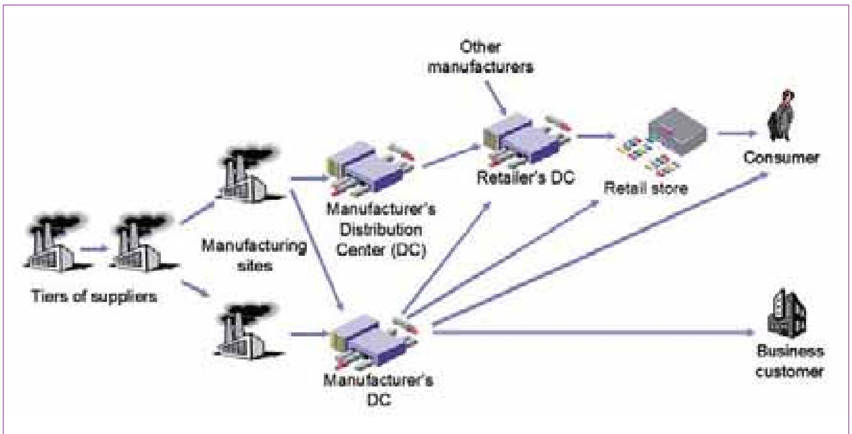

Figure 1. Typical supply chain structure.

Figure 2. Value chain example from sheep farming to clothing (end product).

Supply chain or value chain?

Each industry has its own supply chain structure and set of issues, but many principles are common to all (see schematic in Figure 1). The typical scenario for most supply chains is that the complexity goes from the client down into the supply chain, moving from tier 1 down to tier x. Efficient and flexible management of such a complex chain of events and participants is not a trivial matter.

The value chain consists of the value-added processes that enable a company to bring its products from conception to market, usually comprising the E2E chain from raw material to finished product for the end customer. The supply chain is a subset of the value chain.

Figure 2 clearly demonstrates that any problem encountered at the beginning of the value chain (raw material supply) can cause major problems at the end of the value chain. If the raw material, the sheep and its wool, is not stress reliable, for instance, the end customer will have problems with his/her pullover seeing faster degradation while wearing, washing, etc. This issue will be discussed in more detail in relation to the bullwhip effect (see Figure 9).

In the case of the PV industry, the value chain (E2E) covers from raw silicon (or even as far back as sand) up to the final installed module at the customer's site, including after-sales activities such as maintenance, upgrades, grid management, etc. The supply chains in the PV industry go from raw silicon to wafer (wafer manufacturing); silicon wafer to solar cell (cell manufacturing) and solar cell to module (module manufacturing). Beyond this, the distribution net (grid) starts. The supply of materials such as raw silicon wafers is pretty much based on the static approach, using normal purchasing and long-term contracts, to secure materials availability. Other industries not only order materials in their supply chain, but also transfer technical as well as quality responsibility into the supply chain in order to achieve better improvement potentials in terms of technology, quality, yield and cost.

Supply chain requirements

Various elements must be available to achieve an efficient supply chain that works in a competitive manner and brings about cost savings. The following sections put forth a list of essential elements that must be in place in order to make the graduation from a static to a highly dynamic working supply chain approach. The key items discussed are supply chain integration, process integration, data exchange in the supply chain and supplier auditing and development. When setting about improving an existing supply chain, the working level should be at least at the static supply chain level, from which point the improvement can be performed step-by-step as outlined in the following sections. Improvement steps can be introduced simultaneously if the required capabilities and support mechanisms are in place. It should be mentioned at this

Figure 3. 'Point-of-View on the Progression of Supply Chain Management to a Smarter Future.'

point that the realization of the following sections would, in every case, require a certain IT structure. The elements of this structure can be implemented while applying the individual improvement steps.

Supply chain integration

The process from a static supply chain to an on-demand supply chain takes various steps, as shown in Figure 3. This process also has an integration effect in the supply chain. While the static approach brings only a cost focus, the on-demand approach generates not only cost but also competitive advantages.

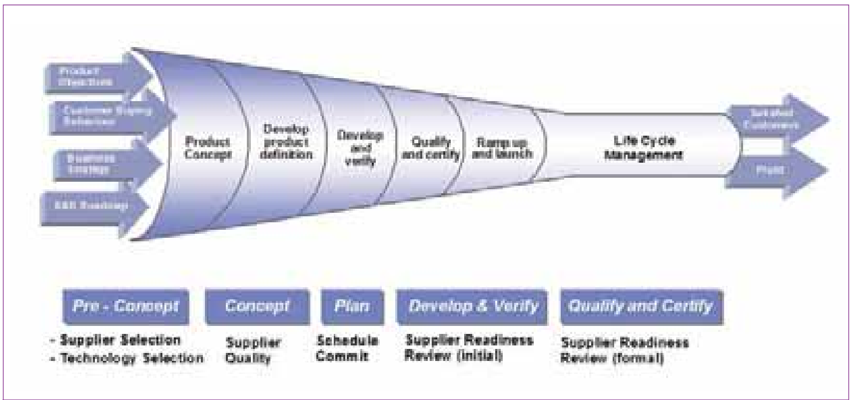

Figure 4. Supplier involvement during product life cycle.

> "The smart supply chain is interconnected, allowing the development of strategies, policies and providing the infrastructure to connect to the thousands of partners involved in a system ."

IBM's 'Point-of-View on the Progression of Supply Chain Management to a Smarter Future' begins with the overall competencies of the organization as it moves from static and isolated departmental performance to functional, focused operational excellence, and from functional optimization to horizontal process integration (or internal collaboration) within the company, and then to external collaboration and integration with partners.

The smart supply chain is flexible in responding to the volatilities and complexities of today's marketplace. At its core, it is instrumented and manages the complexity through integrated transactions (integrating ERPS to ERPS of manufacturers to suppliers and then to customers), and uses sensors and actuators to automate transactions.

The smart supply chain is interconnected, allowing the development of strategies, policies and providing the infrastructure to connect to the thousands of partners involved in a system that balances risk, increases performance and enables shared decision-making.

The smart supply chain is also intelligent and enables the optimization of the '4 Flows': product flow, information flow, people/process or work flow and the one so often forgotten, the cash or financial flow. Implementation of networked planning and smart execution practices across the entire supply chain network with decision support will result in flexibility and stability in the race to achieve profitable growth.

The automotive, electronic and semiconductor industries, for example, have reached the on-demand level, and beyond, while the PV industry mainly works in the static supply chain mode in order to control supplied material cost and secure the material supply with mid- to long-term contracts.

Integration within the supply chain has improvement potential for the PV industry in that it provides:

- Tighter cost control throughout supply chain
- Cost improvements
- Quality improvements
- Utilization improvement
- Inventory improvement
- Efficient collaboration, faster development and NPI (time-to-market)
- A joined technology roadmap.

Process integration

Product life cycles are constantly shrinking, creating a need for a much more flexible and adaptive supply chain. Life cycles are shrinking from years to quarters, resulting in:

- a high ramp-up risk

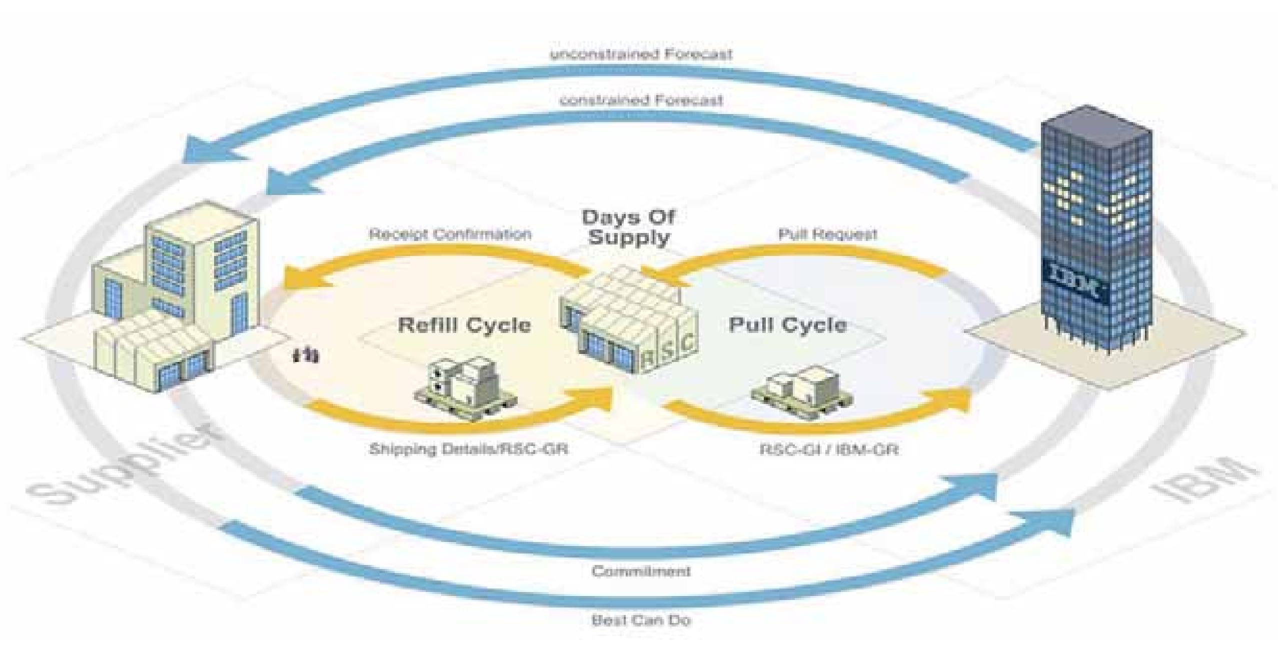

Figure 5. Data exchange model used in the replenishment process.

- short volume production
- the need to plan and execute phase-out very professionally.

The life-cycle reduction carries the risk of missing the time-to-market window as well as the appropriate management of the end-of-life timing of the product, elements that can be managed much more effectively by having a well-integrated process in place. Product development is executed by cross-functional teams following a stringent process with clearly defined rules, objectives and milestones. Figure 4 shows an example of a flow from product concept to end of life cycle. Suppliers are integrated in the product development process to leverage their expertise at key stages.

It is very important to have an E2E management process that is capable of understanding the entire chain and of reacting in a preventive way to any incidence taking place throughout the entire chain. The design principles determine the degree of supplier involvement: in this example, the process flows from white, to grey and to a black box design, as outlined below.

In the case of the white box design, the knowledge is entirely on the OEM side and also provided through the OEM into the supply chain. The grey box approach represents shared activity between the OEM and the supplier which means that the OEM still has to carry pretty much all of the knowledge of the design. The black box approach is set up so that the entire design knowledge is covered through the supplier. Such a set-up certainly requires much higher visibility on the part of the OEM into the supplier development as well as manufacturing so as not to lose track of the OEM's own technology. This is achieved by being involved not only in providing specifications, but also detailed requirements and definitions, with the necessary securing of appropriate interfacing with the OEM follow-on product and processes.

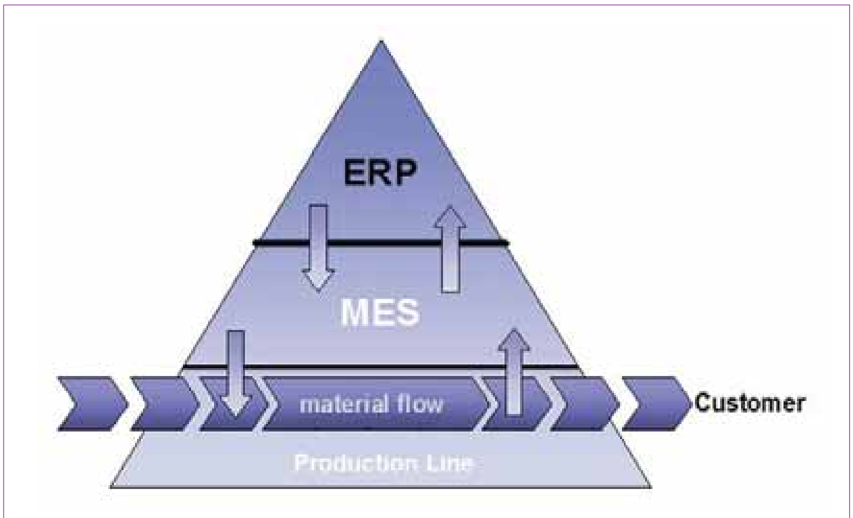

Figure 6. Typical IT structure in a semiconductor or electronic manufacturing environment.

The marketplace we are operating in is a dynamic one of ever-changing ups and downs and, regardless of the state of the market, it will always have high demands. Customers want the best price on a product with delivery as soon as possible, with the supplier holding buffer inventory up to the point of use.

How can we be responsive enough, effective enough, and keep supply chain cost low enough to meet these demands?

Effective collaboration and planning are possible using:

- Resource management
- Demand management
- Availability management
- Manufacturing alignment.

Possible benefits for the PV industry in applying process integration would be:

- The ability to outsource technology into the supply chain
  - Higher quality on supplied material
  - Better controls through supplier responsibility
  - Shared technology roadmaps and collaborative efforts
  - E.Q. technology transfer into the supply chain, such as texturing, doping, characterization (receiving COC – certificates of compliance), etc.
- Supplier involvement in development enables a joined roadmap
- Efficient equipment management on demand ('pull, not push')
  - E.Q. development speed and requirements will be determined by the solar industry, not the equipment supplier.

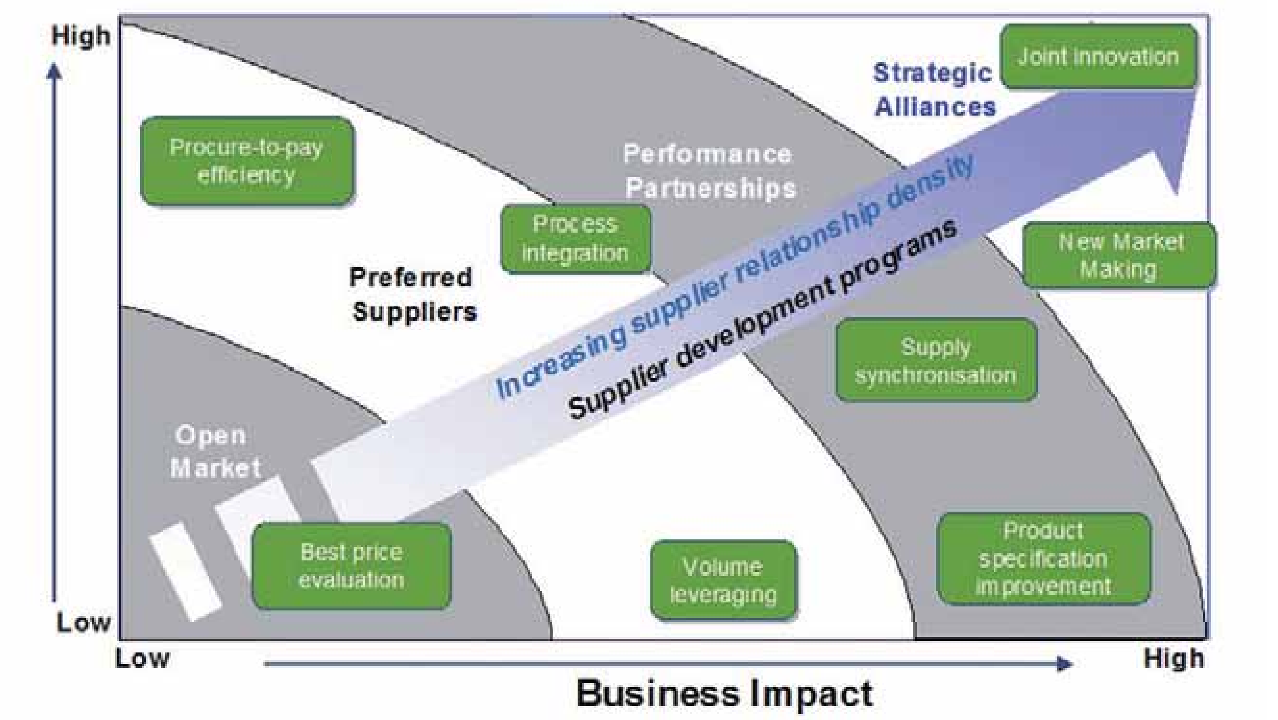

Figure 7. Supplier development framework and relationship chart.

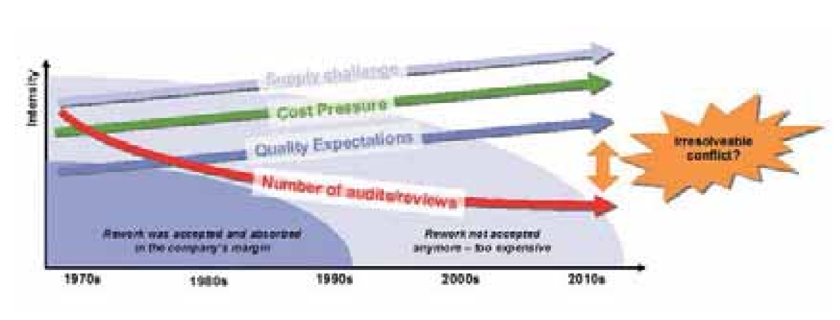

Figure 8. Cost pressure and requirement chart for supply chain management.

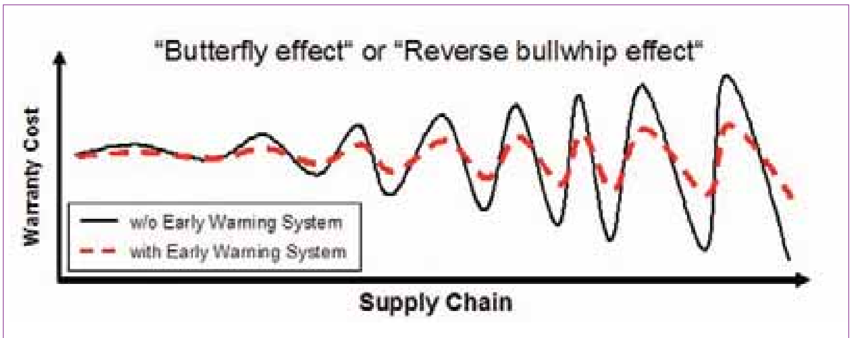

Figure 9. Example of the bullwhip effect reverberating throughout value chain.

Data exchange across the entire supply chain

Real-time data sharing and exchange is a must for visibility into the supply chain and to improve reaction time. Figure 5 gives an example of the data exchange model in the case of supplier collaboration and the replenishment process.

The data exchange in the replenishment process transformed logistics warehousing from 100% owned to 100% vendor-managed. The ability to respond to shifts of hardware demand inside quarterly lead time improved by up to 50%. Using the data exchange within the supply chain effectively necessitates a good IT structure in the manufacturing, as outlined in Figure 6. This IT structure ensures that all data from the incoming supply chain can be used to secure optimized and cost-effective manufacturing; required data is also delivered to the outgoing supply chain. The incoming supply chain, in a best-case scenario, provides all necessary data to secure the optimum quality and material availability. It also can be used to release the material into manufacturing, replacing the COC. The real-time data availability from the supply chain enables the site to work in a preventive working mode rather than a reactive mode, which typically has the disadvantage of reacting after an incidence has already occurred, or 'after the fact.' Preventive mode ensures that there is little or no damage to the production line by, for example, having failed material, or material that has not yet left the site of the supplier.

Possible benefits of applying data exchange in the supply chain for the PV industry are:

- Quality visibility throughout the supply chain
- Traceability throughout the supply chain
- Ability to transfer from reactive into preventive working mode
- Specification management and ongoing improvement
- Improvement management
- BOM management
- Technology roadmap management.

Secure material availability

A part or product may be critical for several reasons, including:

- Supply constraints
  - identified during planning cycle
  - identified during execution
  - identified by surprise
- New technologies
- Single sourced
- Unique part
- Quality problems.

State-of-the-art supply chains are no longer back-office functions – they are developed in a competitive way to

generate value. Customer satisfaction as well as growth and profit are directly impacted by superior supply chain management. Use of a tight integration model allows the OEM to plan the entire parts demand in one planning run, thus avoiding sequential planning.

There are several positive factors that may arise from applying secured material availability, which include:

- Reliability for the customer
- Improved forecasting and planning
- Tigther material and inventory management
- Improved backup structure to secure shortages (unplanned)
- Better utilization of manufacturing, especially within global business
- Speedy collaboration across the entire supply chain.

Supplier development and auditing

Managing a supply base will involve the use of different relationship strategies to support the category strategy. Determination of the appropriate type of supplier relationship provides a framework for how suppliers should be developed, managed and integrated. The relationship overview chart is shown in Figure 7.

Cost pressures and quality expectations have significantly intensified over the last few decades, and may resemble the example given in Figure 8.

How can a more complex world be managed with a reduced number of audits?

- Today's companies are faced with much higher quality expectations than they were a few decades ago.
- In parallel, pressure on cost has been a superimposing imperative.
- Due to increasing supply chain complexity and supply challenges (disaggregating and globalisation) as well as cost pressure, the number of audits had to be reduced.

The 'butterfly effect', also known as the 'reverse bullwhip effect' means that a minor incident can cause major problems (see Figure 9).

- A defective 50 cent chip from a Tier 2 electronic supplier can cause tremendous damage for the end customer and result in major warranty claims to the electronics OEM.
- A quality early warning system could have detected the defective part even before delivery from the Tier 1 supplier to the electronic OEM.

Having a better understanding and knowledge of the supply chain helps in the reduction of warranty costs. A baseline for this is to have an appropriate supplier development program in place as well as auditing, which delivers visibility and knowledge into the supply base. Performing audits ensures that the supply base is aligned with the customer requirements concerning volume, quality, timing, cost, etc.

Various audits are performed, such as:

- Technical audits with the purpose of
  - Qualifications
  - Manufacturing readiness review (MRR)
  - Quality assurance gates
  - Quality audits
  - Following-up
- Business audits with the focus on
  - Manufacturing readiness review
  - Supply chain audits.

Each of these can be performed as external or self audits. An external audit is usually performed by external resources, for example the supplier's customer or another third party, and takes the form of an audit questionnaire which is provided to the party undergoing the audit upfront. Self auditing is normally performed in-house with internal resources, and is also based on the client's questionnaire. The client receives the answered questionnaire and can follow up based on the evaluation.

Audits represent a powerful mechanism with which to assess and assure an expected level of performance in the supply chain, and can be applied in the PV industry with the following possible outcomes:

- Secure the highest quality and best cost within the supply chain; because supplier quality determines final quality, no improvements in follow-on processes are possible
- Supplier performance visibility and proactive mode capability
- Effective supplier management (prioritized)
- Secures volume-based demand and required flexibility
- Maximum mobility and accessibility.

Summary

It is of utmost importance that the supply chain is integrated with the supplier's involvement as well as the related processes. The supply chain should be improved in terms of visibility and data availability (real-time) to secure material flow at an appropriate quality level and cost. The positive numbers resulting from supply chain implementation or improvements are very significant and have beneficial effects for the financial, operational as well as the client-facing areas.

Taking the example of IBM's findings, the company saw cost and expense savings of more than 5% of the yearly revenue (calculated year-over-year for at least four consecutive years). Significant cash sums were also generated on a yearly basis in the magnitude of three-digit million dollar amounts, with further financial potential possible by altering average payment terms by one day or more.

Operational success factors include inventory standing at its lowest level in 30 years, cycle times being improved by more than 7% year-over-year, or audit records reaching the 100% level and remaining at this mark.

Client-facing success factors include significantly improved turning of client orders at greater than 30%, coupled with customer satisfaction improvements of over 2% year-over-year and significant improvements in time delivery as well as order-to-delivery cycle time, each of which saw a rise of more than 10%.

It is clear that the financial, operational as well as client-facing figures are showing outstanding improvement year-over-year, which has been enabled solely by improving the supply chain as discussed in this paper.

The PV industry stands to benefit from these supply chain advancements by enabling a much faster route to grid parity, reduction of material and process cost, improved efficiency and quality and a resulting acceleration of technology roadmaps. In conclusion, it would certainly be worthwhile to investigate how the discussed supply chain enhancements could be applied to the PV industry.

About the Authors

Rainer Krause is manager of the ISC (Integrated Supply Chain) technology centre and has worked at IBM for 13 years in positions including engineering manager for automation, test engineering and lithography. Earlier in his career, he spent several years at DEC (Digital Equipment Corporation) within the storage technology and HDD (Hard Disk Drive) development sector. His additional responsibilities in IBM include master inventor, innovation champion and member of the technical expert council and patent review board, and he is also a member of the worldwide solar council within IBM. A qualified electrical engineer, Mr. Krause also has a Ph.D. in physics.

Udo Kleemann is Senior Procurement Manager and Head of System and Technology Groups, EMEA for IBM. He has over 25 years of technical leadership and managerial experience across IBM's Integrated Supply Chain (ISC) from Production Procurement, Cost Engineering, Manufacturing Engineering to Supply Chain Management, Materials Management and Logistics. Currently serving as senior manager within the ISC EMEA Production Procurement team, Mr. Kleemann has developed and patented a supply/demand collaboration tool, RSC@. He has a Master's degree in mechanical engineering.

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Improving c-Si factory productivity and efficiency via an effective automation software strategy

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ABSTRACT

This paper presents a strategy for improving c-Si factory productivity and efficiency via software, focusing on software systems that improve yield and reduce cost. Specifically, the role of automation software systems and example areas where they can provide impact will be discussed. Key requirements of these software systems will then be identified that guarantee reusability, reconfigurability and extensibility, and thus high and continuing ROI. Case studies will then be presented illustrating how Advanced Process Control (APC) software has been successfully applied in the semiconductor and Flat Panel Display (FPD) industries to improve productivity and efficiency. The paper concludes with a roadmap for automation software implementation to support PV factory productivity and efficiency improvements.

Introduction

The c-Si industry has probably had more pressure for technology ramp-up than any other semiconductor-related industry. In addition, the technology ramp-up is taking place in an environment where economic conditions force a major focus on cost savings and rapid ROI. Luckily, the c-Si industry has many similarities to the more mature LCD flat panel display and integrated circuit industries to the extent that we can leverage productivity and efficiency capabilities along with best practices quickly into the c-Si industry. Key among these capabilities are automation software systems; automation software systems represent a largely untapped source of competitive advantage in c-Si manufacturing. The success of these systems hinges on the individual automation tools collectively providing systems that are reusable, reconfigurable, and extensible, so that the accompanying business application model can provide high and rapid ROI.

In this paper, an overview of critical automation software capabilities that can be employed collectively in c-Si manufacturing to improve productivity and yield and reduce cost is presented. Case studies will illustrate how an effective c-Si automation software strategy will allow the leveraging of these capabilities into the c-Si industry. The roadmap for automation software implementation includes a summary of the next steps that can be taken to achieve immediate ROI [1].

The role of automation software systems

Automation software systems are a key differentiator in c-Si manufacturing. As shown in Fig. 1, these software systems go hand-in-hand with lifecycle and automation and service infrastructure to deliver factory productivity and efficiency improvements while minimizing waste. An automation software system can be subdivided into three categories based on the capabilities they provide:

Manufacturing Execution Systems (MES) provide capabilities for execution of Enterprise Resource Planning production orders including scheduling, dispatch, tracking and traceability, and maintenance management.

Advanced Process Control (APC) provides capabilities for individual and overall factory process control and optimization, equipment and process diagnostics, and statistical process control.

Yield Management Systems (YMS) provide capabilities for yield performance management, and optimization, yield excursion identification and investigation, and links to design for manufacturability (DFM) systems.

Automation software systems provide benefits at the pre-ramp, ramp, production and optimization stages of manufacturing. Specifically at pre-ramp they help define manufacturing platforms and operational strategies. At the ramp stage they provide capacity plans, layout designs, supply chain management strategies and staffing plans, leveraging simulation and modelling, tracking and execution. At the production stage they provide more advanced MES, APC and YMS capabilities, as shown in Fig. 1, thereby providing a mechanism for optimization and continuous improvement of manufacturing systems.

“Automation software systems represent a largely untapped source of competitive advantage in c-Si manufacturing.”

Focusing on cell efficiency improvement during production is vital to profitability, as illustrated in Fig. 2. Experience in implementation of automation software systems in semiconductor and display

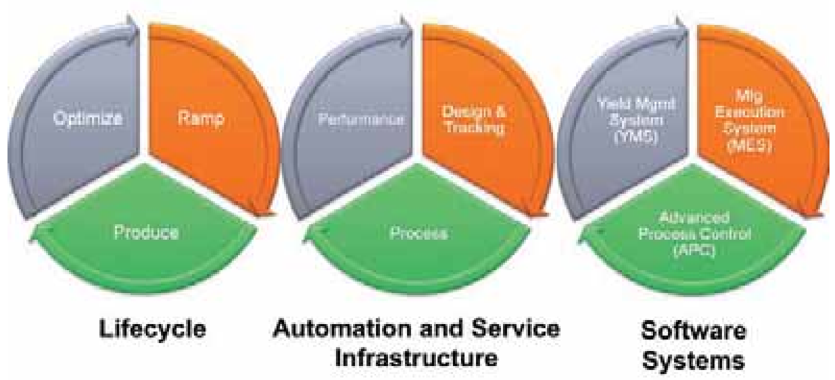

Figure 1. Factory productivity and efficiency contributors.

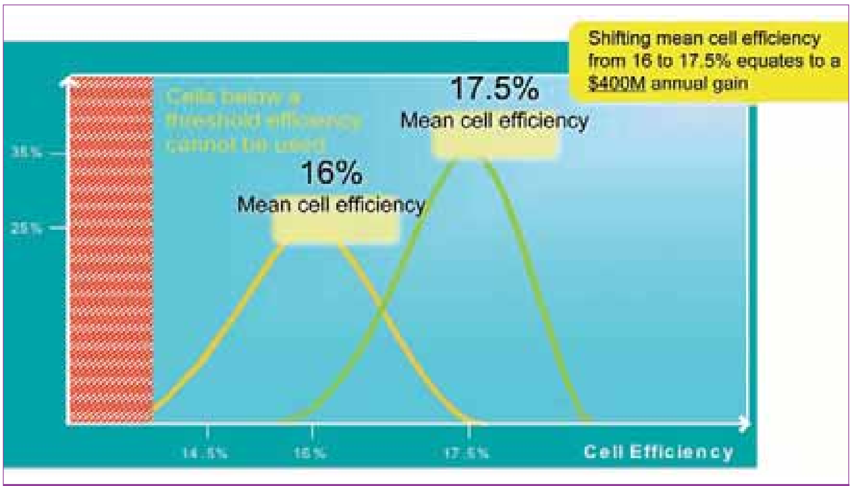

Figure 2. Utilizing APC and yield management to improve cell efficiency.

industries tells us that automation systems can be the key to maximizing this cell efficiency as well as throughput, especially as improvements resulting from hardware and automation begin to plateau. In other words, automation software systems represent an under-utilized resource that can provide c-Si manufacturers with immediate and continuing competitive advantage.

For example, c-Si factories today employ open-loop process control where cells are tested at the end of the line and then batched based on performance and colour. This end-of-line correction scheme can result in lost throughput, scrap, and, most importantly, reduced mean cell efficiency. Automation software systems (notably APC in this case) can address this problem by providing closed loop control targeting improved cell efficiency at each process.

Requirements for effective automation software systems

Achieving high and continuous ROI with MES, APC and YMS automation software systems necessitates that a number of requirements be met. Meeting these requirements should be considered as a critical part of the c-Si manufacturing roadmap [2]. Fortunately, as similar challenges have been faced previously in the semiconductor and display industries, automation software systems developed for these industries can be leveraged effectively into the c-Si industry.

The requirements focus on providing for ease of integration, flexibility, re-usability and extensibility [3]. First and foremost among them is that the *automation software solution be modular, integrated and easily reconfigurable*, allowing for rapid ramp-up of systems, but also rapid tailoring and expansion of these systems to meet the dynamics of manufacturability. As an example, Fig. 3 illustrates two approaches to software integration. In Fig. 3a, software capabilities are integrated in a point-to-point fashion, usually based

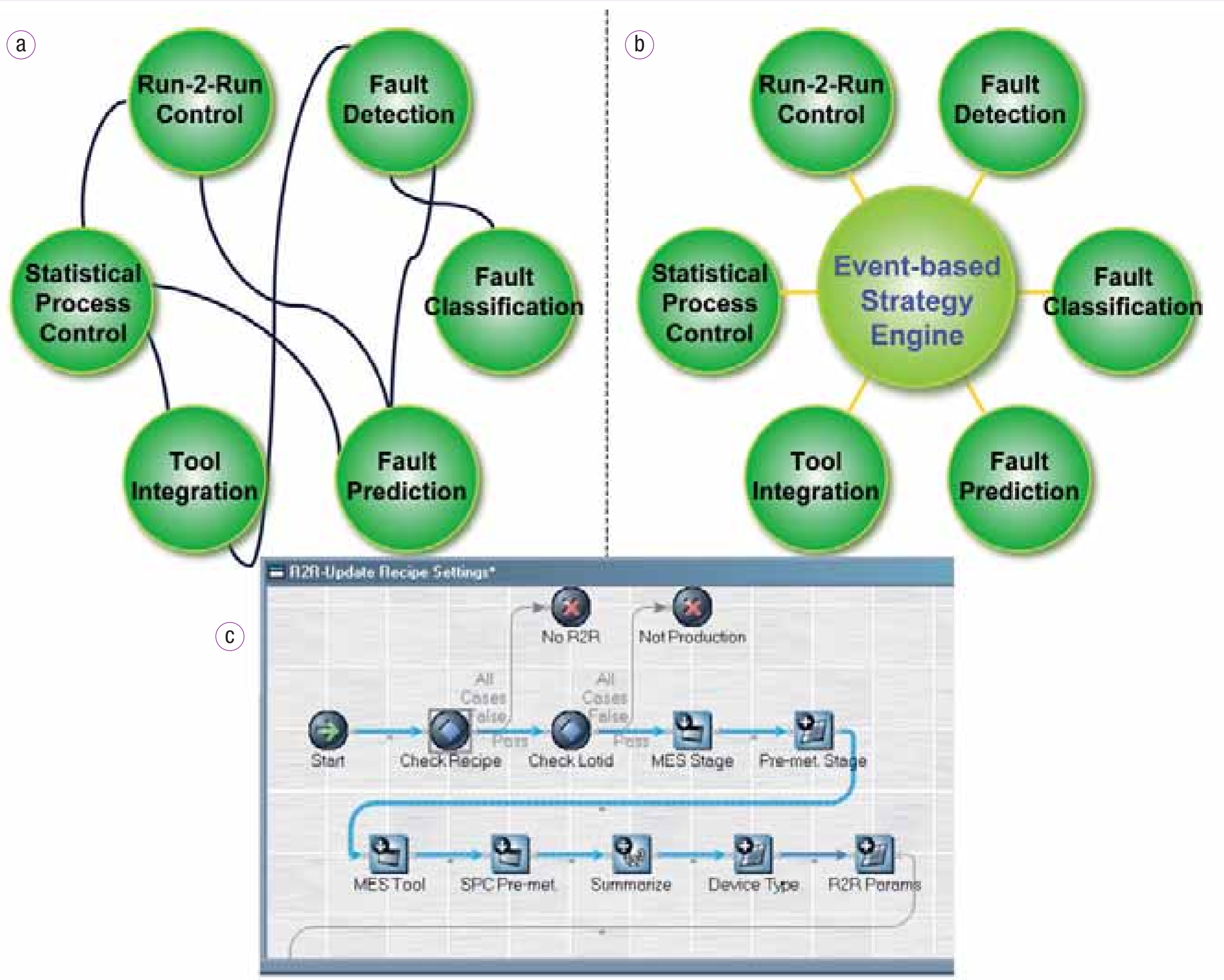

Figure 3. Approaches to software integration. Schematic 3a (top left) represents a traditional 'point-to-point' approach, while 3b (top right) represents a more flexible and coordinated approach where event-based strategies such as presented in 3c (bottom) are used to govern the interaction of software capabilities.

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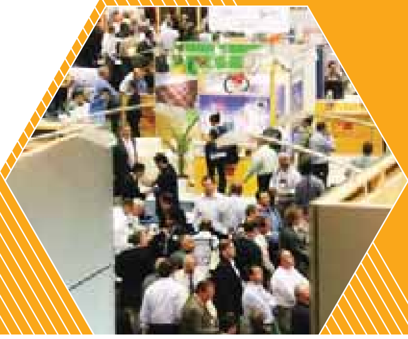

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on requirements identified in the initial stages of production. This solution is difficult to diagnose and modify, requiring cycles of integration software development and quality assurance each time a change is needed. Fig. 3b represents a solution to this problem. Software capabilities communicate in a common publish-subscribe environment via well-defined and consistent interfaces, and event-based 'strategies' define the collaborative interaction of these capabilities to provide manufacturing services are developed and maintained graphically (Fig. 3c), requiring no software programming during re-configuration.

Consolidation of data, objects, naming conventions, etc., among the software capabilities further simplifies the automation software development and maintenance process. The 'event-based strategy' also provides a streamlined knowledge-base system for capturing learning so that knowledge gained can be quickly incorporated as best practices; specifically, the software strategies serve as a graphical tool for conveying and implementing these best practices throughout the manufacturing employment structure. Note that this approach to manufacturing software has been proven effective in both semiconductor and display industries [4, 5].

A second key requirement for automation software solution effectiveness is *adherence to a standardized environment for software-to-hardware and software-to-software integration*. For example, adherence to the SEMI SECS/GEM (SEMI Equipment Communication Standard/Generic Equipment Model) E30 communication standard for all manufacturing equipment will simplify the equipment integration and automation process, reducing unnecessary duplication of effort, and enhancing capabilities for re-usability and diagnosability. Adherence to the Process Control System (PCS) E133 standard for APC software integration allows APC systems to more readily share information and leverage each other's capabilities. SEMI has dedicated significant resources to leveraging the semiconductor manufacturing standardization approach and results into the solar manufacturing industries. Many semiconductor equipment automation standards are being considered for adoption in the solar manufacturing industries with some such as E30 already being adopted [2, 6].

A third requirement is the *utilization of sensors and metrology*. A key to automation software system effectiveness is its ability to view and understand its environment. Metrology systems enable a key process control capability that can be directly linked to improved process capability and improved yield, while maximum utilization of equipment sensory information ensures an optimal capability for equipment and process diagnostics so that scrap and equipment downtime can be minimized. Note that both hardware 'real' and 'soft' (i.e., 'virtual') sensor and metrology systems should be considered [4].

Other important automation software requirements include: 1) integration and consolidation of data management; 2) integration and consolidation of data visualization – often termed 'dashboard'; and 3) proven track record of application in similar industries [3]. Delivering on these requirements will result in an extensible automation software framework upon which key software capabilities can be integrated.

At the software management level there is an additional requirement that a *software services capability* be maintained. As the advantages of software systems are realized, they will become an increasingly large portion of the total manufacturing solution, and will be the source of a large percentage of manufacturing innovations that lead to competitive advantage. The deployment, growth, and tight integration of software systems into the manufacturing process needs to be managed so that costs are minimized, focus on a consistent and extensible architecture is maintained, and individual software efforts necessarily roll up to a consistent enterprise-wide software strategy.

Key automation software capabilities

Fig. 4 provides a summary of automation software capabilities that should be leveraged into c-Si manufacturing production. At the data generation level, standards can be utilized to maximize re-usability in tool and metrology integration. Metrology can be in-line or off-line, real or virtual (as noted earlier). Data collection should be of a sufficient rate so as to be able to capture excursions that result in downtime, scrap and lost yield.

At the process monitoring level, APC capabilities should be leveraged to provide for process monitoring and optimization [3, 6], and include:

Statistical Process Control: a capability that utilizes a set of rules applied to data

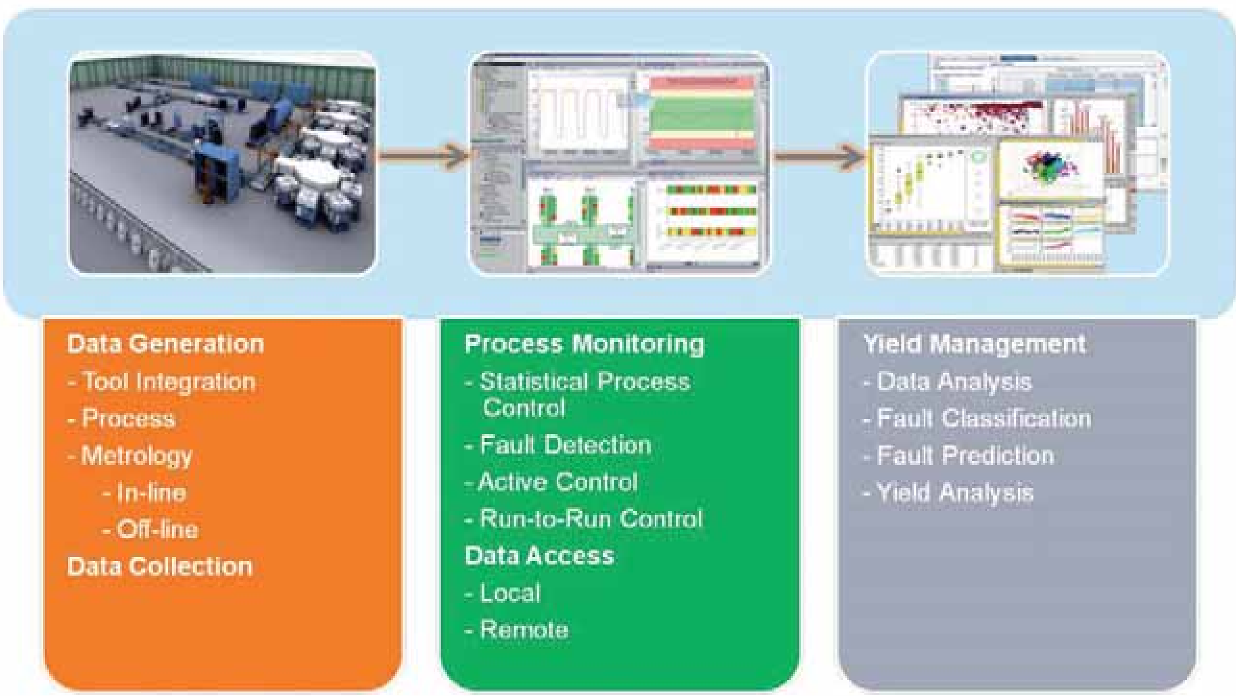

Figure 4. Software capabilities that should be leveraged into c-Si production to support factory productivity and yield improvement.

sets to detect statistical anomalies. These anomalies can then be related to specific equipment or process problems to be addressed.

Fault Detection: an automated equipment and process heath monitoring capability that utilizes equipment data collected during run-time along with a number of analysis techniques to determine the health of the equipment and/or product. It can provide alarming information as necessary to avoid scrap and unnecessary equipment downtime, and convert unscheduled downtime to scheduled downtime.

Run-to-run Control: a model-based control capability that provides for continuous process tuning via run-to-run process recipe adjustment to optimize the process to productivity goals.

APC capabilities developed, customized for, and proven in both the semiconductor and display industries can and should be directly leveraged into c-Si manufacturing facilities.

At the yield management level, Fault Classification allows for fault detection indications, realized at the process monitoring level, to be linked to specific causes or classifications so that appropriate maintenance activities can be readily scheduled, thereby reducing mean time to resolve (MTTR) and the incidence of low yield production.

Fault Prediction additionally allows the utilization of Fault Detection and Classification information to support proactive or preventative maintenance, further reducing MTTR. Finally, Yield Analysis allows for the identification of and investigation into yield issues.

All of these automation software systems contribute to improving c-Si factory productivity and efficiency; however, their effectiveness is significantly enhanced if these systems work together collectively towards factory productivity objectives. Provision of the flexible integration environment along with software services to guide this integration is thus key to obtaining maximum ROI from these automation software systems.

Automation case studies

In this section, select case studies of software implementation in the display industry focusing on the utilization of APC software capabilities are highlighted. As noted earlier, c-Si manufacturing should leverage automation software capabilities in both the semiconductor and display industries as these industries have or have had very similar productivity and/or efficiency issues as part of their maturation process. Reviewing case studies in these industries is an important part of the software evaluation process for c-Si. The particular case studies presented here focus on first illustrating success in the semiconductor industry, and then applying capabilities proven in the semiconductor industry to the display industry. In a similar fashion, all of these automation capabilities could be applied to the c-Si manufacturing industry. In implementing each of these solutions, the Applied E3 equipment automation and APC software solution was leveraged. This software meets the requirements of integration, flexibility, re-usability and extensibility, and thus the cost side of the ROI equation is minimized.

Fault detection and R2R control in semiconductor manufacturing

In these case studies, typical applications of APC capabilities are presented for semiconductor manufacturing [5]. The fault detection capability is often used to detect problems that lead to lost product. In the case study presented in Fig. 5a, a phenomenon called 'etch arcing,' which can be very destructive to product, is detected. Direct detection of etch arcing is very difficult because extremely high sampling rates are needed to catch the DC bias arcing spikes. In this example, the arcing is detected indirectly by monitoring Optical Emissions Spectroscopy (OES) of the etch chamber plasma. The OES intensity profile at a particular wavelength is different if arcing has occurred, indicating that the photo-resist by-product has been created. A windowing tool of the FDC system allows for high-resolution zeroing-in on this feature so that an arcing fault can be clearly determined.

Fig. 5b summarizes a case study of a common application of run-to-run control that generates high ROI via improved process capability. In this case, a Cpk improvement of over 50% is achieved by applying run-to-run control to a lithography process to reduce process variability and better centre processing to recipe targets.

Fault detection in display manufacturing

In this case study, a display manufacturer that makes 42" and 47" TFT-LCDs, flat TVs and monitors, had an issue with glass centre strain and particulates. Working with APC software, they determined that the root cause was a leak: specifically, a cooling block caused a break in ceramic due to temperature differences, which in turn caused a ring type of strain on the glass. The E3 software was configured by setting up the automation component to automatically collect data from the equipment during processing. A Fault Detection software strategy was configured (graphically) to analyze equipment data, detect conditions related to the fault, and provide alarm notification to engineers when the fault conditions first appeared. The engineers were then instructed to shut down, repair and requalify the equipment.

As a result of implementation of the E3 APC system in this case, the incidence of scrapped glass was reduced from 22 substrates per every four lots (approximately 25%), to less than one substrate, which signifies a scrap reduction of over 95%. Considering that the raw glass costs US$1500 and the finished glass costs US$3000 per unit, and that the manufacturer makes about 90,000 panels per month, monthly savings from scrap reduction alone ranged from US$3.2 to US$6.4 million. Additional ROI is achieved from increased productivity by detecting and eliminating scrap, and reduced downtime as a result of identifying specific maintenance issues and instructing maintenance engineers appropriately, thus reducing MTTR.

Run-to-run control in display manufacturing

This case study saw a display manufacturer employ E3 automated run-to-run

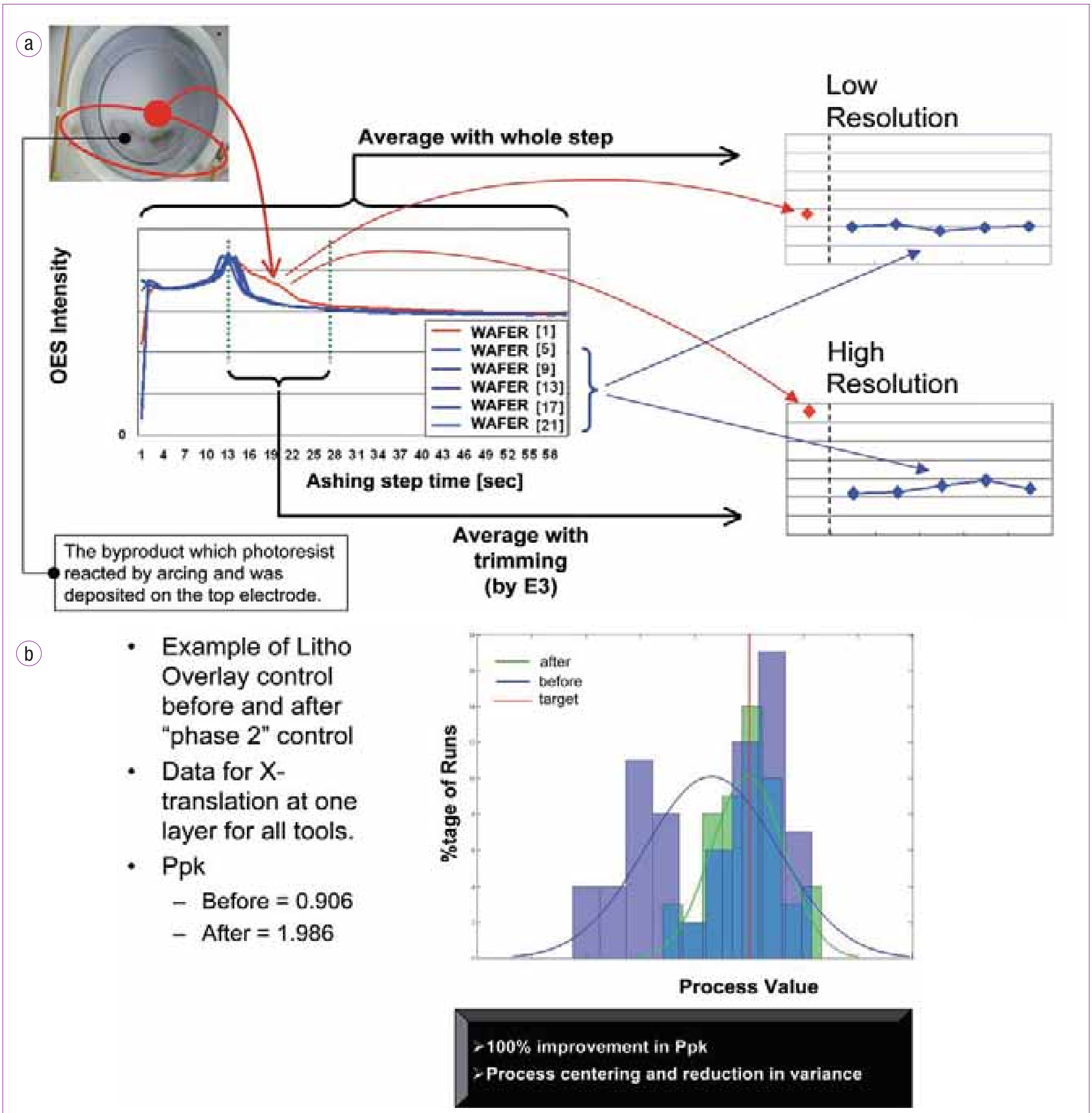

Figure 5. Illustration of application of APC capabilities to semiconductor processing. In 5a (top), etch arcing is detected using fault detection resulting in reduced wafer scrap (of future wafers). The graph in 5b (bottom) shows results of run-to-run control being applied to a lithography process resulting in over 50% improvement in process capability (Cpk).

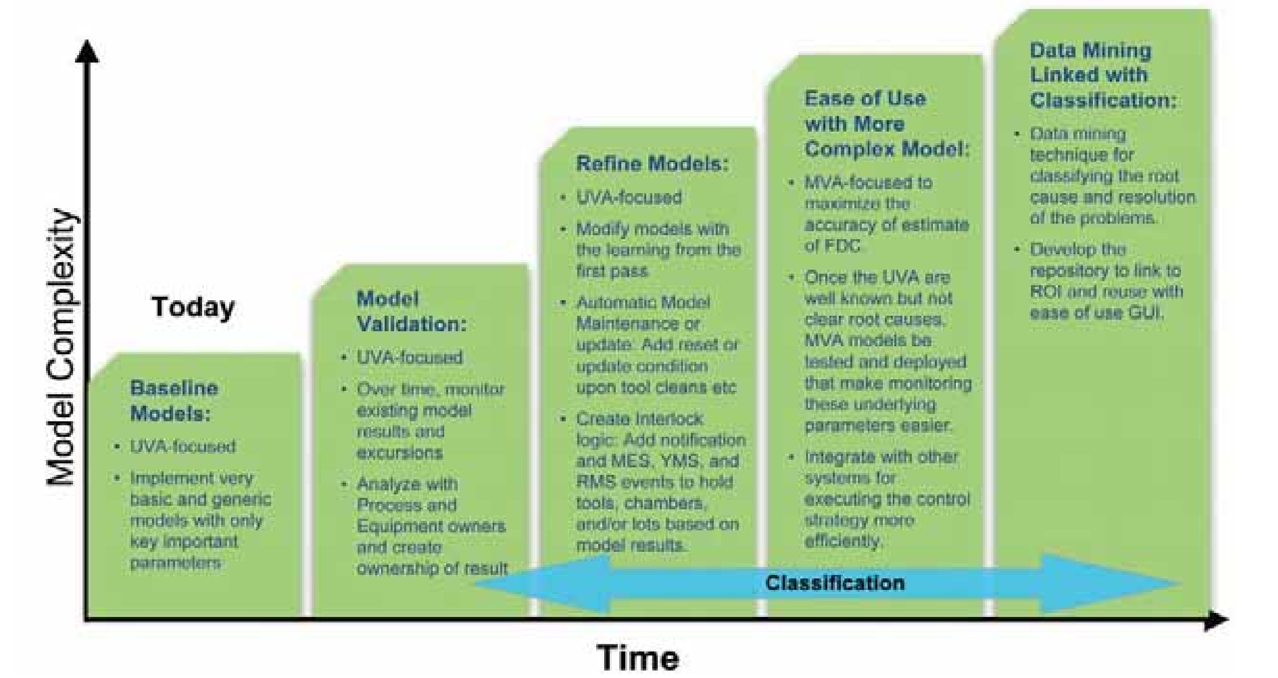

Figure 6. Automation software system implementation strategy and roadmap.

process control on a photolithography process. Prior to application of this control, tool operation was achieved by manual adjustment of equipment recipes, which resulted in lost productivity due to time taken to make equipment recipe adjustments, and which required an operator resource to implement the recipe adjustments. With the implementation of automated run-to-run process control, idle time due to recipe adjustment was virtually eliminated as was the need for operator time to support recipe adjustment. The resulting monthly cost savings are approximately US$2900 (due to savings in personnel) + US$36,300 (due to increase in throughput) = US$39K savings per month per equipment. Additional ROI is achieved from increased process capability and reduced variability of the process achieved from application of process control.

Moving forward: a roadmap for PV factory productivity and efficiency improvement

Automation software systems implementation in c-Si manufacturing represents a potential continuing ROI opportunity for many years to come. As with any software implementation strategy, basic requirements (as presented earlier) should be adhered to so as to allow the automation software solutions to evolve as manufacturing practices mature, and software services should be utilized to guarantee adherence to these requirements on a common extensible framework.

It is also important to start with simple implementations on this framework so that immediate ROI can be achieved. Fig. 6 illustrates a sample automation software system strategy, showing gradual implementation of more complex capabilities after baseline capabilities are implemented and proven. Today's systems should be aligned with these baseline capabilities. These include simple univariate (UVA, one input to one output relationship) models, fault detection only, and focus on basic diagnostic and control models. Such models should be validated to verify approaches and best practices and to establish a baseline from which models can be refined and more complex models such as multivariate (MVA, multiple input to multiple output relationships) can be developed. Fault detection schemes can also be linked to fault classifications and maintenance events, and ultimately solutions can move from reactive fault detection to more proactive fault prediction and predictive maintenance.

The key is identifying a strategy for long-term cost of ownership that continually leverages an extensible automation software system for the collaborative integration of new capabilities as the manufacturing environment matures. In this way, COO is minimized and the full ROI of each automation software capability can be realized as it is incorporated into the factory.

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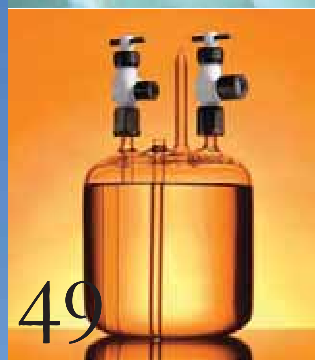
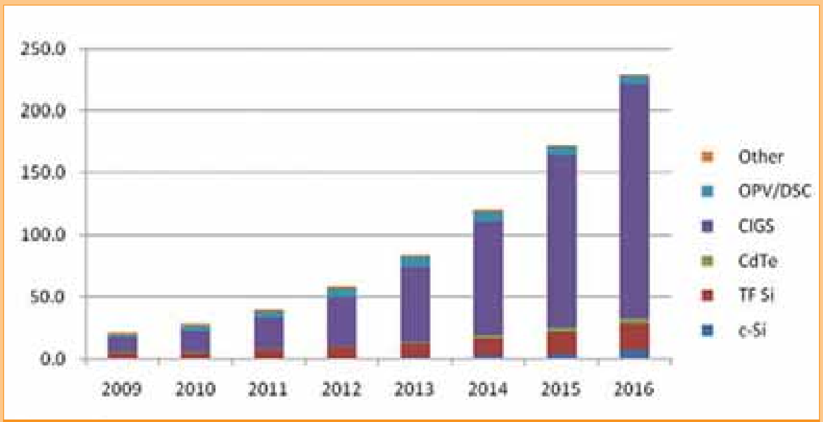
Materials



NanoMarkets report: CIGS growth not limited by indium supply

Often touted as the next thin film technology to take on cadmium telluride thin film leader First Solar, CIGS technology is set to grow and the use of indium, a key absorber material will grow even faster. In a new report from NanoMarkets entitled 'Indium Markets for Photovoltaics,' indium consumption is expected to rise 80% by 2016, equating to 228 metric tons (MT) in 2016, up from the 20MT consumed today. However, the market research firm is forecasting that CIGS PV cells would represent only 8% of PV megawatts in that time.



Source: NanoMarkets, LC

Indium consumption by the PV industry (metric tons).

Unlike the concerns raised over the last few years as to whether there was enough tellurium to meet demand from CdTe PV production, NanoMarkets doesn't see any shortage of indium to limit CIGS growth.

Paul Markowitz, Senior Analyst at NanoMarkets said that the indium market would prove volatile from a pricing perspective as it takes several months to develop new indium capacity. Furthermore, demand spikes can significantly outpace supply, though temporary and not indicative of an actual long-term shortage.

NanoMarkets expects a change over time away from the use of sputtering targets and evaporation slugs as lower-cost deposition methods develop. The market research firm expects a shift towards indium salts for electrodeposition and nanoparticles of indium, indium selenide, and indium oxide inks for printing. Printing and electrodeposition will represent close to 28%, or 52.3MT, of the total indium consumption for CIGS PV in 2016.

Indium consumption for ITO in the PV industry is expected to grow from 13MT in 2011 to 39.4MT in 2016.

Wafer News Focus

LDK Solar updates outlook for second quarter 2009

LDK Solar, manufacturer of multi-crystalline solar wafers, has provided an updated outlook for its second-quarter 2009 financial results.

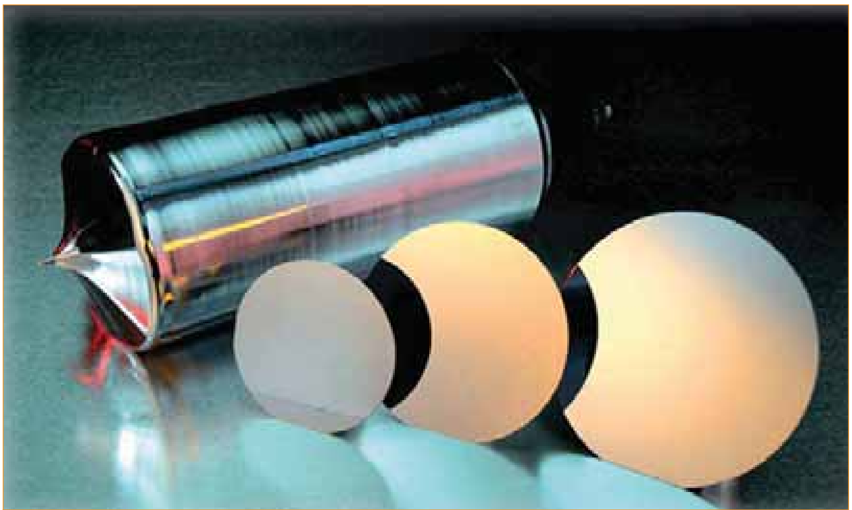
LDK expects to report between US$225 million and US$235 million in revenue, slightly above the recently announced estimated range, and wafer shipments between 230MW and 240MW.

The company also expects to record US$150-$160 million against the cost of inventories for a decline in net realizable value of inventories resulting from the continued market price decline for solar wafers. As a result, the gross margin is expected to be negative with a net loss of US$180-$200 million in the second quarter.

Solar-grade wafer maker SAS to add 80MWp capacity

Taiwan-based Sino-American Silicon Products (SAS) has announced that it will expand its annual production capacity of crystalline silicon wafer capacity by an equivalent of 80MWp to 360MWp in total. Industry sources in Taiwan said that additional capacity was to be set up at a newly completed factory in northern Taiwan at the end of July 2009.

SAS originally planned to add 100MWp at the new factory, but delayed installation of equipment when the factory structure was completed at the end of March 2009. This delay was mainly due to weakened demand in the global PV market.



SAS silicon ingot and wafers.

Chemical and Gases News Focus

XeroCoat taps Air Liquide Electronics to supply delivery systems for solar antireflective coatings

XeroCoat has chosen Air Liquide Electronics U.S. to supply the precision chemical delivery systems for XeroCoat's turnkey antireflective coating platform for glassmakers and end-users in the solar manufacturing industry.

"Our partnership brings customers an innovative antireflective coating (ARC) solution from XeroCoat that increases solar system efficiencies together with a proven worldwide supplier of chemical delivery systems", said Thomas Hood, XeroCoat's President and CEO.

XeroCoat's turnkey coating system.

"XeroCoat has selected a partner that is well-established in the solar industry to make our turnkey antireflective coating systems even more cost-effective and easier for our customers to adopt".

Calling his company a "recognized leader in supplying and distributing gases and liquids with high-performance, cost-effective delivery equipment for the solar industry," Dave LeBlanc, President of Air Liquide Electronics, said that "the combination of XeroCoat's antireflective coating technology and Air Liquide Electronics' chemical systems expertise aligns well with our growth strategy of closely aligning to our customers' needs to develop new markets with innovative applications using new technologies."

Crystalline silicon and thin-film PV, concentrating PV, and solar thermal module, device, and glass manufacturers can integrate XeroCoat's antireflective coating system into their production processes, enabling the processing of a high-performance ARC using the Redwood City, CA-based company's patented methods.

XeroCoat says that by using its ARC technology – which is compatible with existing manufacturing processes throughout the supply chain – solar module makers can expect a 3% increase in peak power output and a 4% increase in energy produced on a kilowatt-hour basis.

XeroCoat also recently won a pair of government grants. The company scored funds from the Australian Climate Ready program to develop antisoiling technologies for solar modules' cover glass, while a grant totaling US$2.96 million from the U.S. Department of Energy's Solar Energy Technologies Program has been designated for a project to commercialize an ARC that can be applied on finished rigid-glass and flexible substrate PV modules.

Targray to supply Peak Sun phosphorus oxychloride to North American, other solar markets

Targray Technology has signed a long-term partnership agreement with Peak Sun Silicon for the exclusive supply of the highest quality phosphorus oxychloride ($POCl_3$), a high-purity liquid phosphorus used as an N-Type dopant for silicon wafers. Under the terms of the deal, Targray becomes the exclusive supplier of Salem, OR-based Peak Sun's $POCl_3$ to the North American, European, Indian, and Australian solar markets.

"The Peak Sun $POCl_3$ is the highest purity $POCl_3$ available to the solar-cell manufacturing industry today," states Jack Bardakjian, product manager at Targray. "Peak Sun is not only committed to manufacturing the best $POCl_3$; the five-star grade has even lower levels of trace elements than the standard grade. For manufacturers, this means better bin distribution and improved minority carrier lifetimes, which contribute to higher efficiencies and a lower manufacturing cost per watt."

First Solar and 5N Plus extend materials supply deal

High-purity metals and compounds supplier 5N Plus has amended the materials supply contract with First Solar to run for an extra year to the end of July 2013. The companies have also agreed to increase the minimum amount of cadmium telluride (CdTe) ordered by First Solar by 50%.

5N Plus supplies cadmium telluride and cadmium sulphide to First Solar for use in the company's thin-film modules. The agreement was amended in August 2008 to extend the original deal to run until 2012, and also included a 50% minimum order increase.

Sanyo awards bulk argon, nitrogen supply contract to Praxair Electronics

Praxair Electronics has been tapped as supplier of bulk argon and nitrogen for Sanyo Electric's new ingot and wafer manufacturing facility in Salem, Oregon. Sanyo is aiming to have the new 70MW plant, located in Salem's Renewable Energy and Technology Park, in operation by October 2009 and to be in full operation by April 2010.

"Praxair provides gases and sputtering targets to over 40 photovoltaic component manufacturers around the world," said Mark Murphy, President, Praxair Electronics. "We are pleased to have been selected to supply argon and nitrogen to SANYO

Electric's new state-of-the-art facility in Salem and to continue our contribution to alternative energy market growth."

Polysilicon News Focus

Timminco receives CAD$25 million in financing

Timminco, a 52.2% owned subsidiary of AMG Advanced Metallurgical Group N.V., has revealed that Becancour, Timminco's subsidiary, has signed a loan agreement for the amount of CAD$25 million. The two-year term loan, which is being provided by Investissement Quebec, will be used for general working capital purposes, according to the company.

The funding will be disbursed in full in the coming week, and is subject to a variable interest rate of prime plus 9%, which is currently 11.25% per annum. The loan agreement stipulates several factors in relation to Becancour Silicon, including a minimum working capital ratio and a maximum long-term debt to equity ratio.

Solar PV wire-saw toolmaker Meyer Burger to acquire Diamond Wire Technology

Meyer Burger is buying all the assets of Colorado Springs-based Diamond Wire Technology. The two companies have been cooperating in the marketing and development of diamond wire used for slicing silicon for the photovoltaic industry since 2003.

Diamond Wire Technology's multi-wire saw

Specifics of the monetary amount of the cash and shares transaction, expected to be completed in September, were not disclosed.

Meyer Burger says it believes the use of DWT's diamond wire technology in combination with its own slicing and wire saws will provide its customers with a significant and decisive technological edge, and help them to achieve a reduction of the total costs of ownership in wafering.

"By expanding our technology portfolio with diamond wire, we once again contribute to a substantial reduction of the manufacturing costs of solar cells for the industry," says Peter Pauli, CEO of Meyer Burger. "Together with DWT we have a lot of experience, innovative power and market strength to introduce this technology in photovoltaics quickly and sustainably."

REC Group sells Solar Vision in South Africa

South Africa-based solar panel and component provider Solar Vision, a former wholly-owned subsidiary of REC Group, has been sold through a management buyout. Following the decision that Solar Vision was no longer considered to be a core business for the Norway-based company, the Solar Vision was divested through a management buyout.

Solar Vision, a major player in the PV rural electrification segment in South Africa, is now part-owned (76%) by Jakes Jacobs, Managing Director of Solar Vision, and is acquired through his South African company Triple J Trust; former REC employee Tommy Fernandes, through his Norwegian company InSite International AS, acquires the remaining 24% of shares.

It is expected that Solar Vision will retain its focus on low-cost solar systems deployment, but will also look to diversifying its peripheral activities.

ReneSola enters Phase 1 trial production at Sichuan poly plant

Adhering to its planned timeline announced earlier this year, ReneSola has commenced trial production on its first batch of polysilicon. The two-phase facility will see the production of 3,000 metric tonnes of polysilicon following the scheduled completion of Phase 2 in September 2009. The facility, located in China's Sichuan province, uses the Siemens process and a closed loop system for polysilicon production.

Mr. Xianshou Li, ReneSola's CEO said, "As an integral part of our vertical integration strategy, this state-of-the-art facility is designed to enhance our competitiveness as we benefit from cost synergies associated with upstream integration. The production output from this new facility will provide us with a stable, cost-effective flow of polysilicon as we strengthen our position as one of the world's leading, low-cost, fully integrated solar companies."

GCL-Poly acquires 100% stake in Jiangsu Zhongneng

GCL-Poly Energy Holdings, a leading integrated renewable energy enterprise in the People's Republic of China (PRC), has announced the approved acquisition of 100% equity interest in Jiangsu Zhongneng Polysilicon Technology Development. Upon completion of this contract, GCL-Poly looks set to become a global leader in the polysilicon manufacturing industry.

Jiangsu Zhongneng is the main operating entity of GCL Solar Energy Technology Holdings (GCL Solar) in the PRC. GCL Solar's annual polysilicon production capacity is expected to reach 18,000MT by the end of 2009, with further technical upgrades, its capacity will further expand to 21,000MT by the end of 2010, making GCL Solar also one of the world's five largest polysilicon suppliers.

Mr. Zhu Gong Shan, Chairman and Executive Director of GCL-Poly, said, "Upon completion of the acquisition, GCL-Poly will benefit from GCL Solar's extensive experience in the production of polysilicon to tap into opportunities in the fast growing solar industry. In addition to manufacturing and selling polysilicon, we also plan to leverage our strengths and expertise to engage in downstream businesses, including the development of solar power plants and the production of silicon ingots and wafers. These initiatives will create synergies through vertical business integration."

Deposition reactors at Hoku's Pocatello, Idaho polysilicon manufacturing facility

Financial problems plague Hoku's polysilicon plant

Hoku Scientific has detailed its challenging financial condition as it struggles to raise a further US$106 million to fund the estimated US$390 million construction budget of its polysilicon plant in Pocatello, Idaho. Executives warned that if the fundraising proved unsuccessful it would put the future of the entire company in jeopardy.

Hoku has been hit by a credit crunch, while its revenue has seen a significant fall in demand for PV systems and a rapidly declining polysilicon process as new capacity come on-stream. The company has had to adjust long-term supply deals and seek new customers that are prepared to provide multi-million dollar deposits so that Hoku can continue to finance plant construction and business operations.

Hoku has also been forced to scale back the original polysilicon plants capabilities, such as trichlorosilane (TCS) production, which will now be supplied by a third party. Even reactor testing and initial small production runs have been pushed out to conserve cash.

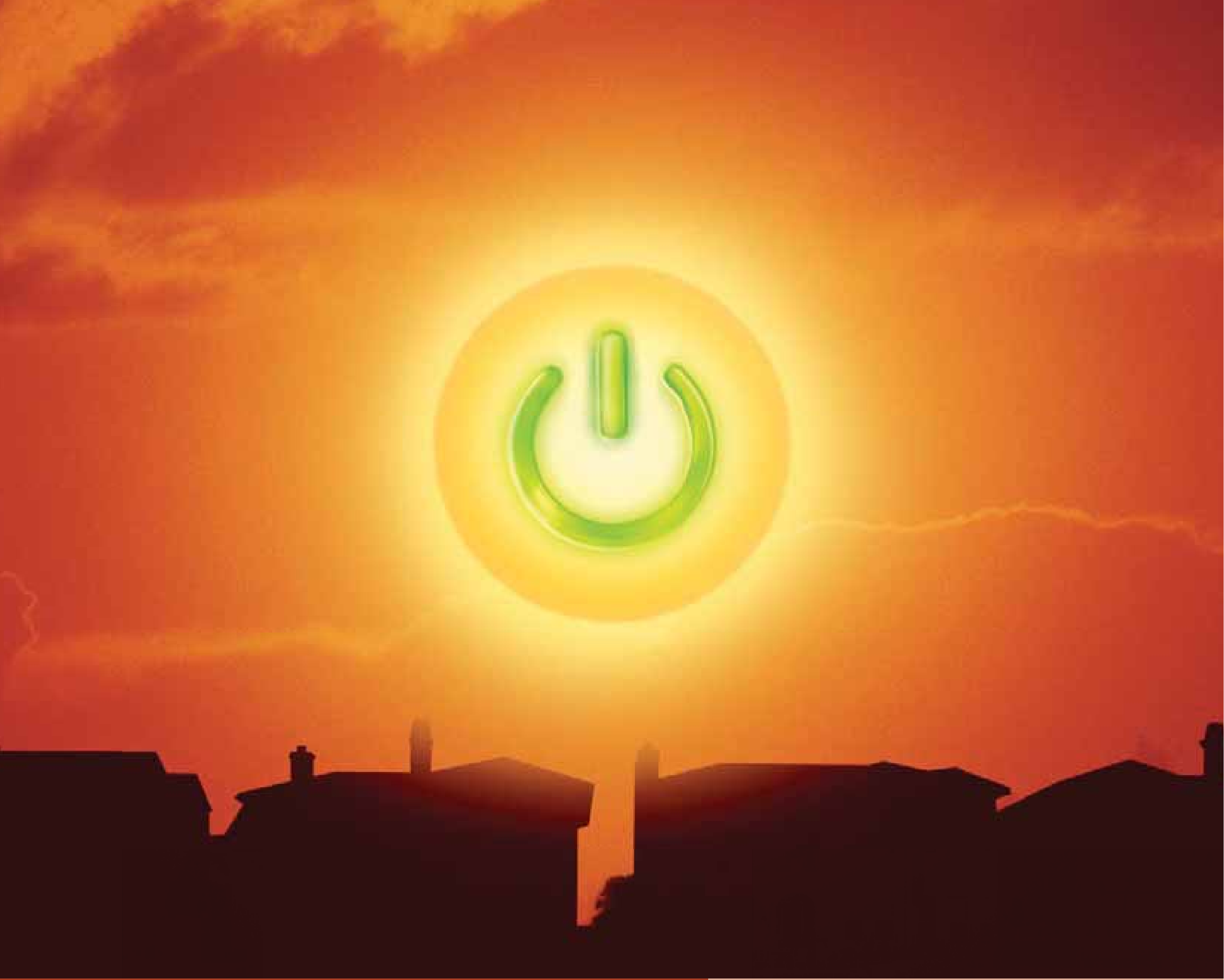
The company said that it would continue to seek new funds, which were hoped to come from new long-term customers as well as seek alternative forms of fund raising. Some of Hoku's polysilicon supply contracts were to start in the second half of 2009, which may force the company to purchase polysilicon on the spot market to meet obligations.

Solarvalue returns to the drawing board over UMG silicon viability

UMG silicon hopeful Solarvalue has cancelled its upgraded metallurgical grade silicon (UMG-Si) supply contract with Moser Baer Group. Their UMG-Si method was to be expanded into full-scale UMG production at its Slovenian manufacturing site, but Solarvalue has not been able to achieve required purity levels in laboratory tests. In addition, UMG and polysilicon prices have declined substantially, making current production processes economically unrealistic.

However, the company is not giving up on the endeavour. Solarvalue said they would develop a new process and a new

GCL Solar fab.



economic feasibility model, all to be evaluated at a different laboratory. The required funds are in hand for these tasks.

Solar silicon producer Timminco shows weak shipments, plans to reduce production, headcount

In an operational update, Timminco said it produced 243 metric tons of solar-grade or upgraded metallurgical silicon (UMSi) from three purification lines out of an available seven lines. The company shipped 34 metric tons in the quarter, at an average selling price of US$39 per kg.

In light of continuing weak demand for UMSi and its plan to maintain production at levels in line with customer orders, the AMG subsidiary said it is temporarily reducing its production to one purification line. This move should allow the Canadian company to further preserve working capital and save costs by temporarily reducing headcount by as many as 60 employees.

Timminco said it expects to resume production of UMSi on the idled purification lines, once demand recovers.

Silicon rocks.

Unidym module.

LDK Solar multicrystalline ingot weighs in at 600kg

LDK Solar has passed a milestone in its ingot production with the successful output of a multicrystalline ingot weighing 660kg. The largest ingot produced to date by the company, the block's weight is an increase of 46.7% on the standard ingot weight of 450kg. The company's maximum furnace capacity is 800kg.

"We reached an important milestone on the roadmap of our technology development for multi-crystalline silicon ingots," said Dr. Yuepeng Wan, LDK's CTO. "We have continued to develop technology aimed at solidifying and augmenting LDK Solar's cost leadership position. Our objective with this development was to improve product quality and at the same time decrease the cost of multicrystalline ingot production. The larger ingots will lower capital expenditure and contribute to the reduction of production cost. The increased charge size directly contributes to lower power consumption, higher yields, improved efficiencies of downstream processing equipment, and reduced unit consumption of consumables and some direct costs."

AU Optronics to purchase majority share in major Japanese polysilicon producer

Taiwan based AU Optronics Corp is to make an initial US$125 million investment in Japanese polysilicon producer, M.Setek with the aim of gradually becoming the majority shareholder in the company as it makes a move to strengthen its position in the renewable energies market.

"This will mark a major step forward for AUO's endeavor in energy business," said K.Y. Lee, Chairman of AUO. "We are very much looking forward to collaborating with M.Setek, jointly bringing greater inputs to solar energy sources and providing better renewable energy solutions."

In May, 2009 AU Optronics established AUO Energy Taiwan Corp (AET), with the intention of becoming an integrated renewable energy provider.

M.Setek is currently the seventh largest polysilicon producer in the world and has aggressive capacity expansion plans in place to reach over 30,000MT production by 2012. If the project is successful, M.Setek would become the third largest producer by the end of 2012.

Product Briefings

Targray Technology

Targray's 'Peak Sun' dopants contribute to higher cell conversion efficiencies

Product Briefing Outline: Targray Technology now offers the Peak Sun $POCl_3$, which is claimed to be the highest purity N-type dopant available. Phosphorus Oxychloride ($POCl_3$) is liquid phosphorus used as an N-type dopant in the diffusion process for silicon wafers. Peak Sun's high purity 99.99999%, 7N, reduces variability in bin distribution, increases minority carrier lifetimes which contribute to higher conversion efficiencies (CE) and provides consistency in the diffusion process – all of which contribute towards a lower manufacturing cost per watt.

Problem: Impurities such as titanium, molybdenum and vanadium are known to reduce minority carrier lifetimes, thus affecting the efficiency of the cell. Impurities trap electrons and reduce minority carrier lifetime in cells and research indicates these have the most detriment on solar cell performance.

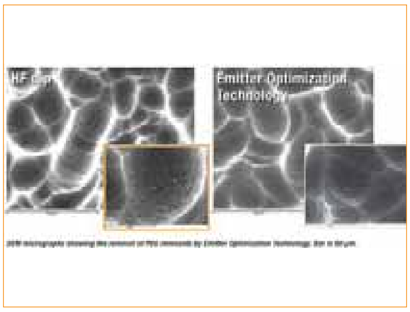
Solution: Peak Sun's $POCl_3$ distillation process was designed to reduce levels of trace elements and other impurities in metals such as titanium, molybdenum, and vanadium that are known to cause problems in the solar cell manufacturing process and are harmful to carrier lifetime. Higher purity means longer minority carrier lifetimes. Break seal technology guarantees the integrity of the chemical by keeping impurities out during transport and storage. The chemical is manufactured in a facility that assures no cross contamination and it is tested for purity in a Class-100 clean room.

Applications: N-type dopant in tube diffusion processes for silicon wafers and formation of the N-Type emitter of P-N junction and to getter impurities in 6N mono- and multicrystalline solar cells.

Platform: Peak Sun $POCl_3$ is available in industry standard 1.5L quartz bubblers fitted with "breakseals" to ensure product integrity. These bubblers are compatible with all current makes of temperature controllers and tube diffusion furnaces. Containers for bulk distribution systems are also available.

Availability: Currently available (excluding Asia).

Mallinckrodt Baker



Surface modifiers from Mallinckrodt Baker boost solar cell efficiency by up to 0.7%

Product Briefing Outline: Covidien's Mallinckrodt Baker business is expanding its solar cell surface modifier product portfolio. The new PV-162 and PV-200 solar cell surface modifiers, are claimed to enhance solar cell efficiency by up to 0.7% absolute by enabling an enhanced cell response to blue light, thereby increasing cell energy output for both in-line and batch solar cell manufacturing processes.

Problem: Solar cell manufacturing is all about improving efficiency in order to reduce the cost per watt peak of energy produced by the cells.

Solution: The PV-162 solar cell surface modifier, a second-generation post-emitter surface modification product is a 100% water-soluble formulation requiring no intermediate rinse that increases cell efficiency by reducing charge recombination. The reduction in charge recombination results in higher open circuit voltage (V_{oc}), short circuit current (I_{sc}) and fill factor (FF). The PV-200 solar cell surface modifier extends the efficiency enhancing benefits of post-emitter surface modification to batch processes, which use phosphorus oxychloride ($POCl_3$ or POCl) doping technology. PV-200's tunable etch gives process engineers the ability to optimize the product's performance in their manufacturing process, while its low bath temperature, between 20° and 40°C, reduces energy expenditures, extending bath life, and reducing overall cost of ownership.

Applications: Solar cell surface modification.

Platform: A 100% water soluble formulation eliminates the need for an intermediate solvent rinse, decreasing total processing time and cost.

Availability: Currently available.

AMB Apparate+Maschinenbau GmbH

AMB offers Wet Wafer Separator system with > 3600 wafers per hour throughput

Product Briefing Outline: AMB Apparate + Maschinenbau GmbH has introduced the new Wet Wafer Separator WWS 3000+. The solution addresses the critical handling and sorting of thinnest wafers between the process steps, pre-cleaning and final cleaning of silicon wafers.

Problem: High breakage rates and decreased throughput can occur in the separation stage of wafer processing.

Solution: Reduced breakage rates and high throughput are the main focus of the WWS 3000+. The newly developed pickup system separates the foremost wafer from the stack without any mechanical stress. After separation, the wafers are moved out of the water bath to the transfer station along a special conveyor belt with a non-slip surface. The transfer station is followed by the automatic fracture identification and double wafer screening system with its integrated ejection mechanism. Broken wafers are sorted out first by gravity alone while an inspection camera ensures the detection of damaged wafers. Double wafer control follows and is done by a contact-free infrared system. The wafers are transferred either to a 1-8 line inline system or to cassettes, depending on the manufacturing process. A buffer system coordinates the production flow and optimizes productivity. In the last work stage, the wafers are transferred to the final cleaning station. During the entire sequence, humidifiers prevent dry spots on the wafers. The water bath is continuously refreshed by a circulation device with integrated filter. WWS 3000+ delivers high quality wafers to the subsequent process steps.

Applications: Wafer types include multi- and mono-crystalline silicon. Wafer Geometry Square and pseudo-square. Wafer thickness 120-300µm.

Platform: With the technology used in the system, wafer damage and breakage is reduced to a minimum of 0.1%. High efficiency separating unit, combined with wafer control units and buffer systems, guarantee high production and yield. Throughput > 3600 wafers per hour.

Availability: Currently available.

Product Briefings

WITec

The alpha500 from WITec enables comprehensive characterization

Product Briefing Outline: The alpha500 from WITec is an automated microscope system combining Confocal Raman Microscopy for chemical 3-D imaging and atomic force microscopy for high-resolution structural surface imaging, which allows comprehensive characterization of various solar cell materials on the nano- and micrometer scale.

Problem: In the research and development of photovoltaic devices, the primary goals are either to increase the conversion efficiency of the solar cells or to improve and monitor the production process.

Solution: The WITec alpha500 is the first instrument on the market to combine Confocal Raman Microscopy for 3-D chemical imaging and AFM for high-resolution structural imaging in an automated system for large samples. A motorized sample stage with a travel range of 150 x 100mm (350 x 300 optional) allows for multi-area/multi-point measurements or overview scans on an arbitrary, user-defined number of measurement points. Specific automated functions such as an integrated auto-focus and an automatic AFM-tip approach guarantee standardized routine measurement procedures or individually defined sequences to be performed without any online process control by an operator during the measurement. An optimized optical system design allows for ultrafast Raman Imaging or very low Raman signal detection. Raman spectroscopy and imaging are nondestructive techniques delivering information on various material properties such as crystallinity, material stress, stoichiometry, material distribution, homogeneity or clustering. The confocal microscope setup allows it to perform depth profiles in order to acquire information on the layering of thin films.

Applications: CIS & CIGS thin films, Si solar cells, ZNO, and DSCs.

Platform: The alpha500 is controlled by the fully digital WITec control unit, alphaControl, and the WITec Control software.

Availability: Currently available.

NanoGram Corporation

NanoGram's ambient, inkjet-able nano-particle silicon ink reaches a-Si performance

Product Briefing Outline: NanoGram Corporation has announced the successful fabrication of the first thin film transistor (TFT) produced by ambient printed nanosilicon to reach a carrier mobility of $2.0cm^2/Vs$. The TFT is based on a non-pyrophoric material and was produced by Sharp Laboratories of America.

Problem: Product stability issues can affect organic semiconductors and there are potential handling issues associated with polysilane-based materials.

Solution: NanoGram's printable silicon material is both inorganic and non-pyrophoric and is based on nano-scale crystalline silicon particles formulated into inks, which can be ink-jetted or spin coated onto a substrate and then fabricated into a TFT. The proprietary ink technology was developed as part of NanoGram's technology development agreement (TDA) with Teijin Limited.

Applications: Printed electronics applications including flat panel display backplanes for LCD and thin film photovoltaics. Doped and intrinsic silicon p+ and n+ are available.

Platform: The silicon ink is produced using NanoGram's proprietary laser pyrolysis-based Nanoparticle Manufacturing (NPM) process, suitable for high volume production. Silicon inks are formulated with common printing solvent systems designed with an emphasis on manufacturability and safe handling using existing printing technologies and equipment.

Availability: Currently available.

LumaSense Technologies

LumaSense Technologies thermal imaging cameras improve process control and product quality

Product Briefing Outline: LumaSense Technologies has launched the Mikron M7604F and M7604G thermal imaging cameras. The Mikron M7604 camera is a versatile, fully-radiometric camera with high-temperature functionality for preventive maintenance inspections, radiometric inspections of internal furnaces and (M7604F) the temperature of glass surfaces (M7604G) for improving process control and product quality.

Problem: There is a growing need for improved process control and real-time measurement and inspection to boost process yields and reduce unscheduled tool maintenance. The use of infrared (IR) light can provide robust, accurate sensors for demanding environments and applications.

Solution: The Mikron M7604 thermal imaging cameras are actually two cameras in one. In addition to low temperature radiometric imaging in the 8–4μm wavelength range, each camera has its own specialized bandpass filter that enables accurate imaging through flames or of glass surfaces. Both the M7604F (for through-flame imaging) and M7604G (for glass surface imaging) have this capability. These cameras enable all the normal preventive maintenance infrared inspections and then easily toggle to the unique spectral filter for either through-flame or glass surface imaging.

Applications: Furnaces as well as for temperature measurements of glass surfaces.

Platform: The M7604 cameras include off-the-shelf batteries, IEEE 1394 (Firewire) capability and MikroSpec 4.0 image processing software.

Availability: Currently available.

Product Briefings

Dark Field Technologies

NxtGen platform from Dark Field Technologies handles washed panel defects and classification

Product Briefing Outline: Dark Field Technologies has developed a new metrology technique for washed panel applications. NxtGen-Wash is a part of the new NxtGen family of inspection and metrology systems, which support laser, camera, hybrid laser cameras, telecentric and divergent optics and retro-reflection for on-line, real-time defect mapping, imaging and classification.

Problem: Special dark field optics detect defects much smaller than the optical pixel while enabling high throughput rates and large depth of fields. In thin-film metrology applications, challenges include inspection of P1, P2 and P3 scribes for width, pitch, offset between scribes, defects within scribes and defects in the active zones between the scribe sets. Detection of TCO coating defects and washer residue defects are normally invisible to the eye, but cause downstream coating defects and reduced panel efficiency

Solution: The NxtGen platform claims to deliver 100% scribe inspection, pitch and offset, on-line, real-time while concurrently detecting coating defects between scribe regimes. The system also delivers metrology results independent of the orientation of the scribes. Conventional rule-based defect classification becomes untenable as defect classes proliferate; logic gaps and overlaps result. Dark Field's NICE AI module utilizes multiple classification algorithms including rules-based, nearest neighbour, Bayesian and neural network.

Applications: The detection of float glass defects, edge chips/cracks, broken corners/flairs, streaks, scratches, TCO coating defects and washer residue. Can be used to measure panel width, length and squareness. Special signal processing algorithms extract weak, persistent signals from a background of noise.

Platform: The system supports laser, camera or laser: camera optics and divergent, telecentric and self-aligning optical systems.

Availability: Currently available.

Neptun Srl

Neptun's Tornado IperClean horizontal washer handles panel cleaning and drying

Product Briefing Outline: Tornado IC is a horizontal washing machine designed by Neptun for the advanced cleaning and drying of PV modules. Based on the Tornado HP for glass applications, the IC version features all Neptun's mechanical solidity and reliability, but with greater use of stainless steel AISI 304. Additional features include transmission by means of conical gears, easy maintenance, an ergonomic control panel with touch screen and an optional pre-washing, low-E device and polishing unit.

Problem: Insufficiently cleaned or inaccurately dried glasses are not easily recognized and negatively affect the quality of the final product, thus compromising the lifetime and the efficiency of a solar module. At the same time, the substrates are delicate and require a careful handling during the washing process.

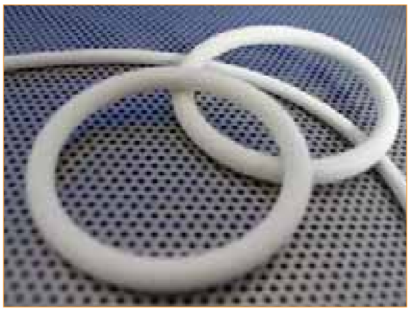
Solution: The system guarantees thorough but delicate washing and drying with six brushes and four or six air knives with a max speed up to 12m/min. Each pair of brushes, and the pre-washing and rinsing sections have their own independent water circuit, which is fed with ultra-pure DI-water. At every stage, the water quality is kept strictly under control by a multi-stage filtration system with constant control of the conductivity and precise dosing of detergent (if required). The combination of filters, valves and tanks dramatically reduces ultra-pure water consumption. The ultra-pure water can be heated up to 70°C in each circuit of the washing section for successful removal of all possible contaminating agents. The system is sealed to avoid problems from the vapour release into the environment. The drying section ensures ultra-pure air within clean room standards up to IsoClass 4.

Applications: Glass cleaning, PV module cleaning.

Platform: Tornado IC claims extremely low noise, remaining below 80dB even during the drying process.

Availability: Currently available.

Perlast Ltd



Perlast Ltd. now offering fluoroelastomer material based process tool seals

Product Briefing Outline: Perlast is launching its latest 'clean,' high performance fluoroelastomer (FKM) material for solar panel manufacture. Called V75SC, the elastomer is designed for CVD, PECVD and PVD vacuum deposition processes. It offers low particulation in these critical sealing applications together with cost advantages over perfluoroelastomer seals.

Problem: Perlast is able to offer V75SC in sizes up to 100 inch diameter, fully molded, O-rings and formed seals manufactured on a single tool, in one pressing operation, within a Class 10,000 clean-room facility. This provides repeatable, dimensionally accurate moldings, negating the quality issues seen with manual 'endless' molding techniques and jointed O-rings.

Solution: The white coloured V75SC has a high fluorine content that provides thermal resistance up to 250°C (482°F), combined with high levels of plasma and chemical resistance. In addition, it has a low compression set and modulus, ensuring maximum long-term sealing effectiveness. V75SC can be used for O-rings and formed seals in static and dynamic applications including door seals, slit valve seals, lip seals, check valves and pumps.

Applications: CVD, PECVD and PVD vacuum deposition process tools.

Platform: V75SC comes in sizes up to 100 inch diameter, fully molded, O-rings and formed seals.

Availability: Currently available.

The solar cell wafering process

Mark Schumann, **Teresa Orellana Pérez** & **Stephan Riepe**, Fraunhofer Institute for Solar Energy Systems (ISE) Freiburg, Germany

ABSTRACT

The process of wafering silicon bricks represents about 22% of the entire production cost of crystalline silicon solar cells. In this paper, the basic principles and challenges of the wafering process are discussed. The multi-wire sawing technique used to manufacture wafers for crystalline silicon solar cells, with the reduction of kerf loss currently representing about 50% of the silicon, presents a major challenge for further research efforts. Another relevant field of research is the reduction of wafer thickness in order to obtain more wafers per millimetre of brick length. The last subject that is addressed in this paper is the general optimization of the wafer surface and geometry, as the multi-wire saw cutting process influences the mechanical properties of the wafers and can have further effects on subsequent process steps.

Motivation

Crystalline silicon is currently the principal material used to manufacture solar cells, and is likely to remain so for the foreseeable future. Thus, it is of utmost importance to improve the currently available process technologies in order to lower the overall costs for silicon solar cells. In this paper we focus on the wafering process, as it has a comparatively large cost contribution of about 22% in the silicon solar cell manufacturing value chain [1].

Fig. 1 summarizes the process steps that form the front-end of the solar cell value chain. The silicon feedstock material is crystallized as either monocrystalline or multicrystalline ingots by various methods. These ingots are then cut into bricks with the footprint area of the silicon wafers. The bricks are mechanically or chemically ground and polished, a process that has been introduced to improve the edge quality on the final wafers and reduce the breakage rate in the subsequent cell processing steps. A multi-wire saw is used to cut the silicon brick into wafers independent of its crystalline structure. Finally, the wafers are cleaned and guided to the next production steps to become solar cells and photovoltaic modules.

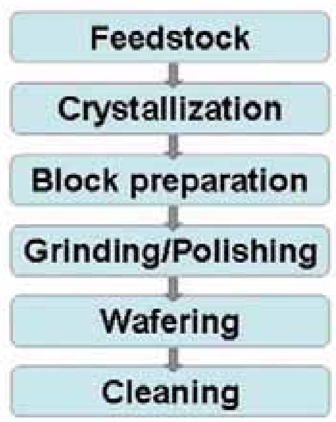


Figure 1. Process steps from silicon chunks to clean silicon wafers.

In order to intensify its activities in front-end processes, Fraunhofer ISE founded the Silicon Materials Technology and Evaluation Center (SIMTEC) as a research laboratory within ISE in Freiburg in 2008.

"The most important motivation for research is the fact that during cutting, about 50% of the expensive solar-grade silicon is lost as kerf."

The following section will focus on the research activities in the field of multi-wire sawing justified by the potential cost reduction in this process. The most important motivation for research is the fact that during cutting, about 50% of the expensive solar-grade silicon is lost as kerf. Another relevant field of research is the reduction of the wafer thickness in order to produce more wafers per kilogram silicon.

Finally, the wafering process step, in combination with the material quality, defines the mechanical properties of the final solar cell, as the wafering process can damage the wafer's surface. This damage has to be etched not only to increase the mechanical stability but also to obtain good cell efficiencies.

Principle of wafering

Fig. 2 shows a schematic of a multi-wire saw. A wire is taken from a delivery spool and guided by rolls/pulleys that are in place to give the wire the desired tension. From these rolls the wire is led to the wire guidance rolls, which are coated with a polymer and feature grooves with defined spaces, commonly known as 'pitch'. The wire is wound as many times as there are grooves on the wire guidance roll, and at the last groove point, the wire is again guided by pulleys to a collector spool.

The wire on the wire guidance rolls forms the so-called wire web, i.e., many segments of the wire are laid parallel to each other, as shown in Fig. 2. The silicon brick is glued on a glass plate before being cut. This glass plate is glued on a metal holder placed above the wire web. During the cutting process, the silicon brick is pushed towards the wire. A slurry is homogenously applied to the wire web via a nozzle. The slurry performs the cutting process on the wire web and consists of silicon carbide (SiC) particles in a solution with polyethylene glycol (PEG).

The silicon carbide particles indent the silicon surface as the wire's movement drags them. Fig. 3 shows an illustration of the cutting process in one sawing channel. The slurry is recollected and driven back in the slurry circuit. By this process, all the wire segments are wetted and form many sawing channels in the silicon brick.

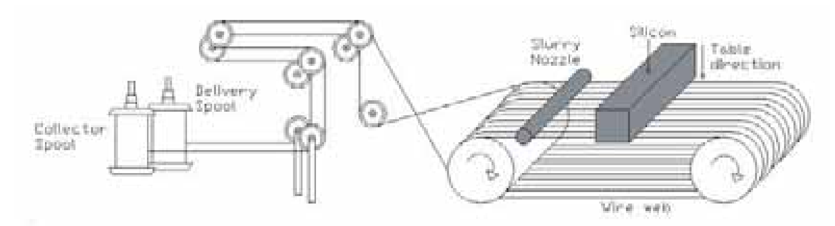


Figure 2. Schematic drawing of multi-wire saw. For industrial use, up to two silicon bricks can be cut in parallel or on the upper and lower part of the web.

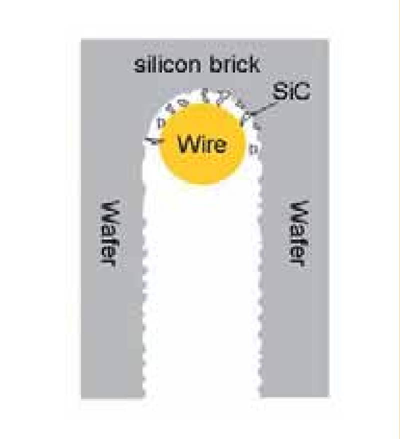


Figure 3. Schematic illustration of the cutting process in one sawing channel. Silicon carbide particles, dragged by the motion of the wire, indent the silicon surface, thus enabling the cutting of a silicon brick into hundreds of wafers.

Figure 4. A silicon brick after the cutting process showing the wire web in the foreground of the photo. The glue on the wafers causes them to stick to the glass plate.

At the end of the cutting process, the wafers are hanging on the glass plate which has been partially cut and is only used once (see Fig. 4). The glue is dissolved in order to remove the wafers from the glass plate.

The following sections discuss some important parameters of the cutting process in more detail.

Wire

Multi-wire sawing uses a brass-coating steel wire. The tensile strength of the wire is approximately 4000N/mm^2 and the standard thickness is between 120 and 140µm for photovoltaic applications. In experimental research wires as thin as 100µm have being tested [2].

Fig. 5 shows a 120µm wire before (left) and after the cutting process (right). Before cutting, the wire has a smooth surface, while after the cut the brass coat is removed, the surface is rougher and scratches occur. The wire is also slightly thinner, leading one to conclude that iron and brass from the wire have been transferred into the slurry. Most of the removed wire material is composed of iron, since the brass coat has a thickness of only a few hundred nanometres. After the cutting process, slurry can also stick to the wafers. Consequently, it is very important to clean the wafers carefully in order to remove the iron, which could cause problems in the subsequent cell processing.

Slurry

Silicon carbide with a defined grain size is the abrasive used. The grain size distributions used for silicon carbide are defined by the FEPA [2]; F600, which has a mean grain size of 9.3µm, is considered the standard grain size. Kerf reduction can be achieved using smaller grains.

SiC particles indent the silicon material and damage the wafer surfaces. This damaged layer has to be removed, which is usually done by wet chemical etching [4]. To reduce the thickness of this layer, experiments with smaller grain size distributions have been performed, resulting in significant improvements [2].

Two different polyethylene glycols, PEG 200 or PEG 300, are commonly used as

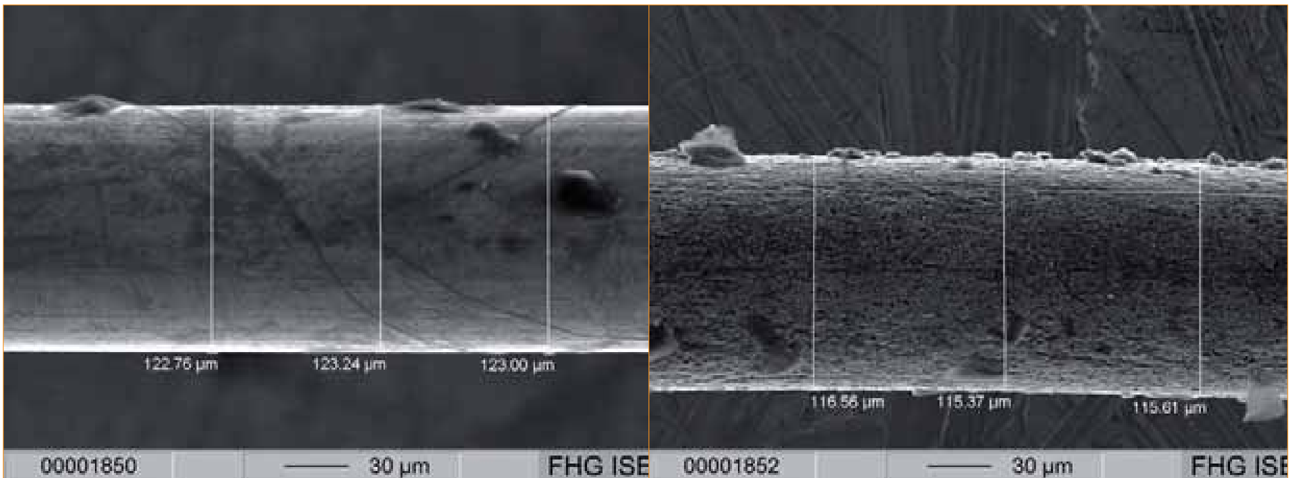


Figure 5. SEM images of a wire of 120µm diameter before (left) and after (right) the cutting process. The post-cutting wire shows some SiC particles on the surface and is scratched and rough in appearance.

carrier fluids. Different carrier fluids, e.g. water, have been investigated by some research groups [5], but PEG remains the dominant carrier fluid.

Another approach for advancing the multi-wire sawing process is the omission of slurry, which is only possible if wires with fixed abrasives are used. For this purpose, diamond wire with small diamond particles attached to the wire is mainly used. Successful cutting has been reported [6]; however, the high price of this type of wire has hindered a wider acceptance of this method for photovoltaic applications.

Machine parameters

The machine parameters for the cutting process depend on many factors such as wire thickness, machine type, wafer thickness, brick length and grain size, among others. The machine parameters that must be chosen are the table and wire speed, the tension of the wire and the flow and temperature of the slurry.

While slurry flow (4000kg/h used at SIMTEC) and slurry temperature (25°C) for standard cuts remain almost always constant, other parameters can vary. The wire tension depends on the chosen wire thickness. For example, the tension for a 140µm wire at SIMTEC is 27N while for a 120µm wire the tension is 22N. The table speed (the velocity under which the silicon moves into the wire web) ranges between 0.3mm/min and 0.5mm/min.

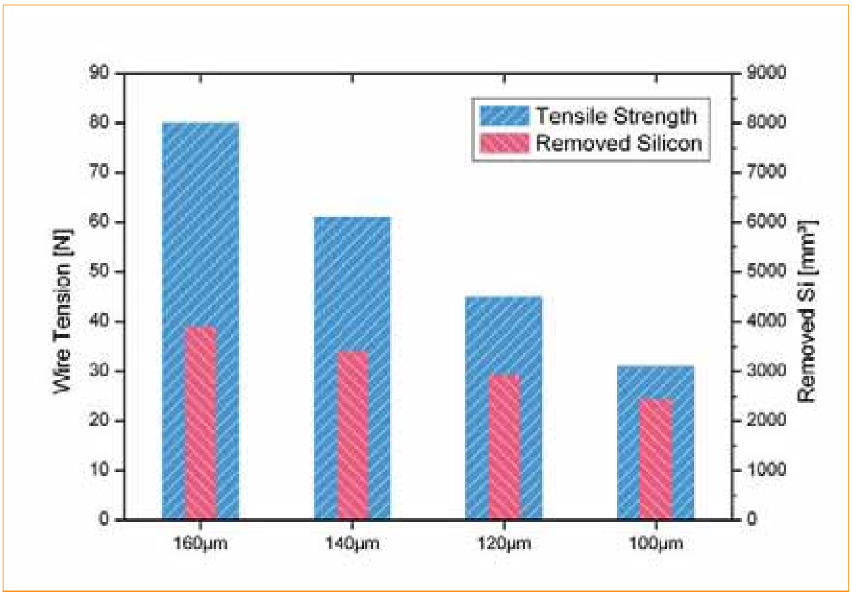


Figure 6. The graph shows the possible wire tension for different wires and the amount of silicon that is removed per kerf for different wire diameters.

This results in a cutting duration between five and eight hours for a silicon block with a 156 x 156mm² footprint. The velocity with which the wire moves from one spool to the other is between 720m/min and 900m/min; hence the necessary wire length for one single cut can be more than 400km.

The setup of the machine as well as the chosen material has an influence on the resulting cutting parameters, which include the viscosity of the slurry, the temperature of the silicon and the bow of the wire. In-depth descriptions of these parameters can be found in the relevant literature [7,8].

Wafering problems and solutions

Kerf

Even though efforts have been made to recycle lost silicon, there has been no established industrial standard process until recently [9]. While the silicon carbide particles are routinely recycled, the reduction of the kerf loss remains an important topic for research. The link between the kerf (which is approximately represented by the sum of double the grain size and the wire thickness) and the resulting wafer thickness can be expressed as illustrated in Equation 1.

Wafer thickness = Pitch – (Wire thickness + 2x Grain size of the SiC) Eq. 1

Potential methods of achieving a kerf reduction are to use either thinner wire and/or smaller abrasive grain sizes. Both approaches are being investigated at SIMTEC.

"While the silicon carbide particles are routinely recycled, the reduction of the kerf loss remains an important topic for research."

Wire thickness

Wire thickness is the most obvious option for kerf reduction. A wire thickness of 160µm was standard in the photovoltaics industry until 2007. In order to reduce the cost for silicon photovoltaics, this thickness has since been decreased to 100µm. This represents a kerf reduction of about 37%, which is equivalent to about 13kg of silicon considering a standard industrial wafer size of 156 x 156mm^2.

Reducing the wire thickness is a straightforward process but only to a certain degree. The disadvantage of reducing the wire thickness is the restriction to lower wire tensions to ensure cutting without wire breakage. In Fig. 6, the wire tension of four different wires is compared with removed silicon per kerf for a 156 x 156mm^2 brick.

Thinner wires also experience a larger percentage decrease in tensile strength due to the erosion of the wire surface caused by the indentation of the SiC, because the removal is independent of the wire's thickness. Some improvements on wire have been carried out recently, mostly with regard to tensile strength of the steel. To further reduce wire thickness, it will be necessary to increase the tensile strength even further. Another possibility is to find alternative materials that could serve as a substitute for steel in this application.

"The disadvantage of reducing the wire thickness is the restriction to lower wire tensions to ensure cutting without wire breakage."

Grain size

Equation 1 shows that another method for kerf reduction is changing the grain size of the abrasive. This has a smaller impact on the kerf due to the used grain size distributions. Currently, a common

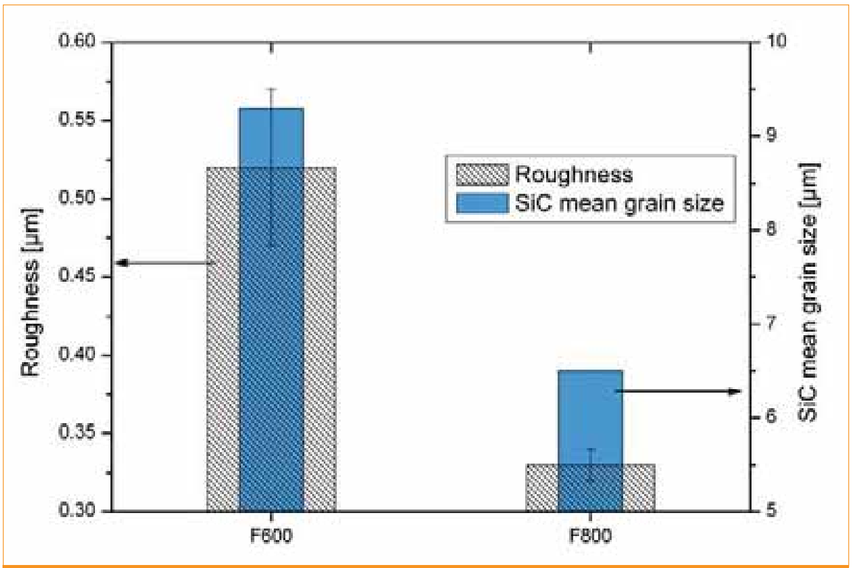


Figure 7. Mean grain size for two different SiC types and resulting wafer roughness.

Figure 8. Photo of a 70µm multi-crystalline wafer, which demonstrates the flexibility of thin wafers.

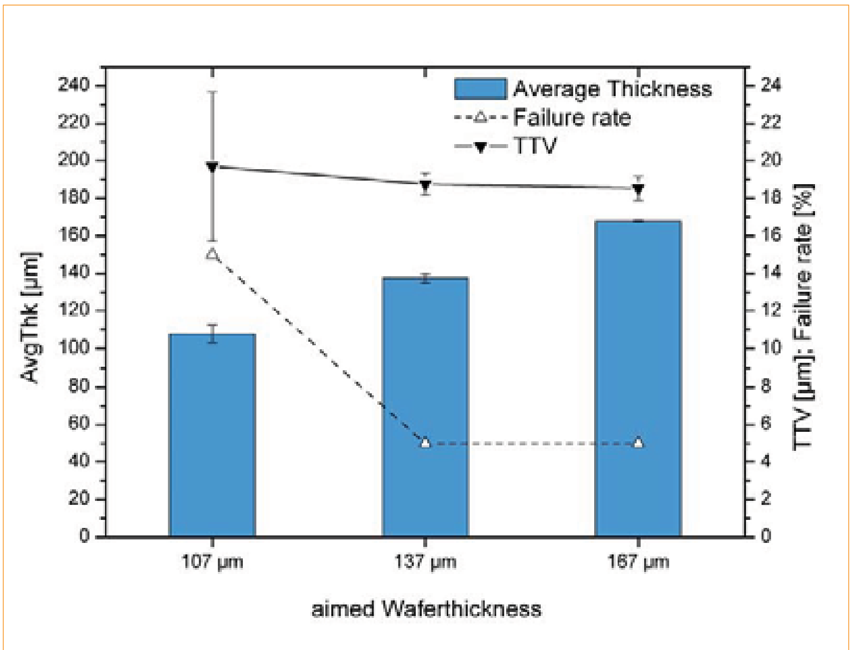


Figure 9. Wafer geometry parameters (AvgThk = average thickness; TTV = total thickness variation) and failure rate for wafers of different thicknesses.

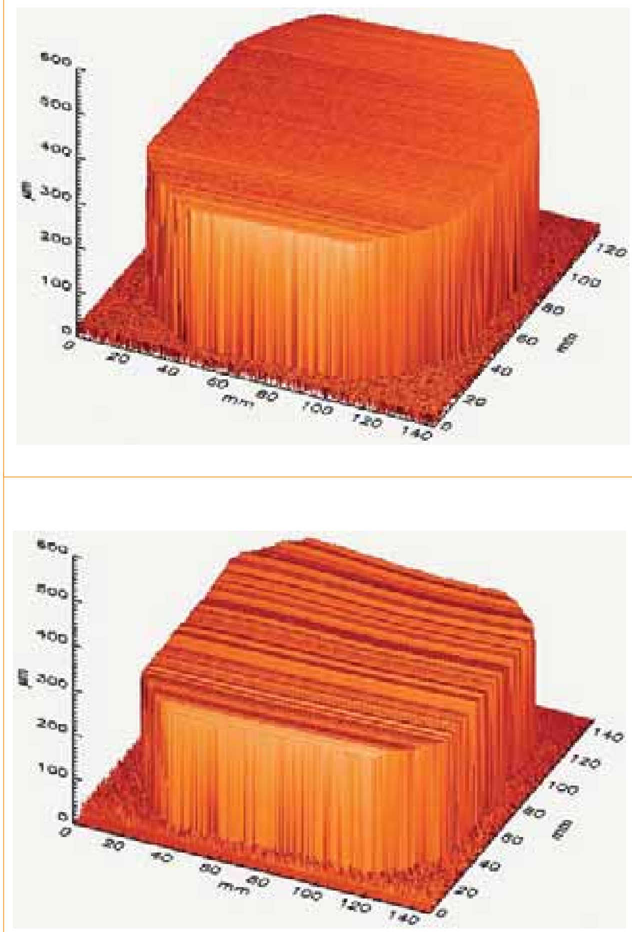


Figure 10. Different wafer surfaces measured with a surface profilometer. Cutting parameters have a strong influence on the resulting wafer surface.

grain size distribution is F600, with a mean grain size of 9.3µm. If this is changed to F800 with mean grain size of 6.5µm, the kerf will be reduced by about 10µm. In calculating the kerf, it must be taken into account that particles larger than the mean grain size also exist. These larger particles are important during the cutting process and are the reason why the kerf caused by the SiC is higher than twice the mean grain size [11]. Another advantage of smaller grain size distribution is that the surface roughness is reduced (see Fig. 7).

Wafer thickness

Another option to get more wafers per millimetre brick length is to cut thinner wafers, an area that has been the focus of quite a large amount of research. Throughout the last five years, the industry has seen a decrease in wafer thickness from 325µm down to 200µm or, in some cases, even as narrow as 180µm. Another advantage of thinner wafers is their improved flexibility; however, this improvement is only a feature of wafers thinner than 130µm, which have low values of breaking strength (see Fig. 8).

Fig. 9 shows the results of an experiment where wafers of three different thicknesses were cut. The thinnest wafers had an average thickness of 107µm, while the thickest wafer was 167µm. As the graph shows, the failure rate decreases with increasing wafer thickness, which was expected due to the reduced breaking strength of thinner wafers. The medium value of the total thickness variation (TTV) increases only slightly for thinner wafers but shows a much larger spread. Thinner wafers inflict less force on the wire, which allows the wire to move more freely in the sawing channel, resulting in an increased TTV. However, this feature could only be seen for the thinnest wafers, and no trend was apparent in this case.

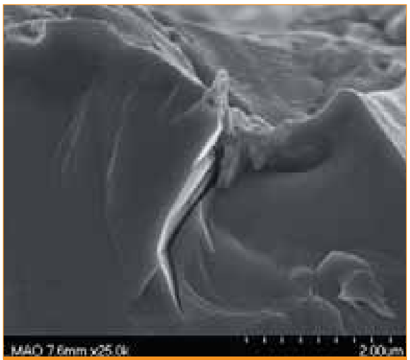


Figure 11. Groove on the surface of a monocrystalline silicon wafer featuring a micro-crack developed under the groove due to the indentation of a silicon carbide particle during multi-wire sawing.

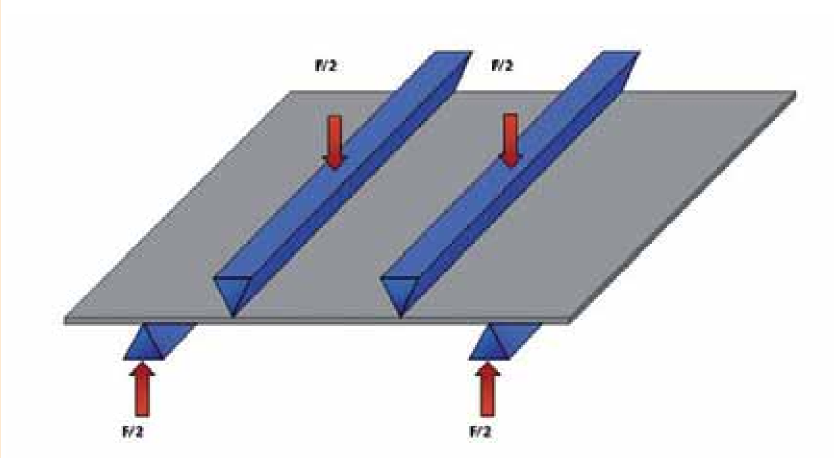


Figure 12. 4-line bending test scheme for testing cracks on the wafer surface and at the edges [1].

Wafer quality

Fig. 3 clearly shows how the cutting process's indenting abrasive has a strong influence on the surface quality of the wafers. The main mechanical properties influenced by the sawing process are wafer surface and geometry.

In the photovoltaics industry, cost is a preventative factor in the decision not to grind and polish wafers to obtain desired wafer geometry. Therefore, as-cut wafers already must fulfil the necessary wafer geometry after multi-wire sawing and should adhere to controlled parameters – like those followed at SIMTEC – such as thickness, total thickness variation and bow.

Fig. 10 shows as-cut wafers cut with different parameters. Obviously, the chosen cutting parameters have a large influence on the wafers' roughness. Furthermore, wafering not only causes surface roughness but also damage below the surface, referred to as sub-surface damage [12]. Much research has gone into eliminating all damage; as a rule, a damaged wafer will lead to a poorly performing solar cell. However, sub-surface damage has yet to be decreased to sufficiently low levels. Today its removal still demands a step involving a wet chemical process.

Mechanical properties

Sub-surface damage has a huge effect on the mechanical stability of the wafers. The indentation of abrasive SiC particles in the silicon crystal yield a distinct pattern on the wafer's surface as well as the sub-surface layer a few microns deep where the presence of micro-cracks is dominant (see Fig. 11) [13].

Silicon wafers behave as brittle materials at room temperature and are thus very sensitive to defects. Under loading conditions, any mechanical stress applied to the silicon wafer is intensified at the cracks' tips. Given that cracks are expected on the surface and at the edges of the wafers (due to the multi-wire saw cutting), the 4-line bending test (see Fig. 12) can be selected to characterize the mechanical properties of the wafers [14].

The probability of failure of a wafer is a function of the stress level, distribution of micro-cracks and volume of silicon subjected to stress. Weibull statistics analytically describe the dependency of fracture probability on these factors.

$$S(\sigma) = 1 - \exp\left(-V_E\left(\frac{\sigma}{\sigma_0}\right)^m\right) \quad \text{Eq. 2}$$

The parameter m in Equation 2 is the Weibull modulus and describes the width of the distribution of crack lengths. A high m-value means that the crack lengths and thus the failure stresses are within a narrow scattering band and vice versa. σ is the applied load on the wafer and σ_0 is the fracture strength of the wafers, usually given as the load level at which 63% of the tested wafers have failed. Finally, V_E is the effective loaded volume.

Weibull parameters m, σ_0 and V_E are estimated by the least square fitting of a linearized form of the Weibull distribution [15].

Weibull graphs plotting the probability of wafer breakage against the applied stress are depicted in Fig. 13. A significant increase in mechanical resistance can be observed for silicon wafers when the micro-cracks on

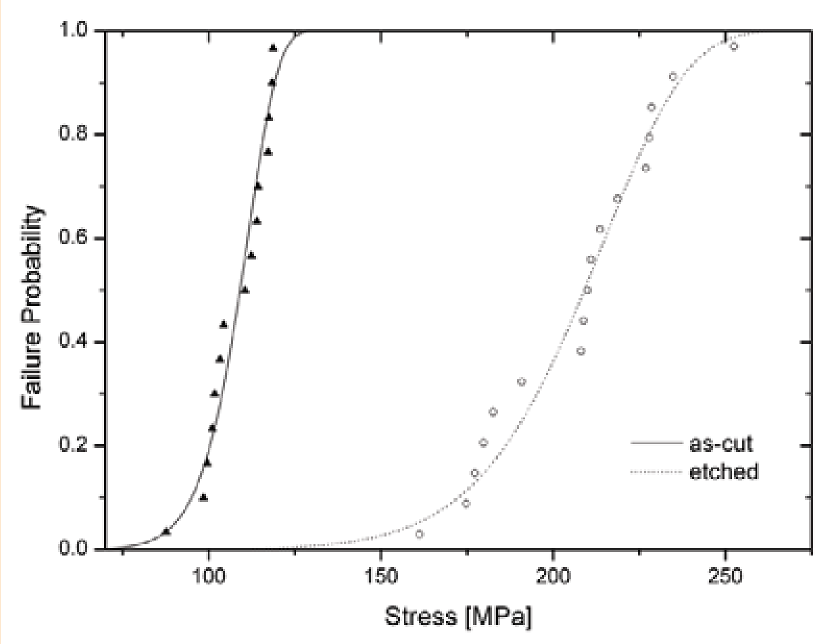


Figure 13. A Weibull graph shows the failure probability versus bending stress applied during the 4-line bending test of two sets of monocrystalline silicon wafers. The black triangles correspond to the experimental data obtained with as-cut wafers; the open circles guide the (dotted) line representing the experimental data obtained with alkaline etched wafers. The continuous line represents the Weibull functions best fitting the experimental data.

their surface and at the wafer edges are removed by a standard alkaline etching solution. An experiment taking 17 wafers per group gave a characteristic stress of 112Mpa for as-cut wafers, while etched wafers had a characteristic stress of 217MPa. These results highlight the importance of a micro-crack-free wafer surface for providing the most stress-resistant wafers.

Summary

Wire sawing will remain the dominant method of producing crystalline wafers for solar cells, at least for the near future. Recent research efforts have kept their focus on reducing the wafer thickness and kerf, with both approaches aiming to produce the same amount of solar cells with less silicon material usage. There have been successful outcomes in the recent past: where kerf reductions of close to 50% have been achieved using smaller-grained abrasive particles and thinner wires. Wafers with a thickness of 100µm have been cut and processed to solar cells.

The wire saw wafering process is determined by a variety of factors. In order to optimize the wafering process, a large number of tests are necessary; Those presented in this paper illustrate that multi-crystalline wafers can be cut with a thickness down to 70µm while maintaining high quality.

In the future, the multi-wire sawing technique will be further optimized, but alternatives to the wafering process need to be investigated. Although some new promising alternatives have been introduced recently, all of them have yet to prove their industrial feasibility and relevance.

Acknowledgements

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Mark Schumann studied process engineering at the University of Applied Sciences, Wildau and received his degree in 2005. His diploma thesis at Fraunhofer ISE was concerned with wire sawing for PV applications. He is currently doing research on wire sawing and writing his Ph.D. thesis.

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Cell Processing

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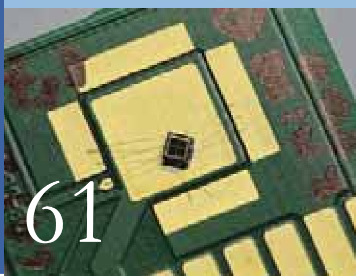

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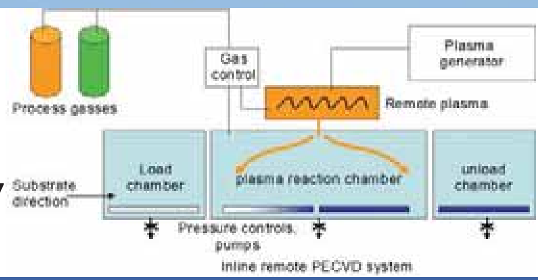
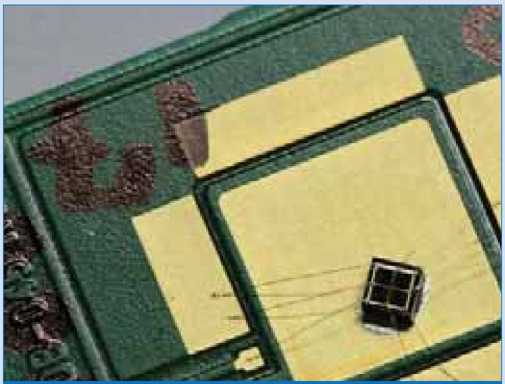


QuantaSol reaches high efficiency levels in move toward multijunction world record

Independent designer and manufacturer of strain-balanced quantum-well solar cells, QuantaSol, a spinout from Imperial College, London, has announced what may be the most efficient single-junction cell ever manufactured, which was developed in just two years at its Kingston-upon-Thames development laboratory. An efficiency level of 28.3% at 500 suns was recorded at lab level and has been independently tested and certified by Fraunhofer ISE.

In order to achieve these high levels of efficiency, QuantaSol uses a strain balancing process which is a technique employed to allow the epitaxial crystal growth of nanostructures from materials that have a slightly different 'lattice constant' – or regular spacing distance between atoms in the lattice – from each other.



QuantaSol's multi-junction cell.

Dr. Tim Tibbits explains that in order to achieve perfect crystal quality, without so-called defects, all the atoms in the crystal must be arranged perfectly next to one another in the right place – if this does not occur then the electrical properties of the crystal or solar cell made from it deteriorates.

QuantaSol is able to use the technique of strain balancing to achieve perfect crystals of alternating layers of family III-V semiconductor materials, Indium Gallium-Arsenide (InGaAs) and Gallium-Arsenide-Phosphide (GaAsP), even though the two materials, if grown independently, would have different lattice constants to the substrate material, Gallium-Arsenide (GaAs). It is the ability to manufacture this nanomaterial that enhances the absorption and hence efficiency of QuantaSol's solar cells.

QuantaSol's CEO Kevin Arthur told *Photovoltaics International* that this single-junction cell is "the first step on our product development roadmap towards a multi-junction device, we aren't planning to offer the single junction for sale unless there is a significant customer interest. However we think that some of the new system ideas that we are seeing would be ideal platforms to utilize the high performance of our single junction but confidentiality agreements preclude any further discussion."

The developers have not disclosed costs or prices, but plan to approach production in the pattern of LED and mobile phone power amplifier manufacturers. CPV has the potential to reach a level that will demand gigawatts of production per year. QuantaSol is a fabless semiconductor company, which means it specializes in the design and sale of cells and out-sources fabrication to a specialized foundry. QuantaSol has recently completed a £2 million second funding round, which will be put towards upping the amount of team members and to funding the research and development of a multi-junction cell.

News

R & D News Focus

Magma Design Automation, Orion Metrology partner on PV manufacturing yield analysis platform

Magma Design Automation and Orion Metrology have partnered to integrate Magma's just-launched YieldManager Solar yield enhancement package with Orion's inline inspection technology for photovoltaic manufacturing applications. Through this partnership, Magma says it plans to expand the capabilities of its yield analysis platform, which enables solar panel manufacturers to increase their defect identification rate and improve process control.

The integration of Magma's yield enhancement software system customized for solar fabs with Orion's inline inspection technology will allow PV cell manufacturers to monitor random and parametric inline defects and instantaneously feed this information back to manufacturing to minimize the impact and severity of defects, thus improving yield and product efficiencies.

Orion has also adopted YieldManager as the central data analysis solution for its inline process and parametric measurement applications.

Suntech's R&D facility.

Suntech eyes Pluto transition with US$50 million loan agreement

Bolstering its finances ahead of a major technology transition, Suntech Power Holdings has secured a convertible loan agreement worth US$50 million with IFC, a member of the World Bank Group. Suntech has earmarked the funds for debt refinancing and to support the company's transition to the Pluto technology approach, which is based on the PERL (passivated emitter with rear locally diffused) cell technology and has demonstrated world-record lab efficiencies of 25%.

Suntech has received permission to draw the loan on condition that a number of stipulations are satisfied.

IMEC announces new partnerships for its solar cell research program

IMEC has announced new partnerships with solar cell material and equipment suppliers including MEMC Electronic Materials Leybold Optics Dresden GmbH, Roth & Rau AG, and Mallinckrodt Baker B.V.

The group has concluded joint-development agreements with IMEC in the frame of IMEC's newly launched wafer-based silicon PV industrial affiliation program (IIAP). As part of this multi-partner R&D program, and with support by the Flemish Government, a solar pilot line will be set up.

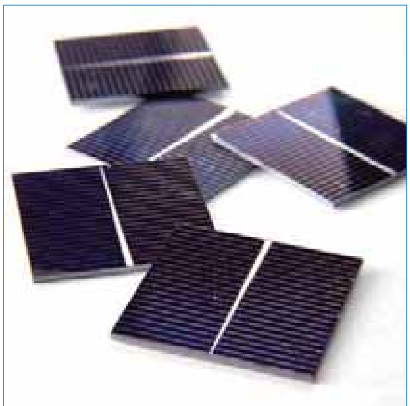
This initiative will allow the group to conduct advanced solar cell process development research in a semi-industrial environment, enabling an efficient transfer of the results of this research directly to the industry's production lines.

MEMC has made its initial shipments of high lifetime, thin crystalline silicon solar wafers to IMEC while Leybold Optics Dresden GmbH is building an inline sputtering system A550V7 that will be shipped to IMEC in late 2009.

Roth & Rau will ship an AK-1000 RIE inline plasma system for PV plasma texturisation and PSG removal to IMEC in the same period. Mallinckrodt Baker B.V. will be providing novel fluoride- and non-fluoride-containing chemistry for the development of Hydrogen Fluoride (HF) replacement processes.

To extend its silicon photovoltaics research infrastructure, IMEC will also benefit from the recent decision of the Government of Flanders in Belgium to invest in renewable energies. IMEC will receive a grant of €8.7 million. This grant will be used to set up the pilot line that will allow developing new processes in a semi-industrial environment.

IMEC's silicon solar cell IIAP concentrates on a sharp reduction in silicon use, increasing cell efficiency and further lowering substantially the cost per Watt peak. The program explores both wafer-based bulk silicon solar cells and epitaxial cells.



Thin-film epitaxial silicon solar cells.

Business News Focus

Q-Cells announces second quarter market drop

Q-Cells has announced a drop in its full-year sales outlook after prices fell sharply in the second quarter – €142 million from €310 million a year ago, posting a loss before interest and tax of €62 million, down from a profit of €60 million. Solar cell makers have been hit by a steep decline in prices for cells in 2009. This has been caused by an oversupply that built up during the boom years of 2007 and 2008.

"[The case of] Q-Cells is more problematic since it suggests the company has problems with the Asian competition that can produce at much lower prices," added Philippe de Weck, fund manager at Pictet, who is managing the company's Clean Energy fund.

Trina Solar sees revenues rise, profits return, PV module shipments increase during quarter

Trina Solar saw its second-quarter revenues increase over the previous quarter although sales numbers were down from the same period in 2008, while net income went back into the black compared to the first quarter. The Chinese integrated photovoltaics manufacturer shipped nearly 31% more modules in the quarter versus the preceding three months. Trina's net revenues in the second quarter were $150.0 million, an increase of 13.5% sequentially and a decrease of 26.5% year-over-year, due to a decline in module average selling price. Total shipments were 63.9MW, compared to 48.8MW in 1Q09 and 47.6 MW in 2Q08.

The company attributed the sequential increase in total shipments to improved demand conditions in major European markets, improved customer access to PV system purchase financings, and an increasing number of government incentive programs for solar energy projects in Europe, North America, and Asia.

Gross profit in the quarter was (in US$) $41.2 million, compared to $22.7 million in 1Q09 and $47.4 million in 2Q08. Gross margin was 27.4% in the second quarter, compared to 17.2% last quarter and 23.2% in the 2Q08. Net income was $18.9 million in 2Q09, an increase from a $10.6 million loss in 1Q09 and a $17.1 million profit in the second quarter last year, while net margin was 12.6% in 2Q09, compared to negative 8.0% in 1Q09 and 8.4% in 2Q08.

Trina estimates it will ship between 90 and 110MW of PV modules in the third quarter and 350-400MW for the year, which would represent an increase of 74% to 99% from last year. The company's nonsilicon manufacturing cost for its multicrystalline modules decreased approximately $0.06 to $0.73 per watt during the just-completed quarter. It expects multicrystalline modules to account for approximately 70% of its production in 2009.

The Chinese firm also reiterated expectations to reduce its manufacturing costs by 15-20% through a combination of technology and manufacturing process improvements together with supply chain and logistics management initiatives currently under testing or development.

Through R&D and technology transfer, the company said it continues to improve its cell production processes to meet its previously announced 2009 conversion efficiency targets of 18.5% and 17.5% for its mono- and multicrystalline commercial product lines, respectively. Based on recent on-site laboratory test production, Trina has achieved monocrystalline cell efficiencies of up to 18.6% by leveraging advanced passivation and metallization techniques involved in the PV manufacturing process.

Through yield increases achieved from improved cell and production efficiencies as well as manufacturing line enhancements, the company said it is on target to increase its annualized in-house production capacities of PV cells and modules from the current 400MW to approximately 450MW by the end of September.

Trina also expects to add approximately 150MW of additional capacity as part of its new East Campus capacity expansion, reaching a total cell and module nameplate annual capacity of 600MW by year's end.

Cell Production News Focus

China Sunergy updates 2Q09 estimates, sees slight increase in solar cell shipments

In an update of its second-quarter 2009 estimates, China Sunergy said its quarterly solar-cell shipments slightly exceeded its previously announced guidance of 35-40MW. The company also said it expects to return to quarterly profitability in 2Q09, after showing a net loss in the first quarter.

China Sunergy's gross profit margin is expected to be around 9%, compared with prior guidance of a positive low-single-digit number and a negative 23.7% gross margin experienced in 1Q09.

The company brought in US$37 million in revenues in the first quarter, posting a net loss of US$13.2 million. Cell shipments for 1Q09 totalled 23.9MW, 37.2% of which were high-efficiency (>17%) devices.

Arise Technologies completes site acceptance tests on second solar-cell line in Germany

Arise Technologies has completed site acceptance tests for Line 2 at its photovoltaic cell manufacturing plant in Bischofswerda, Germany. It has produced more than 100,000 cells on the line during the commissioning and SAT process, and has begun shipping cells to customers for evaluation.

"Line 2 is designed to produce two- and three-busbar monocrystalline PV cells," said Sjouke Zijlstra, GM/VP of Arise Technologies Germany. "We expect that the PV cells produced on Line 2 will achieve efficiencies of up to 18%, once the line is fully optimized. Current efficiencies of Line 2 are at our initial target of up to 17%. Our inline process uses significantly fewer production people and faster cycle-time compared with the more typical batch process. The line was delivered on time and on budget by our turnkey equipment supplier, OTB Solar." Arise is now able to ship more than 80MW of PV cells per year.

Motech Suzhou sees solar cell demand exceed capacity

Motech Industries' Kunshan, China-based subsidiary Motech (Suzhou) Renewable Energy has announced that it is running at full capacity of 65MWp and demand is exceeding supply in the company's facility. Motech (Suzhou) plans to increase to 130MWp by the end of the year and also to increase prices by 1–2%.

The company acquires silicon from the spot market and sells all of its solar cells to China-based module makers in China. It won three Kunshan government open-bid projects for the supply of a total of 180kWp of solar cells, according to the report.

Amtech's Tempress clocks up US$6 million from two Asian orders

In the second twin order from Asian customers this year, Amtech Systems' subsidiary Tempress has revealed its receipt of US$6 million in orders for diffusion processing systems. Each of the two new customers has ordered multiple systems, which are lined up for delivery in the next six to nine months.

Major German cell manufacturer selects Lotus Systems' wet chemical process line

In a multimillion-euro deal with an unnamed German solar cell manufacturer, Lotus Systems has sold its wet chemical process lines, designed to increase throughput and reduce cost. Lotus Systems also announced that further to the purchase, an agreement for future cooperation was signed with a potential product order of €8 million. The first process line will be installed at the customer's site in January 2010.

Bruker receives first order for 263GHz EPR Spectrometer from Helmholtz-Zentrum in Berlin

Bruker BioSpin is celebrating its first order for an Elexsys E780 system, dubbed the world's first commercial mm-wave 263 Gigahertz (GHz) EPR (electron paramagnetic resonance) spectrometer. The US$2.2 million order was received from the Helmholtz-Zentrum in Berlin and will be used for researching new EPR applications in solar energy technology. It marks the first step in a collaborative research partnership between the two companies on EPR probe development for electrical detection.

Innovalight installs OTB Solar silicon-ink inkjet printing production tool

Innovalight has installed what is being called the industry's first high-throughput silicon-ink inkjet printing system at the company's headquarters in Sunnyvale, CA. Netherlands-based OTB Solar engineered and manufactured the system in cooperation with Innovalight.

Through the use of high-precision touchless inkjet printing of silicon ink, Innovalight said it can cut in half the number of manufacturing steps usually required to produce high-efficiency solar cells. The OTB platform can print more than 2000 solar cells per hour, faciliating high-volume production of ultrathin crystalline-silicon solar cells with thicknesses down to 50 microns.

"In OTB Solar we found a strong partner with experience in both solar industry and inkjet printing technologies," said Conrad Burke, CEO of Innovalight, adding that the Dutch company's "team delivered a very sophisticated and powerful solution to Innovalight in record time."

Chris Boomaars, head of OTB Solar's new business development division said that "inkjet printing is becoming the next generation solar-cell manufacturing technology. Using silicon-ink processing, Innovalight will dramatically improve the cost and efficiency of today's silicon solar cells. This partnership is a great example of how we take solar cell production to the next level."

Innovalight announced in January that Roth & Rau had installed a scaleable 10-MW pilot production line, which combined aspects of traditional solar-cell process tooling and the venture-backed company's proprietary silicon ink manufacturing systems.

Suniva buys PV wafer/cell crack detection system from Ultrasonic Technologies

Solar-cell maker Suniva has bought a crack detection system from Ultrasonic Technologies. The Norcross, GA-based manufacturer will use the tool, equipped with fully automatic functions, for incoming quality control of silicon wafers as well as final inspection of its monocrystalline silicon solar cells.

The RUV-2.2 system will help Suniva reduce wafer breakage and other production costs by nondestructively detecting and removing mechanically unstable wafers and cells, which have been affected by periphery of bulk cracks.

Suniva and Ultrasonic Technologies will continue to collaborate on how to improve the manufacturing line, and the tool supplier will also perform offsite crack detection of the cell maker's inventory at its own facility in Tampa, FL.

Taiwan's INER adds another Aixtron MOCVD tool for solar cell development

The Institute of Nuclear Energy Research (INER) in Taiwan has placed a follow-up order for an Aixtron AIX 2800G4 planetary reactor system for MOCVD growth of germanium/III-V based solar cells. The MOCVD tool is to be delivered in the 15x4 inch wafer configuration with options to utilize up to 200mm wafers. The system was due to be shipped to INER in the second quarter of 2009.

"Thanks to the approval of a second MOCVD equipment budget, we are in position to acquire a second Aixtron AIX 2800G4 system, which will allow us to separate development from pilot manufacturing," noted Dr. Cherng-Tsong Kuo, Project Leader of the High Concentration Photovoltaic System Research and Development Project. "Aixtron MOCVD tools have established an excellent reputation for the manufacture of solar cell materials. The utility of these tools is backed up by the local Aixtron team which has been responsive at all times, and we anticipate adding to our good working relationship in the months ahead."

INER has built a working prototype that demonstrated energy conversion efficiency over 35%. It is accumulating the epitaxy manufacturing capabilities required for production of solar cells that will have conversion efficiencies of 45%.

Fraunhofer ISE orders Aixtron's 2800G4-R MOCVD

The Fraunhofer Institute for Solar Energy Systems (ISE) has ordered an Aixtron 2800G4-R MOCVD tool with automated wafer handler, due to arrive in the fourth quarter of 2009.

This tool will enable the company to change wafer configurations flexibly to 8.5 inches and will also allow for the incorporation of advanced in-situ monitoring technologies.

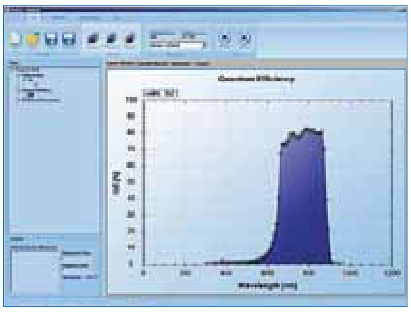
Comdel ships power generator to Korea-based solar cell manufacturer

RF and DC power supplier Comdel, Inc. has applied its experience to the photovoltaics industry and has been tapped to supply its CXH 50k 40MHz generator for solar applications to an unnamed Korean solar company. The CXH generator is one of the highest frequency and power generators for solar applications, and will be used in the production of glass-type solar cells.

Providing a power source of between 15kW and 100kW, the CXH power supply portfolio is designed to operate at a fixed frequency over the range of 2 to 40MHz.

Product Briefings

LOT Oriel



New Product: LOT Oriel offers spectral response characterization of solar cells

Product Briefing Outline: LOT Oriel has introduced the SPEQUEST, a spectral response measurement system that incorporates a monochromatic light source. SPEQUEST also operates a QTH light source with a dual-grating Czerny Turner spectrograph to provide monochromatic light between 300 and 1700nm. For UV measurements below 300nm, SPEQUEST can be upgraded with a xenon arc lamp to provide output down to 200nm.

Problem: In today's rapidly evolving markets for solar cells, characterisation of the spectral response (quantum efficiency) is one of the most important parameters for research and development of new materials and devices but also for production and quality control.

Solution: SPEQUEST takes into account the latest developments in solar cell research; the modular and very flexible setup enables quick and simple adaptation to research and production requirements. Accurate quantum efficiency measurements of solar cells require a light source for biased characterization measurements. The standard SPEQUEST system comes with a white light bias lightsource, with multicolour bias light sources also available. The electrical signal is fed into a Lock-In amplifier via a Melles Griot large-range IV converter.

Applications: All type of solar cells: polysilicon; c-Si; mc-Si; nc-Si; III/V compound cells; thin film; CdTe; CIS; CIGS; Si; 3rd generation; organic polymer; dye. Single and multijunction devices; spectral range from 200 – 2500nm; variable bias light (white light or multicolour).

Platform: Electrical probing is done via standard PH100 Karl-Suess-Probes. PHOTOR software operates under Windows operating system, and the company is currently developing support for Linux and MacOS platforms. Algorithms used in PHOTOR meet all IEC standards for spectral response measurements.

Availability: Currently available.

DR YIELD

DR YIELD's SolarDataCenter enables modular solar cell productivity management

Product Briefing Outline: DR YIELD has introduced its new 'SolarDataCenter' software solution that allows solar cell manufacturers to deploy yield management software (YMS), statistical process control (SPC) software and advanced process control (APC) tools in one integrated, highly modular solution. SolarDataCenter can accommodate the data volume generated by manufacturing equipment, measurement and inspection tools and the cell sorters from small to large manufacturing lines. The system can handle manufacturing of solar cells in batches or on conveyer belts, with or without tracking systems.

Problem: Continued yield and productivity improvements are required to reduce production costs, resulting in the need for better systems to monitor tool operations and prevent production loss by identifying early warnings of impending manufacturing problems.

Solution: SolarDataCenter integrates data from all sources in a wafer cell factory, including cell sorter data, equipment parameters, and measurement and inspection data, even in large volumes. While the yield management module facilitates effective engineering analyses with a huge range of data visualization and correlation functions, the SPC module can prevent production loss by identifying early warnings of impending manufacturing problems, and the APC module enables better distributions for optimized production. This module allows active recipe control like run-to-run forward and feedback control.

Applications: Solar cell manufacturing lines, either in batch or conveyor production formats, either with or without tracking systems.

Platform: Designed as a modular system around one central data server, it covers the functionality of YMS, SPC and APC software – or just those components currently required with the option to activate other features at a future date.

Availability: Currently available.

KUKA Systems

KUKA Systems' ultra-thin wafer handler avoids breakage

Product Briefing Outline: KUKA Systems has designed a new generation of wafer gripping solutions that is based on KUKA's KR Sixx and Scara Robots. As the PV industry strives for thinner wafers and higher efficiency cells, KUKA has developed a new high-speed ultra-thin gripper made of carbon fibre, which allows for fast gripping and precise positioning at the same time. A new ultrasound and vacuum-based touchless gripping and transport system developed by Zimmermann & Schilp is used to avoid wafer warp and vibration while fast and accurate pick and place operations are carried out.

Problem: Manual handling of wafers needs to be avoided due to the high breakage rate. As thinner wafers become adopted in high volume production there is a need for new automated wafer-handling techniques that reduce breakage and improve productivity.

Solution: The carbon fibre wafer gripper allows high speed gripping and precise positioning by integrating multiple vacuum channels which firmly grip the wafer for fast movement and soft holding for accurate positioning. A special configuration allows an easy rotation through the centre of the cells for placing in cell carriers for wet benches, CVD processing applications, etc. By using carbon fibre, a gripper thickness of 3mm is made possible, allowing for single wafers or cells being picked from carriers from any position. Touchless gripping is enabled by an ultra-sonic cushion that ensures non-contact gripping, avoiding wafer warp and vibration, while the 'Ultrasound Air-Bearing-Technology' allows different substrate sizes in one machine and high distances during the picking process.

Applications: Crystalline solar wafers.

Platform: Due to a very low demand of compressed and cleaned air, the systems are claimed to have a large advantage compared to other solutions based on the Bernoulli technology. The non-contact gripping lessens the need for repair or spare parts as suction cups or cushions are no longer in direct contact with the cells or wafers.

Availability: Currently available.

Product Briefings

Oerlikon Systems

Oerlikon Systems' 'SOLARIS' offers high-throughput single wafer processing

Product Briefing Outline: Oerlikon Systems has launched the 'SOLARIS,' a new production solution that simplifies the manufacturing of crystalline solar cells. Billed as the first single substrate 'Nanotech Machine' designed for mass production, the system is designed to deposit very thin layers of silicon nitride on the front of the solar cells. The system, due to its flexible configuration, can also coat the wafer backside with various materials.

Problem: Production costs of solar energy do not only depend on cell efficiency but also on the productivity of the manufacturing process. The existing standard fabrication method for coating crystalline solar cells is based on complex processes with high demands made on cleaning and manual maintenance.

Solution: In the Solaris system, each wafer is handled and coated separately. The system incorporates six coating chambers, a special carrier transport mechanism and a wide range of potential layer material. The machine is able to treat standard wafer formats from $125mm^2$ to $156mm^2$, with an average of up to 1,200 wafers per hour (dry cycle time < 3.0 sec). Changing substrate formats, layer materials or processes takes less than an hour. A new system at a customer site can be ramped up in less than one week, according to company estimates.

Applications: The multilayer capability allows passivation and SiN coating on the front side as well as passivation and Al-contact layer on the backside.

Platform: The SOLARIS platform dimensions are 2.0 x 3.3 metres, resulting in an acclaimed 80% less floor space usage compared to competitive solutions. The fully automated solution requires minimal maintenance and uses less power (-50%) compared to traditional tools. Low maintenance requirements result in significantly higher uptime.

Availability: Currently available.

3D-Micromac AG

3D-Micromac offers customized integrated laser system for R&D through to production

Product Briefing Outline: 3D-Micromac AG's microSTRUCT Pvario, a modular laser micromachining workstation used for photovoltaic applications in research and development environments, can also be transferred to production requirements. The system is suitable for the processing of fragile silicon wafers and thin-film systems and can perform a wide range of other micromachining tasks, such as micro drilling, micro structuring, and micro cutting of different materials.

Problem: In order to achieve the reduction of manufacturing costs and to increase the efficiency in parallel, manufacturers of solar cells readily invest in state-of-the-art production lines. In such fabs, the utilization of lasers guarantees high efficiency and throughput at best attainable precision and minor damage to the cells.

Solution: Adaptable to different configurations, the workstation is suitable for applications both in R&D and industry. The modular concept allows the possibility of retrofitting the system with different automation systems, such as wafer and substrate handling systems. The system can be equipped with up to two different laser sources depending on customers' needs. Available options are short pulse, disc, and fiber lasers with different wavelengths and pulse durations. Depending on the chosen laser source, it is possible to machine materials with highest thermal conductivities, lowest melting points, and as well as transparent dielectric, superconducting or organic materials.

Applications: Most important machining procedures include laser surface structuring in process steps P1, P2 and P3, edge isolation, and laser marking of thin-film solar cells on glass-based and flexible substrate wafer-based solar cells.

Platform: The system is available as a stand-alone product. A customized integrated solution for existing, fully automated production lines for laser machining of thin-film solar cells is also available.

Availability: Currently available.

Bosch Rexroth Corporation

TSsolar conveyor line from Bosch Rexroth operates in high-temperature environments

Product Briefing Outline: The Linear Motion and Assembly Technologies group from the Bosch Rexroth Corporation has developed a special transfer system that takes into consideration the special demands of solar production. The TSsolar Conveyor is designed with carefully-engineered features and materials to serve the unique manufacturing requirements of wafer-based solar cell modules or thin-film technology modules.

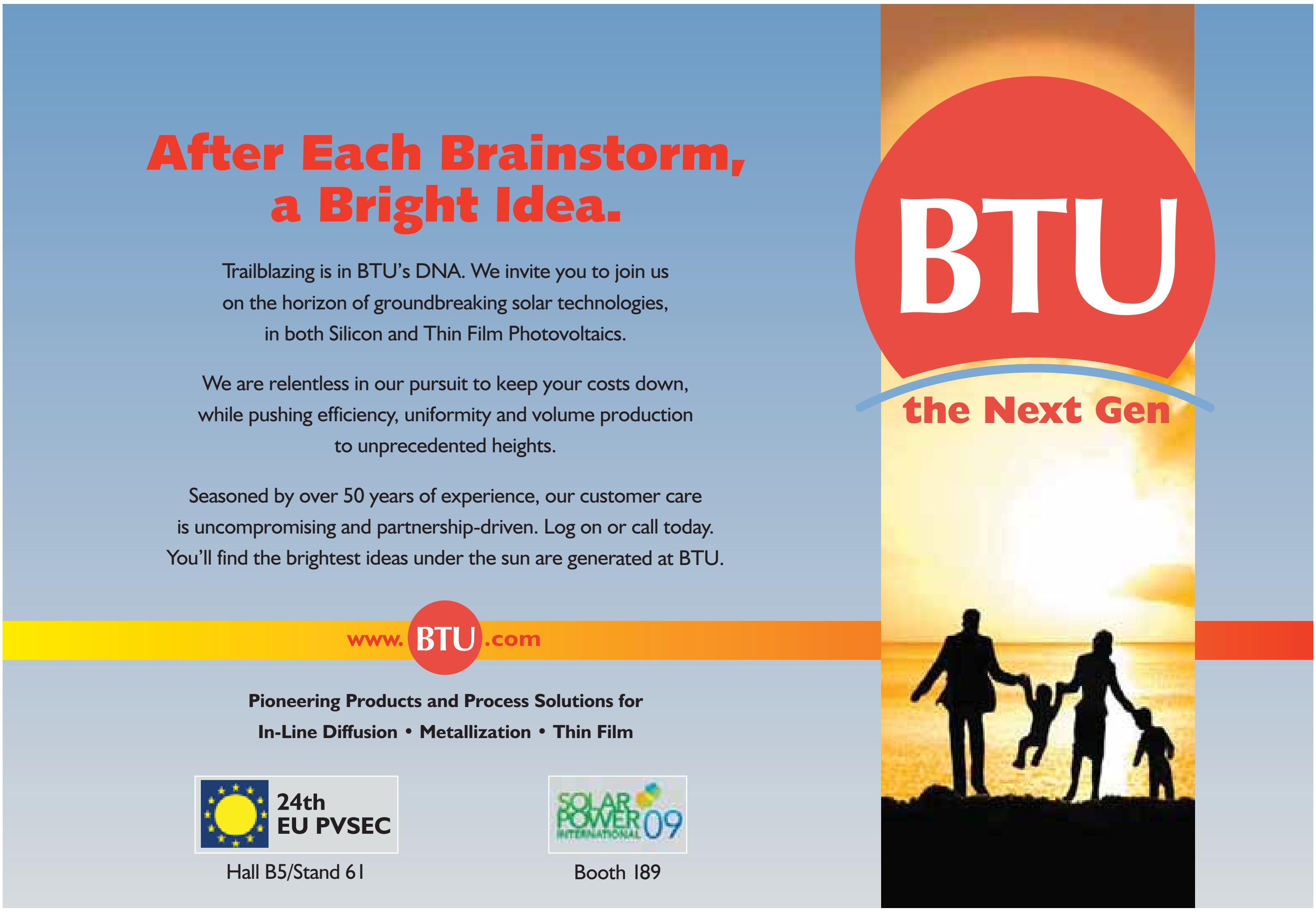
Problem: With the explosive growth in demand for solar power technology, manufacturers are ramping up solar cell production across the globe. Wafer-based and thin-film solar module manufacturing processes are extremely complex and sensitive, demanding ultra-smooth, vibration-free material transport.

Solution: Bosch Rexroth has incorporated high-friction belt technologies, special routing and handling devices, and variable speed drives into the TSsolar conveyor line to help ensure a gentle material flow, an extremely clean, particulate-free operation, and the ability to operate in the high-temperature environments (up to 200°C) required for solar module manufacturing.

Applications: Wafer-based solar modules or thin-film technology modules.

Platform: TSsolar conveyors are based on Rexroth's TS family of modular conveyors, designed for a wide range of flexible assembly and material transport applications for both automated and manual assembly operations. Rexroth's broad offering of conveyor components for transferring, routing, stopping and positioning products of all types gives the company an ideal starting point in providing effective technologies to solar panel manufacturers.

Availability: Currently available.


After Each Brainstorm, a Bright Idea.
Trailblazing is in BTU's DNA. We invite you to join us on the horizon of groundbreaking solar technologies, in both Silicon and Thin Film Photovoltaics.
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LOCAL SUPPORT
VACUUM EXPERTISE

Product Briefings

Despatch Industries

Despatch Industries' thermal oxidizer destroys 99% of VOCs

Product Briefing Outline: Despatch Industries has launched its new patent-pending VOC Thermal Oxidizer, designed and engineered to destroy over 99% of volatile organic compounds (VOCs) from gasses exhausted during the drying of photovoltaic metallization pastes in solar cell manufacturing.

Problem: An important process step in the manufacturing of photovoltaic cells is contact firing of the screen printed metallization pastes. A drying step follows each of these printing steps with the final drying step occurring just prior to contact firing of the pastes (the process of thermally creating a robust electro-physical connection to the silicon). Ductwork between the drying furnace and any abatement equipment is at risk of becoming fouled with condensed VOCs if not thermally managed. Improper cleaning of condensation and facility ductwork can create equipment maintenance issues and hazardous conditions.

Solution: The Oxidizer mounts directly to the furnace to eliminate any risk of solvent condensation. Oxidizers are located at the entrance and exit of the dryer section to achieve more effective abatement with faster belt speeds. This solution also meets legal and environmental requirements regarding the capture and destruction of organic materials.

Applications: The VOC Thermal Oxidizer can destroy 100% of odours; and is capable of 99%+ destruction of organic particulate matter; 99%+ destruction of VOCs and 99%+ destruction of hazardous air pollutants.

Platform: The VOC Thermal Oxidizer is available on new firing furnaces and on existing Despatch firing furnaces via field retrofit. A total of two Oxidizers are provided per dryer and comprise a heating element, the venturi exhaust and the facility hood connection. There is no need to plumb in propane or other combustible gasses, and the system claims zero NO_x emissions.

Availability: Currently available.

Heraeus

3rd generation front-side silver paste from Heraeus offers higher efficiency

Product Briefing Outline: The Photovoltaic Business Unit of Heraeus has introduced its 3rd generation front-side silver paste (SOL 953) for lightly doped silicon solar cells. SOL953 and all of the Heraeus SOL Series of silver pastes are specially formulated to provide better yields and higher output for cell manufacturers. The specially designed front side pastes offer higher efficiency and the lead-free backside bus bar silver pastes correct adhesion and coverage.

Problem: Silver thick-film contact paste is screen printed on the ARC and forms a contact with the emitter after reacting with the ARC during contact firing. Correct aspect ratio and fine line resolution are required for optimum cell efficiency.

Solution: The SOL953 paste is cadmium-free and specifically designed for high sheet resistance emitter applications, providing excellent aspect ratio and fine line resolution for advanced cell designs. SOL952 is a front side Ag conductor for single and multicrystalline silicon solar cell wafers. It easily penetrates the SiNX:H anti-reflective coating during the firing process and provides low contact resistance. SOL952 can be co-fired with commercially available backside Al and Ag/Al pastes.

Applications: Front-side Ag conductor for single and multicrystalline silicon solar cell wafers.

Platform: SOL953 paste is typically dried in an IR dryer with set points of 250-300°C in less than 20 seconds or 150°C for 10 minutes in a circulated air oven. Fired in an IR furnace with Actual Wafer Peak Temperature at 740-800°C, the material is guaranteed to meet specifications for six months from date of shipment.

Availability: Currently available.

Rehm Thermal Systems

Rehm Thermal Systems adds new series of firing systems for solar cell metallization

Product Briefing Outline: Rehm Thermal Systems recently announced the launch of an advanced new series of firing systems for solar cell metallization. The RFS and RFS-D Fast Firing Systems offer a range of advanced process features and thermal control recently underwent exhaustive testing by the Fraunhofer ISE.

Problem: The metallization step is critical as it often sets conditions and limitations for the other process steps. The main metallization technique used today in Si solar cell production is screen-printing of metallic pastes, specifically, Ag pastes for the front side, Al pastes for most of the rear side, and Ag or Ag-Al pastes for the solder pads at the rear.

Solution: The new Rehm Fast Firing Systems feature a host of innovative design features that are claimed to enable new levels of metallization process performance, including very high throughput rates (e.g. transport speeds up to 6m/minute and multiple lanes). Flexible transport systems are used to enable single-, dual- and triple-lane handling of wafers. An integrated residue management system maintains the clean process chamber that supports extended maintenance intervals. The system includes profile control and process monitoring including reference products for baseline profiling. Rehm Visu2 software includes traceability tools, remote diagnostics and an extensive product library. Separate heating and cooling zone transports are designed to improve the cooling gradient and shorten the necessary cooling zone length.

Applications: Solar cell metallization.

Platform: A complete lineup of thermal solutions for metallization now includes the RFS Firing System and RFS-D combination Drying and Firing System in addition to the model RDS series dryers. All feature low energy consumption and a compact footprint that are designed to optimize factory space while minimizing expense.

Availability: Currently available.

Product Briefings

Magma Design Automation, Inc.

Magma's 'YieldManager Solar' software improves yield and cell production costs

Product Briefing Outline: Magma Design Automation, Inc. has introduced YieldManager Solar, a yield enhancement software system customized for solar fabs that is intended to improve energy conversion efficiency, increases yield and reduces the manufacturing costs of solar cells. Based on software proven in the semiconductor industry, YieldManager Solar provides fast, accurate analysis and correlation of all metrology, inspection and performance data used throughout the solar cell manufacturing process. With this information, solar fab test and production engineers can quickly identify and correct root causes of solar energy conversion efficiency and yield degradation caused by subtle fab processing fluctuations or instability.

Problem: Inefficient energy conversion and the need to produce a very large number of wafers contribute to the high cost of solar-converted electricity and slow the growth of the alternative energy market. Solar cell production involves using a variety of manufacturing tools and equipment, each of which presents data in a unique format, which can lead to problems when identifying the source of errors.

Solution: YieldManager Solar can collect and organize current and historic manufacturing data from all the process equipment. It allows fab engineers to easily filter data by lot, ingot, substrate, wafer or other parameters and to generate customized reports and dashboards. With this comprehensive analysis system, problems can be identified quickly and easily.

Applications: Solar cell production data analysis.

Platform: This yield enhancement software system has been customized for solar fabs based on software proven in the semiconductor industry.

Availability: Currently available.

Semilab SSM

Semilab SSM's SRP metrology system provides density and resistivity depth profiling

Product Briefing Outline: Semilab SSM, a division of Semilab, has launched its newest member to the 'NanoSRP' family of metrology products. Designed for small and mid-tier sized semiconductor and solar cell manufacturers, the SRP Express 170 is a manual system that provides density and resistivity depth profiling using spreading resistance profiling technology (SRP).

Problem: To date, small and mid-tier companies have had to choose between high-end, high throughput systems designed to support multiple samples at a time or obsolete, low-end manual systems of about 10 years of age. These old systems are DOS based, unfamiliar to younger operators, and the PC hardware is prone to failure, while spare parts are becoming increasingly difficult to source.

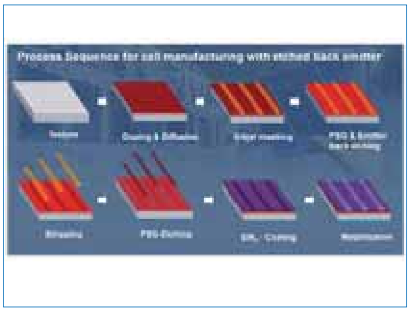
Solution: With the SRP-Express 170 system manufacturers can replace their aging manual systems or outsourced services to bring a cost-effective modern spreading resistance profiling system in-house. The SRP-Express 170 features a modern touch-screen based Windows computer interface, which provides a user-friendly, time-efficient operation and analysis platform. A vision system that incorporates an electronic camera makes operation faster and acquisitions of images possible. The use of a modern piezo drive allows for a very smooth operation with higher resolution and flexibility.

Applications: SRP is used whenever an electronic semiconductor structure needs to be profiled. In epi growth, SRP is used to check on autodoping, outdiffusion, hydrogen annealing, and reactor problems like temperature instabilities. After ion-implantation SRP controls dose, depth, and sheet rho and allows for transistor threshold adjustments. SRP can verify Silane or dopant gas cleanliness to avoid massive production scrap.

Platform: The SRP Express 170 probing setup is integrated into a light tight cabinet, with integrated electromagnetic, vibration and acoustic isolation.

Availability: Currently available.

Schmid



Schmid's inSECT technology simplifies selective emitter processing and reduces costs

Product Briefing Outline: Schmid of Freudenstadt, Germany has created a new type of crystalline solar cell with selective emitters. The 'inline Selective Emitter Cell Technology,' or inSECT, can be integrated into the manufacturing process and increase efficiency by up to 0.7 percentage points.

Problem: Selective emitters combine a low resistance of the emitter directly under the contacts (high n-doping) with a somewhat higher resistance in the areas between the contacts (low n-doping). However, these concepts always required two separate processes for diffusing the phosphorous, which can be expensive and can lead to imperfection.

Solution: The inSECT concept involves only one proven, standard diffusion process instead of carrying it out in two stages. Only one further process step is necessary to reduce the surface between the subsequent contacts down to a depth of 50nm. Thinning the material reduces the high rate of doping with phosphorous atoms; however, the area on which the contacts are later printed remains intact. For the selective etching process, which produces these steps, a mask is again required; however, for this purpose wax only needs to be applied to the surface with a special ink jet printer. Such contact-free printers are the Schmid Group's own development and achieve a positioning precision of ±15μm at a printing resolution of 900dpi. To etch, inSECT technology uses a thin solution of hydrofluoric acid, nitric acid and water, which is gentler on the wafers and more economical. The electrical degree of efficiency can be increased from, e.g., 16.7% using homogenous emitters to 17.4% using selective emitters, which corresponds to an increased output of 4%.

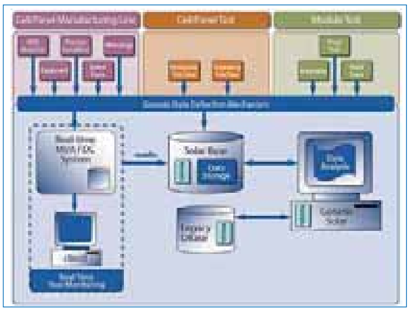
Applications: Crystalline solar cells.

Platform: The Schmid Group's system is designed for integration into an inline production line adding only 5m to its length.

Availability: Final trials are currently being held with test wafers from customers; serial production is due to start later this year.

Product Briefings

MKS Instruments, Inc.



MKS Instruments' 'Genesis' Solar Yield Management System enables fast track yield analyses

Product Briefing Outline: MKS Instruments, Inc. has launched the Genesis Solar Yield Management System for solar cell manufacturers. Its patented, solar domain specific data analysis and visualization software is based on proven, reliable semiconductor and flat panel analytical tools. It permits users to quickly identify and correct solar cell production failures, and enables faster production ramps for continuous yield and cell efficiency improvement.

Problem: There is a growing need to quickly identify and correct solar cell production failures, achieving faster product ramps, higher yields and improved cell efficiency.

Solution: The Genesis system delivers yield solutions in a cost-effective and expandable platform. The modular architecture of the system allows for ease of scalability and flexibility from R&D to pilot line to full production. The Solar Base integrated database contains all of the metrology measurements, quality measurements and process data necessary for one-stop engineering data analysis, and the enterprise Metadata manager enables three-tier connectivity to any existing database, eliminating the need to duplicate storage of engineering and production data. It also provides connectivity to any legacy databases for seamless data unification through extraction along with full drill-down capability from any chart or previous analysis.

Applications: Solar cell production.

Platform: The system includes MKS's 'Yield Mine' automated decision-making technology. The Design of Experiments module enables process optimization and the Genesis Workflow Development Platform with a full API library allows users to create, extend, automate and share any custom analyses critical to yield improvement efforts. Operating systems compatible are Windows 2003 Server, 2008 Server, Linux Red hat AS/ES 4.0 or later and Unix Sun Solaris 10, 9 and 8.

Availability: Currently available.

Lotus Systems GmbH

Automated spray cleaning system for cleaning of trays from Lotus Systems

Product Briefing Outline: Lotus Systems GmbH, a manufacturer of wet process, cleaning, and chemical management systems for photovoltaic, semiconductor and MEMS production, has developed a vertical spray cleaner for cleaning trays from nitride residues.

Problem: Coating solar cells with silicon nitride results in a build up of nitride on the cell trays. In order to maintain mechanical properties these residues must be removed periodically. Usually, manufacturers have an external service clean the trays in immersion baths and then return them. This takes up an unnecessary amount of time and money and requires additional trays to continue production. Significant quantities of trays break when they are handled. On top of everything, immersion baths use up large volumes of chemicals.

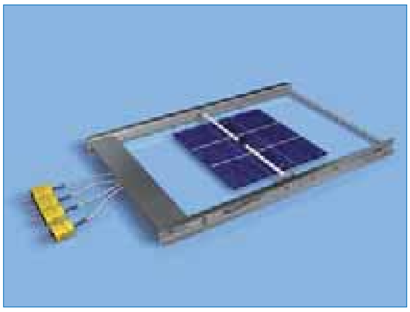
Solution: Lotus Systems has developed vertical spray cleaners that allow manufacturers to clean the trays themselves – quickly, efficiently and at their own facilities. Spraying ensures that there is always a reactive medium on the surface and makes cleaning two to three times faster compared to immersion cleaning. Only about a tenth of the chemicals are needed. Uniform cleaning of all surface areas is achieved by sophisticated arrangement of the nozzles and linear motion of the spray bars. With this technology LOTUS brings the costs down to about €20 per carrier. This means about 75% savings compared to costs for external cleaning. Plus, the carriers are ready for use again after 12 hours. The vertical spray cleaners, with their extremely small footprint of 1.8 sq. metres, can easily be integrated into a cell fab.

Applications: Tray cleaning, removal of SiN by HF/HNO_3.

Platform: The tool can handle six trays up to 1840 x 1000mm or 3 trays up to 2000 x 1500mm with an uptime of >98 %. Optionally it can be offered in FM4910-compliant material and the waste-water tank can be equipped with a drain pump instead of gravity drain.

Availability: Currently available.

KIC



The e-Clipse solar cell thermocouple system from KIC offers precise, repeatable readings

Product Briefing Outline: KIC has introduced the e-Clipse, a solar cell thermocouple (TC) attachment fixture. The compact profiler and thermal shield accommodate width and height restrictions of metallization furnace tunnels.

Problem: TC attachment has been a long-standing challenge for the production of solar cells. Traditional TC attachment methods have suffered from inaccurate and non-repeatable readings. The e-Clipse addresses this challenge and helps manufacturers advance toward better thermal process control, resulting in higher solar cell efficiencies.

Solution: The e-Clipse promises fast and convenient TC attachment, as well as repeatable profile readings. It features four spring loaded TCs within a lightweight fixture that also holds the solar wafer. The TCs have disk-shaped beads, rather than the traditional spherical shaped beads. These flattened TCs offer a more reliable contact to the surface of the solar wafer, as well as repeatable profile readings. To operate, the user simply slides a solar wafer into the fixture and the TCs seat themselves automatically. Today's solar wafers break easily due to their inherit brittleness and thinness. The e-Clipse allows for quick replacement of broken wafers. Four standard type K TC connectors plug into the profiler.

Applications: Metallization furnace.

Platform: Graphical navigation software provides ease of use. Flexible software accommodates numerous current and future needs. Twenty readings per second allow for more accurate profile data. Manual 'prediction' feature comes built-in. 'Area under the curve' measurements are included.

Availability: Currently available.

Wet processing trends for silicon PV manufacturing

Kris Baert, **Paul W. Mertens** & **Twan Bearda**, IMEC, Leuven, Belgium

ABSTRACT

Wet processing can be a very high performing and cost-effective manufacturing process. It is therefore extensively used in Si solar cell fabrication for saw damage removal, surface texturing, cleaning, etching of parasitic junctions and doped oxide glass. PV manufacturers have succeeded in bringing down the cost of ownership of batch-type and in-line tools. The trend to back-side passivated solar cells requires cost-effective single-sided processing solutions. With the future pointing to ever-thinner silicon solar cells, handling these thin wafers in wet environments is a major challenge for any wet process. This paper reviews the major wet processing steps, emphasising some new developments and unknown issues, and provides a more general outlook on trends in wet processing.

Introduction

With the aim of realising aggressive future cost targets of 0.5 €/Wp put forward in strategic roadmaps [1], every step in the process sequence is under severe cost pressure. At the same time the search for higher efficiencies is on. This dual request calls for the build-up of thorough understanding and characterization of each process step. It can be expected that based on such knowledge, critical aspects can be improved, leading to higher cell efficiencies, while process specifications for non-critical aspects can be relaxed and offer cost savings. As wet processes play an important role in solar cell manufacturing, some solutions to these issues are presented, such as single-sided wet process sequences that can alleviate some of the concerns, assuming that throughput requirements can be maintained. There is also potential for novel wet processes. For example, Cu electroplated metallization could substitute Ag screen-printed metallizations, while high-performing passivating layers that require exquisite (wet) cleaning sequences could employ process know-how from ultraclean ULSI cleaning cycles.

Standard process sequence of Si solar cells and cost reduction opportunities

Silicon feedstock material

Wet processing is used in several stages of the silicon supply chain. Some wet

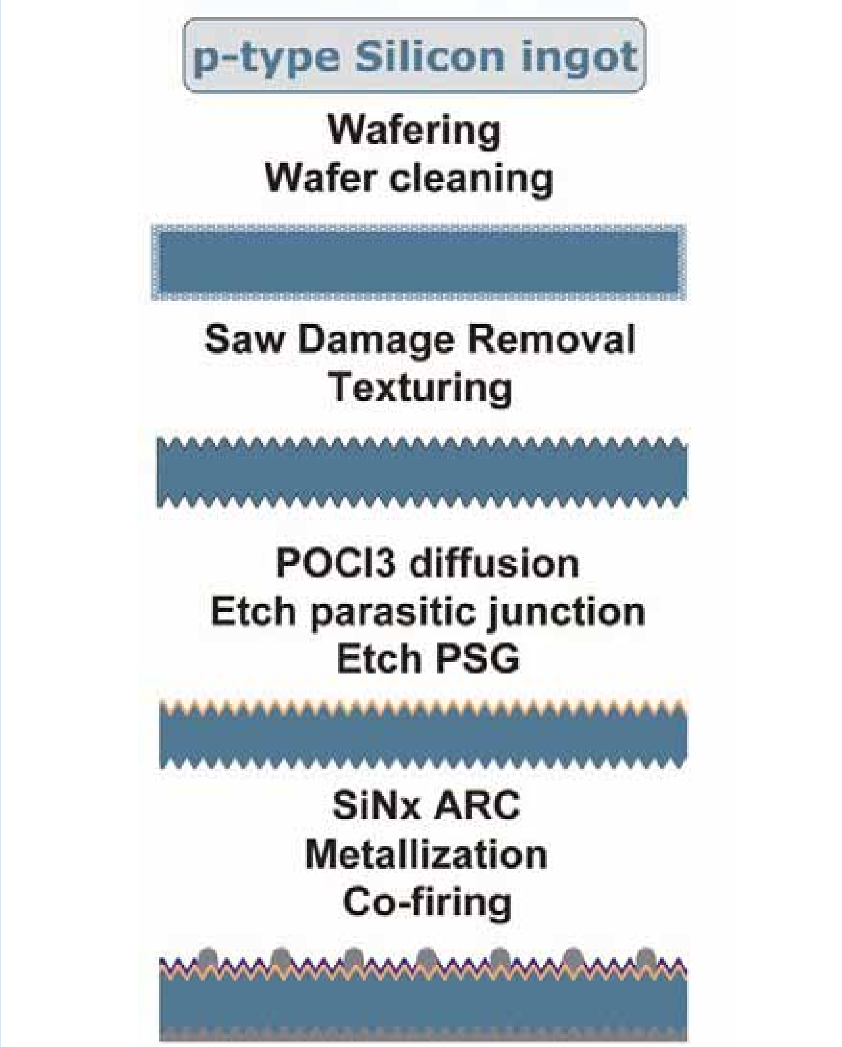


Figure 1. Standard industrial process flow for silicon solar cells.

treatments occur at the wafer producer side such as HNO_3-based cleaning of the pure silicon chunks prior to pulling or casting.

Wafering

The general manufacturing flow of a standard Si solar cell is depicted in Fig. 1. After the wire sawing process, the wafers are singulated from the silicon ingot and wet cleaning is applied. The abrasive slurry used in the sawing process can leave slurry and sawing residues, and metallic contamination left behind from the wire will eventually have to be removed from the wafers in the typically proprietary wafer cleaning process. At this stage, the wafers are shipped to the cell manufacturer.

At this point, the wafers are usually damaged to a depth of over 5 to 10µm by the mechanical wire sawing process and some metallic contaminants may also have diffused into the first few µm. This adversely affects the mechanical integrity of the wafer as well as the cell efficiency by recombination. Typically 10µm of damaged layer is removed in the saw damage removal (SDR) step by wet chemical etching (either in a alkaline or HF/HNO_3-based mixture) of the damaged layer.

Prior to applying the SDR, a wet cleaning step is performed to remove organic contaminants that may have deposited during shipping and storage and could (locally) mask or retard the SDR process. An alkaline mixture is usually used to lessen further damage to the silicon, in which case the surface should be free of all native oxides. Alternative organic removal solutions that could be more cost effective could be dilute HF/O_3-based cleans [2].

Texturing

The SDR step is immediately followed by the texturing process, which creates an intentional topography on the surface. The texturing is essential for reaching high efficiencies as it results in 'light trapping' inside the cell of the photons at the lower end of the energy spectrum, which might otherwise escape prior to being absorbed in today's thin wafers which are only 180 µm thick. The ideal topography of the textured surface is a critical trade-off between increased effectiveness of light trapping versus increased surface recombination.

With cost reduction in mind, the SDR and texturing processes are typically done in one process sequence. Two types of chemistry prevail, with best results obtained by an alkaline etch based on KOH (or NaOH) which etches silicon

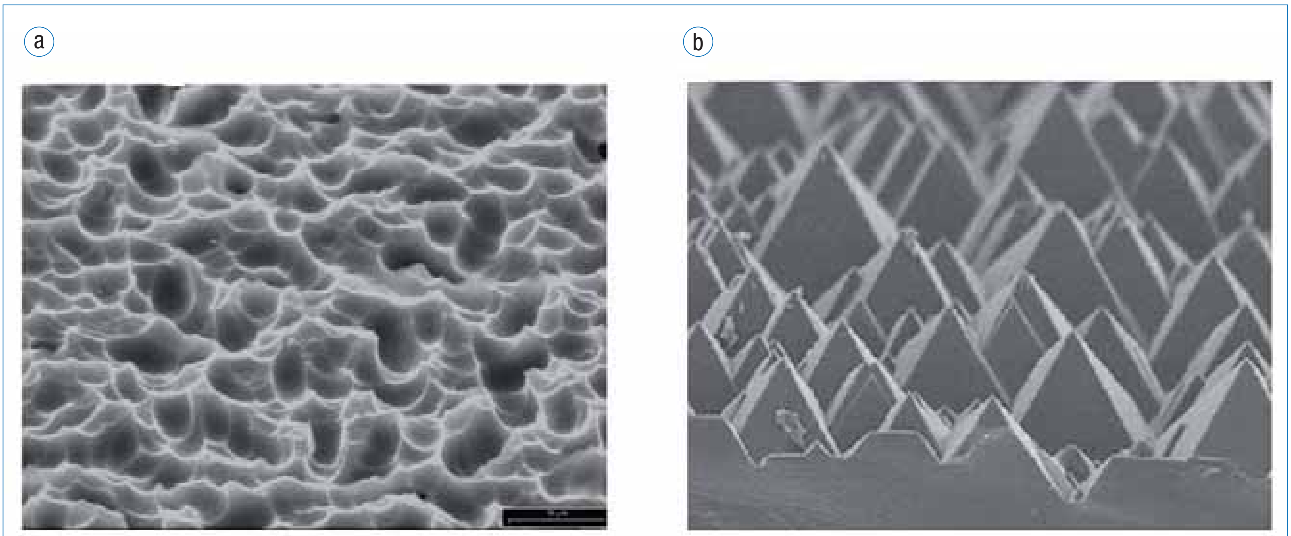


Figure 2. SEM pictures showing (a) random texture obtained after an isotropic etch in HF/HNO_3 mixtures and (b) random pyramids after an anisotropic etch in KOH solution.

etches silicon anisotropically and results in a random pyramid surface exposing only <111> planes (Fig. 2a). In practice, IPA is added to the solution at a temperature slightly above the boiling point of the IPA (which is recaptured in the solution).

> "The ideal topography of the textured surface is a critical trade-off between increased effectiveness of light trapping versus increased surface recombination."

However, this process is only effective on (100) monocrystalline silicon, not on multicrystalline silicon. An infinite orientation selectivity of the texturing, cleaning and etching chemicals may not be desirable as it results in very sharp edges of the texturized surface. Subsequent processes such as amorphous silicon deposition may be affected by this. Various schemes exist to 'round off' the sharp edges, for example by means of wet chemical polishing [3, 4] or by repetitive wet chemical oxidation/etch steps.

For multicrystalline silicon, an etch mixture of HF and HNO_3 usually in combination with acetic acid is used to etch the silicon isotropically and also creates a certain topography on the wafer (Fig. 2b). This process asks for precise control as it is a very vigorous exothermic reaction, and tends to form a porous Si layer on the surface, which is subsequently removed in a cold alkaline solution [3]. While the electro-optical performance of acidic etching may not match that of random pyramids, the process is widely used since it is applicable to multicrystalline silicon and the etch time of the process is significantly lower than alkaline etches. After the alkaline treatment process, a HCl cleaning step is applied to remove the metal impurities, particularly the alkali residues.

Various manufacturers provide equipment for wet processes [5]. Batch-type tools have typical batch sizes of at least 100 wafers. In-line tools are also available, especially for the isotropic etch process.

In order to avoid wasted effort in this scheme, a close coupling should be set up between the substrate supplier and the PV cell manufacturer. Clear specifications should be given as to how clean the wafers will be when delivered by the supplier to avoid unnecessary excessive cleaning at either side. It seems logical that SDR etch should be performed by the wafer supplier as it is a process that should be matched to the actual sawing process. As texturing is already cost-effectively done in combination with the SDR etch, one could consider transferring this step to the substrate supplier. Indeed, as the texturing techniques and methods seem to converge it may be subject to standardization and could be transferred to the wafer manufacturing location as it could result in further cost reduction. For decades, wafer suppliers have used and improved damage removal and (backside) wafer texturing with caustic processes as well as with acidic processes for the ULSI wafer market. Additionally, wafer suppliers have developed excellent track records in low-cost manufacturing and delivering high standards of consistency and quality control.

It should be noted that for future high efficiency cell concepts such as i-PERC [7] and back contact cells the wafer texture should be present on the front side only (Fig. 3). Therefore, single-sided texturing processes should be developed, which will most likely fit better with in-line processing rather than with batch processing. Needless to say, the relatively long process times required for the caustic texturing are challenging to implement in an in-line production line. This is clearly an area where faster chemical processes are highly desirable.

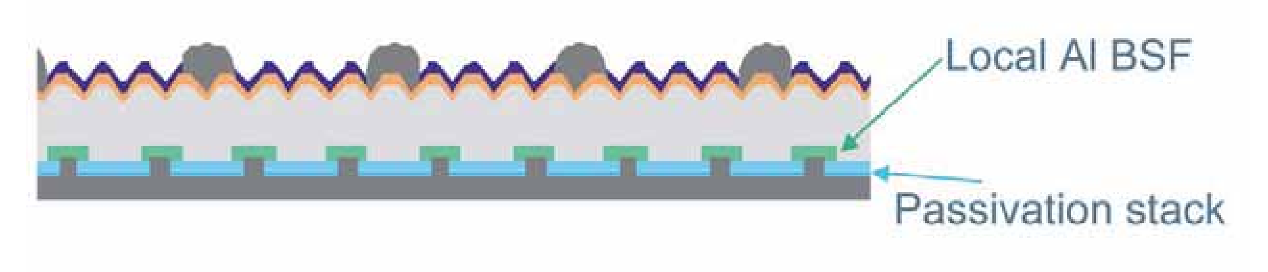


Figure 3. In the i-PERC process, an additional dielectric stack passivates the backside and therefore allows for higher cell efficiencies, especially for cells thinner than today's standard of 180μm.

Emitter

The process sequence continues with the formation of the emitter. For p-type substrates, the emitter formation itself is typically done by gaseous diffusion of $POCl_3$ in a furnace. For this process, not only is the wafer front-side doped (intentionally), but the wafer edges and back-side are also doped unintentionally, or in the case of back-to-back positioning, only partially. The $POCl_3$ diffusion also leaves a P-doped oxide glass that must also be etched. The PSG etch is often performed during a HF step. Both of these processes are offered in batch and in-line tools similar to those used in, and both processes can be combined in one tool.

> "Passivation requirements will become even more stringent in view of the trend toward using less highly doped emitters in high efficiency solar cells."

An alternative and possibly more cost-effective approach for emitter doping [8] is based on one-sided in-line deposition of H_3PO_4 liquid aerosol and subsequent drive-in in a furnace step. This approach avoids back-side parasitic doping and more importantly eliminates the need for a HF step to remove the PSG. In order for this process to be successful, good dosing and uniformity is required, which in turn requires good wetting of the substrate. An additional surface preparation step with oxidizing chemistry can be introduced. The metal decontamination HCl step could be efficiently combined with a surface preparation step such as in a $HClO_3$ process [2, 9].

Edge isolation

As any doping at the wafer back-side is eventually overcompensated by the aluminium back-surface field formation (at the end of the cell process sequence), the edge junction must still be removed as otherwise it would short-circuit the emitter to the back-side metal. The parasitic junction etch can be carried out in several ways, of which wet etching using an HF/HNO_3 mixture is one.

Passivation and antireflective coating

Subsequently, the surface is passivated and SiN is deposited to form an anti-reflective coating (ARC). Reduction of surface recombination is a key aspect for high efficiency solar cells, and therefore much effort is being put into the reduction of interface states. At the interface with the ARC, as mentioned earlier, texturing increases the surface area and consequently the number of surface defects. Passivation requirements will become even more stringent in view of the trend toward using less highly doped emitters in high efficiency solar cells. Surface recombination is also becoming increasingly important at the back-side of the cell as the industry moves towards thinner wafers. Cells like i-PERC (Fig. 3) use a dedicated dielectric stack at the backside to improve the surface passivation.

The trick is to treat atomic surface defects in such a way that they are not and will not become electrically active. Passivation by oxidation is ideally suitable for interfaces between silicon and dielectrics such as the AR coating. The growth of a clean, metal-free chemical oxide is a key process that is best achieved in an acidic regime as was described in the IMEC clean [9] and other processes. Extensive knowledge in this area is available in the CMOS community, where interfacial oxides have been studied to optimize the deposition of high-k gate dielectric materials. Recently, an improved UV response for a standard solar cell process (such as that in Fig. 1) was obtained using a HNO_3 process on n-type substrates. This improvement was attributed to the removal of excess P at the emitter surface [10]. The trend to higher cell efficiencies and thinner wafers renders improved surface passivation schemes imperative. Apart from the i-PERC passivation, very low recombination rates have been reported using ALD of Al_2O_3. Acidic surface oxidation may be applicable to PV for p-type silicon in this case. In practice, the remaining defects at the interface of oxide and Si are further passivated by hydrogen released from the SiN ARC during the firing of the metallization.

Another innovation in very high efficiency solar cell development is based on a-Si:H/c-Si heterojunctions. Passivation of defects is realized by adding a thin layer of undoped hydrogenated amorphous silicon, as is used in the heterojunction solar cells of Sanyo [11]. However, even the deposition of such i:a-Si layers requires careful surface cleaning and pre-treatment. It is well known that, in class 1 cleanroom environments, adsorption of hydrocarbons occurs within 30min after the clean [12]. This may significantly affect the deposition of subsequent layers such as amorphous silicon [13]. Therefore, after passivation the storage time and storage ambient need to be carefully controlled, possibly adding to the cost and complexity of the process.

> "Pastes already constitute a major part of the consumable cost in solar cell manufacturing, and the price of the Ag material used for the front-side metal grid is expected to rise as continued PV growth might exhaust the available Ag raw material."

Metallization

A new and promising wet process in this respect is Cu electroplating, a mature and low-cost production process used for printed circuit boards, which is seen as a viable alternative for the expensive screen-printing pastes. Pastes already constitute a major part of the consumable cost in solar cell manufacturing, and the price of the Ag material used for the front-side metal grid is expected to rise as continued PV growth might exhaust the available Ag raw material. Cu metallization for the emitter contact also has a cell performance advantage when combined with shallow emitter profiles and can lead to significant efficiency increases due to increased blue response. The main differentiator between the various processes under scrutiny is in the choice and technology for seed and barrier layers for which Ni electroless plating is one option. Some schemes allow higher aspect ratios to be reached than are possible with regular screen-printed electrodes, which leads to additional cell performance increases. Cu plating equipment for PV is being offered of late by several companies [14].

General opportunities for cost reduction and manufacturing issues

Chemical consumption: understanding the chemical processes will allow the limits to be pushed

It is felt that chemical usage, including DI water, can still be pushed down by more extensive research. The use of recycling schemes in combination with low full-lifecycle cost of ownership chemicals such as O_3-based solutions (e.g. O_3- water, or O_3– H_2SO_4) should be considered.

When using mixtures, the assay accuracy window needs to be assessed with respect to the desired processes. This has an important impact on the cost of the chemical as well as on the mixing hardware, and will eventually affect concentration monitoring and spiking. The selection of chemical mixtures and lifetime determination should also take into account potential instabilities in mixtures through chemical reactions amongst the different components as well as drift in assay through evaporation.

Today there is very little quantitative information available on the actual purity level requirements of the chemicals, with respect to metallic contaminants. Chemical mixtures are in most cases chosen based on lab or pilot line tests. Mixtures are configured based on merits in their fresh state, without significant loading, and often with little attention to the actual purity level. With particular reference to cleaning applications, the relation between the bulk concentration of contaminants in the liquid mixture versus the resulting surface concentration of contaminants deposited on the wafer surface need to be investigated [15]. This relationship should be used to set up purity specifications for starting chemicals as well as for determining bath lifetime limitations based on contamination loading. These relations can also be used to extend the lifetime of chemical mixtures based on quantitative models. Chemical processes that are less demanding on purity requirements should be favoured with respect to more 'sensitive' processes. As an example, it was demonstrated for ULSI manufacturing that trace metal specifications of DI-water used for rinsing before critical hot processes could be relaxed by acidification [16]. For etching applications (such as SDR and texturing), the loading of the mixtures with reaction products and any impact on the process need to be assessed and modelled.

Once optimal chemistries are identified, strategies should be set up to stretch the lifetime even further by bath monitoring and appropriate respiking. All of the above need to be studied in the frame of cascaded use of chemicals. This mode of operation is common in many hardware platforms, but much more systematic studies need to be made to optimize this approach. For example, the last cascade stage(s) should not contribute anything to the overall process.

Not only would these measures lower the processing cost but they would also lead to a reduction of process fluctuations that affect the cell performance, ultimately resulting in smaller variations in overall cell efficiency.

Equipment – batch versus in-line

Several aspects of wet processing hardware can play important roles such as minimizing pick and place actions, which can reduce cost. Exemplary measures which the PV industry has implemented to bring down cost of ownership are the 'merging' of processes and increasing the areal throughput of equipment to the range of 3000 wafers/hour [6].

Conceptually, in-line processing should be preferable (with respect to batch processing) as it creates a streamlined production line. In-line processing also offers better 'selective' access to one side or the edges only. In view of the high throughput, measures have to be put in place to swiftly overcome wafer breakage events without noticeable down time.

> "In view of the high throughput, measures have to be put in place to swiftly overcome wafer breakage events without noticeable down time."

Throughput matching of typically slower processes such as alkaline texturing are still major challenges for in-line implementations. The need for studies on required purity of the chemicals naturally extends to requirements for the materials. This in turn impacts the hardware cost. Installation of in-situ generation of chemicals (such as O_3-based chemicals) or in-situ purification should be considered with the goal of extending the lifetime of chemicals and enhancing quality while reducing waste and cost.

Impact of thinner wafers

Apart from reducing operational costs, another challenge is the expected reduction of Si wafer thickness. With silicon constituting 30% or more of the module cost, the trend to thinner wafers is foreseen to continue the next decade. For wafer thicknesses from 150 to 180µm, commercial wet process equipment is already showing high yields (0.1 % or lower breakage rate), but yield on thinner substrates has yet to be widely established. This problem will be even more pronounced once substrates become thinner than 100µm. Nevertheless, this should not be a showstopper as the wafers will most likely be supported by some sort of carrier throughout the process cycle, and the wet processes will need to be compatible with such an approach. For this reason, in-line processes in which the substrate is mounted on moving holders or chucks would seem to be most suited.

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Inline processing of crystalline silicon solar cells: the holy grail for large-scale manufacturing?

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ABSTRACT

Lowering the cost of production of solar cells requires higher throughputs and higher production yields for thinner and more fragile silicon wafers, and inline processing could hold the key. However, current processes used in production do not enable full inline processing and often require a substantial amount of handling between process stations as the throughputs per station and tray requirements differ greatly. It will take many years before a full inline process flow is available and if it comes, wafers will most likely be positioned on a single tray throughout all process stations. This paper will discuss the current processing methods for all individual process steps and will provide an outlook on inline processing in view of the three cost reduction strategies: thinner wafers, higher throughput, and higher efficiency cell designs.

Introduction

The solar industry needs to reduce production costs of solar modules by at least a factor of two in the coming years. For silicon wafer-based solar modules, the largest cost savings can come from reducing silicon wafer thickness, since silicon feedstock, crystallization, and wafering make up 50% of the direct manufacturing costs. Large cost savings can also be obtained by upscaling production lines [1]. The challenge is then to obtain high throughput processing while maintaining yields for very fragile wafers and cells. Further cost reductions can be achieved from increasing the efficiencies of solar cells with developments such as the Interdigitated Back Contact cell design (IBC) [2] recently making it to market. These solar cells have design requirements that are more difficult to meet and need more and new process steps, as illustrated in Fig. 1.

Inline processing promises high throughput manufacturing of silicon wafer-based solar cells while maintaining high yields, and has the advantage of minimum wafer handling and a continuous flow of cells through a production line on a belt (Fig. 2). The method involves a continuously running process with wafers flowing through equipment to obtain the specified treatment. During batch processing, the wafers are first placed in a cassette or boat before being loaded into the process chamber (see Fig. 3). All wafers get the required treatment in one position in the equipment, after which all wafers are offloaded. This has the advantage of very dense wafer packing, which reduces space requirements for equipment. However, wafers require substantial handling as they are placed in and out of cassettes, especially when all process stations have different cassettes or boats.

Inline and batch compare to each other in the following qualitative manner:

	Inline process	Batch process
Handling	Minimal	Maximum
Floor space	Large	Minimal
Process time	Short	Long

Deciding whether a process should be batch or inline depends very much on the existing process conditions and requirements. Therefore, solar cell factories will often use a combination of batch and inline processing. The following is a breakdown of processing methods for all individual steps, as well as an insight into the possible cost reduction strategies of producing thinner wafers, achieving higher throughput and developing higher cell efficiencies.

Surface damage removal, texturing, and cleaning by wet processing

The majority of wafers used in the industry are grown in large ingots and separated by wire sawing, both of which are batch processes. During separation, the wafer surface is damaged and covered with small cracks, leading to high recombination

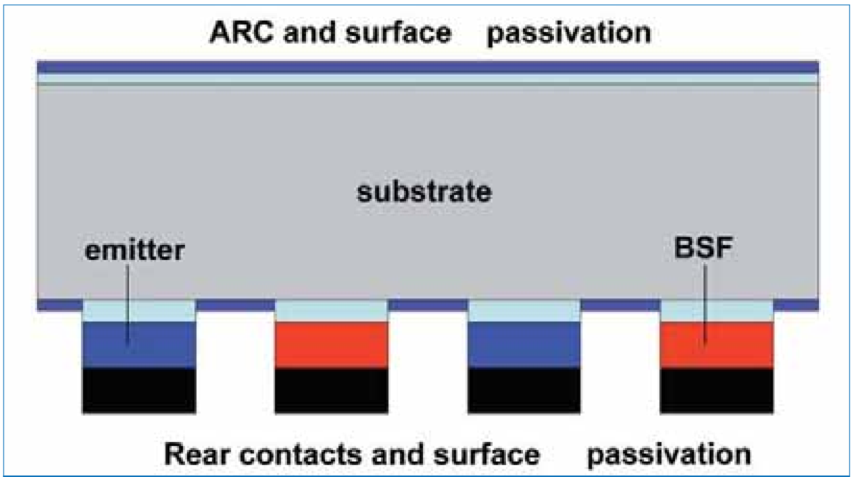

Figure 1. Interdigitated back-contact cell – a high efficiency cell concept.

Figure 2. Optimal inline processing from process to process on a moving belt.

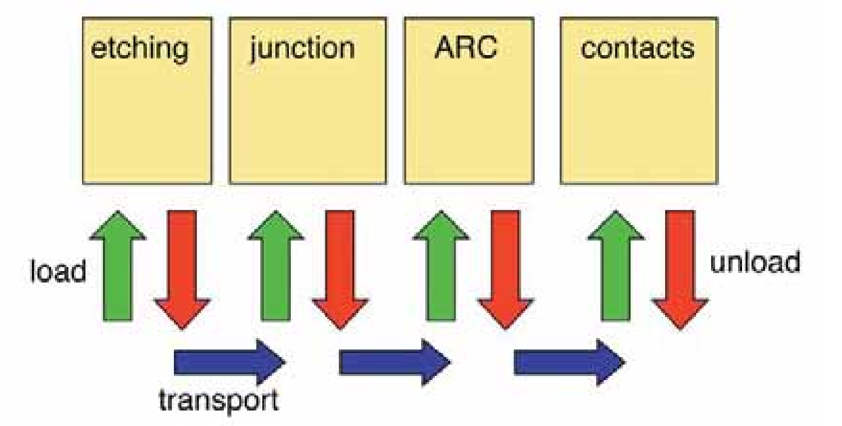

Figure 3. Typical industrial processing with loading and unloading at every process step.

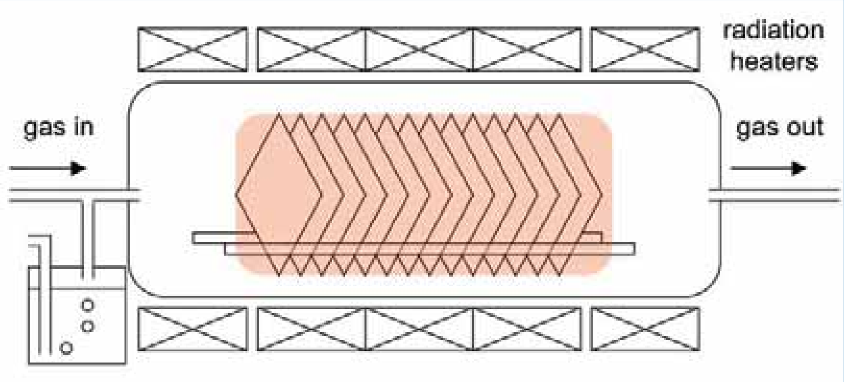

Figure 4. Quartz tube furnace layout for emitter junction fomation.

in these regions that will have a negative impact on solar cell efficiency. The wafers are textured at this point, giving them superior light coupling compared to a smooth surface. Optical reflection is reduced from ~35% (polished surface) to in the best case less than 10% (random pyramids), with the wafer texture increasing the light absorption by up to 40%.

Processes currently in use

Two fundamentally different processes are dominating the industrial market. One process is inline, based on acidic etching and used almost exclusively on multi-crystalline wafers. The second process is batch, based on alkaline etching of mono-crystalline wafers.

The acidic etch is based on the chemical reaction between silicon and a mixture of hydrofluoric acid (HF), nitric acid (HNO_3) in the presence of additives (e.g. water). In a process taking less than three minutes, between 4 and 6µm of silicon is removed from each side of the wafer, resulting in a random texture with a reflection of 20-25% at 1000nm. Process temperatures are, depending on the additives used, between 6°C and 30°C.

During alkaline etching, silicon is dissolved by an endothermic reaction with hydroxide (OH^-). The process is in most cases a two-step etch: the damaged surface is removed at high temperatures and high alkaline concentration. Random pyramids are then grown by the slow anisotropic reaction between silicon and hydroxide. This second step is normally performed at a lower concentration and temperature and in the presence of an additive (e.g. 2-propanol) to increase selectivity for different crystal lattices.

Pros and cons of inline versus batch and on-substrate

The selection of inline or batch texturing is not one of preference, but is determined by the wafer material being used. Acidic etching is a relatively fast process and therefore inline processing is possible at a lower cost of ownership than batch processing. Acidic etching can be used on mono-crystalline wafers, resulting in higher reflectivity than with alkaline etching and subsequent efficiency loss of about 0.5% absolute.

Alkaline etching is strongly dependent on temperature and composition of the etching mixture. A short process time is possible, but for good light coupling a structure of random pyramids is necessary. This structure can only be obtained when there are large differences in etch rates for different crystal lattices (anisotropy). To obtain a high difference in etch rates, it is necessary to use additives, a lower temperature and a lower concentration – all of which result in slower reaction speed and longer etch rates. Therefore, inline alkaline texturing etch is, at the moment, not used on an industrial scale.

Future developments and outlook

To make inline alkaline etching and texturing possible, the processing time must be reduced to times comparable to those of inline acidic etching. This reduction can be achieved for the initial saw damage removal step, but new reaction mixtures (different alkaline sources or additives) must be sourced that have an as high or higher anisotropic etching preference at a higher reaction rate.

Acidic etching can be performed both in inline and batch processes. The next breakthrough will have to be an acidic etch with a reflection comparable to that of mono-crystalline wafers with random pyramids. An example of this etch already exists [3] and ECN is working on upscaling this process, which could potentially replace alkaline texture etch for mono silicon wafers.

Wet texturing may be replaced by gaseous techniques (RIE, plasma) for structural etching, but should remain the only cost effective process for saw damage removal. For high efficiency concepts, the texture is important; however the cell design does not impose extra process requirements.

Cleans

Only two different post-emitter cleans are used in the industry: standard PGS removal with an aqueous solution of HF and ECN-Clean, consisting of an additional cleaning step/surface modification using Bakerclean PV-160 [4]. Both cleans can be applied during inline and batch processes. The choice will mainly depend on the stations before and after the clean.

Emitter formation

Emitters provide the driving force in the solar cell. During emitter processing, a dopant is provided at the surface and diffused into the silicon. In this way, a layer with opposite doping is made and a p-n junction is formed.

Processes currently in use

Batch process – quartz tube furnace

When the solar cell industry came on the scene in the 1970-80s, production technologies were transferred from the semiconductor industry. Emitter formation processes, also known as the phosphorus diffusion process, was one of these technologies, and saw the introduction of the quartz tube furnace. This type of furnace is still dominant in the production of silicon wafer-based solar cells. Nowadays, a single quartz tube of a typical horizontal furnace can process 400 wafers at a single batch and each process can take up to 2.5 hours including the loading and unloading steps (see Fig. 4).

Typically, machine throughput can be increased in a number of ways:

- increasing the number of wafers to be loaded in a single batch process using a longer tube

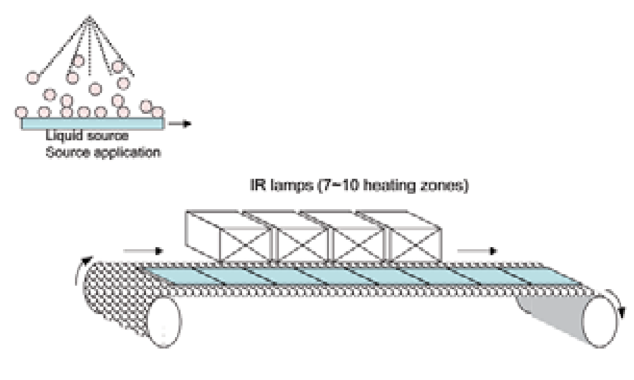

Figure 5. Inline phosphorus emitter junction formation with a sprayed phosphorus deposition and diffusion in a belt furnace.

- narrower spacing between wafers
- back-to-back processing by loading two wafers in one single slot. The wafers contact each other on the back-side and the front-side of each gets diffused
- shortening process duration with faster replacement of the chamber with ambient, intensive cooling
- loading/unloading at higher temperatures, and
- reducing machine floor space by stacking tube furnaces vertically.

However, almost all of these solutions – with the exception of stacking – have an impact on the doping profile, diffusion uniformity within a wafer, and diffusion uniformity from wafer to wafer. Careful investigation is required when any of these solutions is introduced into production. The maximum throughput will be determined from the point of view of device performance rather than mechanical limitation.

As a phosphorus diffusion source, two types of sources were developed: gas source application and coating source application. A typical gaseous source is $POCl_3$ (phosphorus oxychloride), which is introduced into the furnace by N_2 or Ar bubbling. It is quite popular these days because of its relatively easy handling and the self-cleaning effect of Cl_2. However, its byproduct being corrosive and harmful to humans, the chamber ambient should be isolated and correctly replaced when wafers are unloaded. For coating source application, the source is normally supplied as a liquid and spun on wafers. It has been less popular for tube furnace diffusion because it requires coating and pre-baking before being heated, while the coated film is prone to incorporate contaminations.

Inline process – conveyor belt furnace

Recently, the inline conveyor belt furnace has been used for emitter formation. As shown in Fig. 5, silicon wafers are spray-coated with a liquid diffusion source and are then transported horizontally by conveyor belt and heated. This simple concept of conveying wafers originally came from metal sintering for semiconductors. The spraying method could be replaced by spin-coating, screen-printing or dipping, while the conveyor belt can be constructed using a metal mesh belt, ceramic rollers, walking beams, etc.

Inline furnaces were originally not used for diffusion because there was widespread agreement in the semiconductor industry that metal elements such as the belt should not be used for diffusion processes to prevent metal contamination, which can harm the reliability of the manufactured semiconductor device. On the other hand, a heavily-doped phosphorus layer was known to capture metal impurities like Fe, Cr, Ni etc. which exist within the original wafer material. This capturing – or gettering – effect was also expected to be valid when such metal impurities exist in the doping material or the diffusion furnace itself.

ECN has shown that no degradation occurs in minority carrier lifetime of the wafer material that was treated with phosphorus diffusion in an inline metal conveyor belt furnace [5]. The results even suggested that contamination level is equivalent as that of quartz tube furnace diffusion using $POCl_3$ source.

Pros and cons of inline versus batch

Contamination

The inline conveyor process is more likely to cause metal contamination than the quartz tube batch process. This effect is negligible during phosphorus diffusion due to the metal gettering effect. For other very high temperature process steps, thermal oxidation and boron diffusion, the quartz tube process might be better suited. This is because for these processes the gettering effect is small or absent and the wafers become contaminated with metal impurities reducing silicon quality and solar cell efficiency.

Diffusion source application and process controllability

The phosphorus diffusion source is applied as liquid before wafers are heated in the inline conveyor furnace, while the source is applied as vapour after the wafers are heated in the quartz tube furnace. This enables the use of open chamber, often leading to shorter process duration per wafer. However, process control parameters have less flexibility, which makes it difficult to optimize the proper doping profile for higher device performance.

Handling wafers and floor space

Silicon wafers are transported horizontally during the whole process of diffusion for the inline conveyor furnace, while they have to stand vertically in the quartz tube furnace. Horizontal transportation requires minimum handling when the wafers are removed from one process machine to another, and it can distribute the stress caused by the wafers' weight. The wafers undergo more thermal stress when they are heated in the quartz tube furnace because they are supported at several points on their edges, which greatly impacts the breakage yield. Horizontal wafer transportation requires more floor space than vertical wafer placing in furnaces; stacking the inline furnaces vertically has little benefit. For batch furnaces, stacking vertically allows the expensive loading/unloading system to be shared.

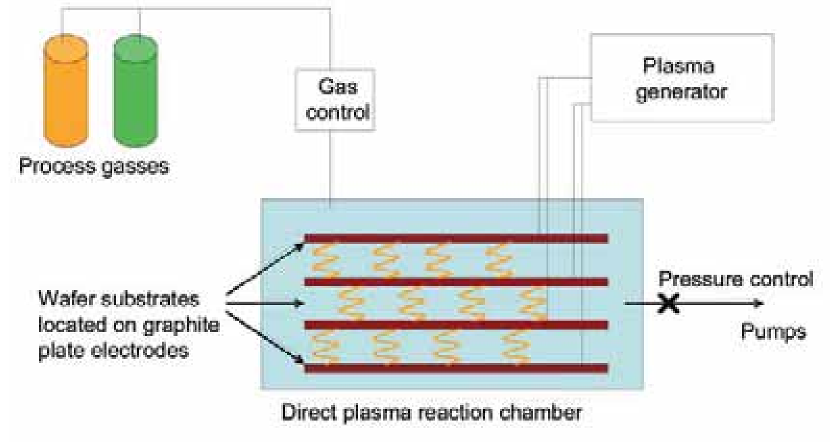

Figure 6. Schematic showing a direct PECVD system.

Operation and maintenance

Recent developments in automated technology have almost eliminated the difference in the practical operation of both types of furnaces, but troubleshooting an inline conveyor furnace is easier. A typical example concerns the heaters used by the quartz tube furnace. When the furnace accepts the group of wafers, the temperature inside decreases rapidly, though the heater should keep the whole wafer group at the same temperature, ramp up to the process temperature, and cool down to the unloading temperature. Even though recent technology is robust, troubleshooting this part requires specialized skills.

The inline conveyor furnace uses static heaters, the output of which is almost constant once the set point is adequately settled. If an IR-lamp breaks, the machine users can replace it and readjust the set point with appropriate maintenance training.

Limiting factors for increasing throughput

There are several solutions to increase throughput for both types of furnaces. However, most solutions for the quartz tube furnace impact diffusion quality and care must be taken if any of these avenues is brought into play. For the inline conveyor furnace, the maximum throughput is limited by mechanical factors like belt strength, conveying speed, and homogeneity of the line heater. This contrast suggests the future technological and mechanical improvement may give more room for throughput improvement to the inline conveyor furnace.

Future development and outlook

Improving device performance at larger throughput is not easy. Inline conveyor or quartz tube? Both systems appear to experience setbacks in reaching larger throughput and higher efficiency, and some technology breakthroughs will be necessary such as Centrotherm's 'inline-tube furnace' concept [6]. Although the effectiveness of the concept has not yet been proven, such an attempt is really stimulating the PV sector and encouraging others to tackle technology innovations.

	Inline	Batch
Typical process time per single wafer incl. load / unload	20 ~ 40 minutes	1 ~ 2.5 hours
Contamination	Most contamination can be prevented by metal gettering effect of phosphorus.	No metal contamination.
Diffusion source application	As liquid & before being heated Pros: Use of open chamber enables quicker process. Cons: Less control of process chamber	As vapour and after being heated Pros: More control of process chamber Cons: Closed chamber required which causes longer process duration.
Wafer handling	Horizontal transportation throughout the process Pros: Minimum handling and lower breakage rate Cons: Larger floor space needed	Vertical wafer location during the process Pros: Small floor space Cons: Higher breakage rate due to the handling and thermal stress
Maintenance & troubleshooting	Operators can solve most of issues with appropriate maintenance training.	Help of skilled engineers is sometimes needed
Limiting factor to increase throughput	Belt length and width (the belt material should be strong enough to support the length and width) Conveying speed against breakage yield Homogeneity of the line heater	Adequate doping profile Diffusion uniformity within a wafer Diffusion uniformity from a wafer to another

Table 1. Pros and cons comparison of inline and batch method with typical constructions.

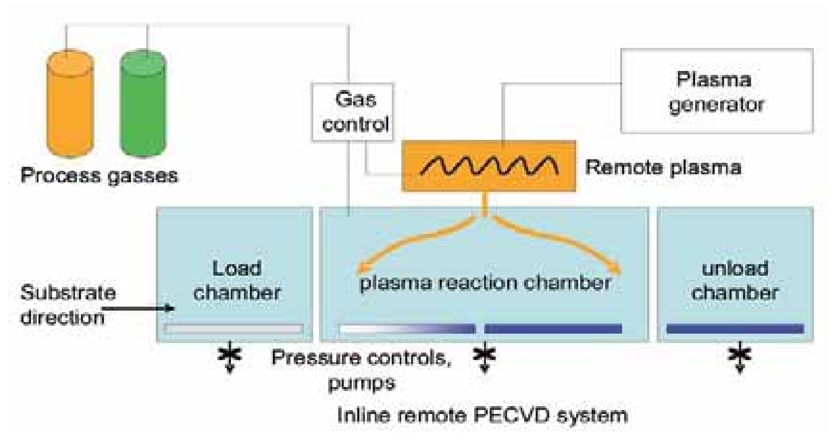

Figure 7. Schematic drawing of an 'inline' remote PECVD system.

For high efficiency concepts, the diffusion process must be adapted to allow for both n-type and p-type regions to be formed on the back of the solar cell (see Fig. 1). Therefore, local diffusion is necessary. Local diffusion sources can be applied by printing methods; local heating can be applied with laser doping; local diffusion masks can be deposited. Diffusion masks are currently being used in production to form the interdigitated diffused regions. Boron diffusion has to be applied, which requires higher temperatures and longer times than for phosphorus diffusion to obtain the optimal doping profile. On the other hand, boron diffusion does not provide the same gettering effect as phosphorus diffusion; therefore, quartz tube diffusion is preferred for these cell designs.

Dielectric coating deposition

Reducing the reflection of incident light on solar cells requires coating with anti-reflective coating, such as metal oxide layers like TiO_x or SiO_x. However, since the first application in 1981 [7], the use of silicon nitride (SiN_x) as an anti-reflective coating has become dominant in crystalline Si PV technology. The refractive index *n* of silicon nitride can be tuned between 1.9 and 2.5, which enables excellent anti-reflective properties both for solar cells in air and behind glass in a module. Furthermore, SiN_x passivates the surface of the solar cell by reducing the defect density and by creating a positive field effect [8].

The third function of SiN_x is the supply of bulk passivation by means of hydrogen diffusion. This property is especially important for mc-Si solar cells, which are used in more than 50% of total crystalline Si cell production. By using hydrogen-containing gasses like SiH_4 and NH_3 as precursor gasses for the SiN_x layer deposition, hydrogen atoms will be integrated in the SiN_x layers by diffusing into the bulk of the mc-Si solar cell during the high temperature firing step, providing passivation for crystal defects (dangling bonds) and impurities (C, O, metals).

While the anti-reflection properties of the SiN_x layer are determined by the optical constants *n* and *k*, the surface and bulk passivating properties are found to depend strongly on the mass density and bond densities (Si-N, Si-H, N-H) of the SiN_x layer [9,10]. Both need to be optimized to reach high cell efficiencies [11].

Processes currently in use

In most solar industries, the SiN_x coating is deposited using plasma enhanced chemical vapour deposition (PECVD), which is based on ionizing the precursor gasses (usually NH_3 and SiH_4) using an electric field. Ionized molecules – or radicals – will react and deposit on the surfaces creating an amorphous SiN_x layer. By changing process parameters like pressure, temperature and silane or ammonia gas flow, the plasma properties change and the optical and physical properties of the deposited layers can be tuned to optimal values.

There are essentially two forms of PECVD:

Direct PECVD: In this case, the plasma is in direct contact with the substrates. This principle has worked, up to now, only in batch mode since the substrate carrier itself is used as one of the electrodes for the electric field (see Fig. 6). The EM-frequencies range from 40 to 440kHz. Industrial applications consist of several stacked chambers into which the substrates are loaded and processed, and subsequently unloaded. During loading and unloading of the substrates the plasma is, naturally, turned off.

Remote PECVD: In this case, the plasma is excited some distance away from the substrates. Several types of remote PECVD have been developed, such as: microwave PECVD (2.45MHz), pulsed PECVD (13.56MHz – 100kHz) or expanding thermal plasma (DC). These applications can run both in batch and in inline mode. In the inline case, the plasma stays turned on while substrates are loaded, processed and unloaded from the process chamber (see Fig. 7). Recently, other deposition methods like sputtering of SiN_x from a solid silicon source have been developed [12].

Pros and cons of inline versus batch and on-substrate

Both PECVD and sputter processes involve low pressure conditions and ionized dangerous gasses (i.e., silane and ammonia). Due to the nature of these processes, so far the processing itself has been batch or hybrid (a 'batch' process, enveloped in an inline machine). The process itself runs continuously in the process chamber, with large batches of samples transported in and out of the chamber by means of load locks. The batch (or so-called tray) is heated in the load lock chamber before it enters the process chamber.

Compared to batch, inline processing, even in this 'hybrid' manner, provides a better process stability. This is due to the fact that the plasma is continuously turned on and the temperature in the process chamber is kept constant. Hybrid inline processing is only possible for remote PECVD or sputtering processes where the plasma is controlled separately and independently from the substrate transport.

Besides this, remote PECVD has several other advantages compared to direct PECVD methods:

- There is less influence of substrates (size, mass, etc.) on the plasma conditions as

Courtesy: Asys.

Figure 8. Rotary platform for faster printing.

the substrates do not act as one of the electrodes.

- The substrates will not be heated additionally by the plasma.
- Moreover, as the ionized particles are formed some distance away from the substrates, the ion impact on the substrates will be less. This will decrease the damage done to the surface of the substrates, which will be important for high efficiency processing.

However, direct PECVD has the advantage of a low energy density, point-of-use activation and less downstream loss of activated reactants. Furthermore, the lower frequencies allow for a larger deposition area.

SiN_x layers of good quality can be deposited with both PECVD systems. Furthermore, optical parameters and densities can be tuned to optimal values. Recently, a comparison for bulk passivation was made between a direct and an indirect plasma source using both n- and p-type mc-Si, and p-type string ribbon and EFG material [13]. The authors found that although the different wafer types could react slightly differently to the two different systems, overall with both remote and direct PECVD good bulk passivating layers can be deposited.

Future developments and outlook

Both batch and hybrid PECVD (or other SiN_x deposition) systems can be integrated very well in an inline production line. This is already happening on a large scale in industrial solar cell manufacturing lines. However, these processes will always require handling of the thin wafer substrates before and after processing of the SiN_x layers. Should the wafers become even thinner in the future, this will lead to more and more breakage.

For PECVD (or other) processes to become truly inline, they would have to work at atmospheric pressures. This way, no load locks are necessary and the substrates can be transported directly inline through the deposition chamber. Although such a PECVD system was mentioned some years ago [14], no cell results were published at that time and to the authors' knowledge the system has not yet been industrialized.

For new cell designs, coatings will likely need to be deposited on both sides. This will require a redesign of the trays, since trays are now designed for single-side deposition. The first commercial systems are now available for this process, while for IBC cell designs, thermal oxide passivation is used, which requires quartz tube furnaces.

Metallization

In the metallization process steps, the electrical contacts are fabricated onto the solar cell. For standard type cells, this means a front side H-pattern using silver, rear-side silver contacts as pads or bars, and further full aluminum coverage on the rear side.

Processes currently in use

Already 30 years old, thick-film screen-printing and contact-firing is the leading manufacturing technology for all three contacts on the crystalline silicon solar cell. In screen-printing, metal conductor paste is transferred onto the cell through a framed screen mesh with a patterned emulsion. The printed paste is dried prior to a next screen print step. After all contacts have been printed and dried, the cells pass in-line through an IR lamp conveyor-type firing furnace. Here, the actual contacts are established: the metals are baked and electrical and mechanical contact with the cell surface is made.

Co-firing or triple firing is standard since it became possible to fire front contacts through the SiN anti reflection coating, realizing direct contact with the emitter, in conjunction with BSF formation on the back-side using aluminium. At first, multiple lanes were used in a firing furnace to obtain throughput, then single lane fast firing furnaces with more emphasis on peak firing became necessary to realize good contacts. Dual- or even triple-lane fast firing are or will soon become available.

A main advantage of screen-printing is that it allows the deposition of a high volume of material (the thick film) in complex patterns in one stroke. In addition, screen print pastes allow dispersion of the highest metal fractions. Furthermore, screen-printing technology has gained considerable momentum, since it has been and is applied for most crystalline silicon solar cell manufacturing [15]. Only a few alternative technologies were or are being used.

For non-flat silicon wafers, such as EFG silicon material and string ribbon material, pressure as applied by transferring metal paste through the screen gives rise to breakage of the ribbons, which led to demand for non-contacting or low-pressure methods. This group includes dispensing of paste, decal transfer and pad printing. Another approach is plating technology, e.g. such as that used for the Saturn-type cells of BP. The method applies various plating in laser-buried grooves on the front-side of the cell, focusing on improved efficiency through enhanced contacting and low shadowing. Today, some manufacturers use variations on printing and plating, again in a proprietary manner.

Pros and cons of inline versus batch and on-substrate

Screen-printing is considered a batch-type and on-substrate process. A wafer is positioned on the print table, accurately aligned, moved under the print station and then paste is printed onto the cell. After repositioning the table, the cell is removed. The handling takes time, as does the printing stroke itself. For faster handling, e.g. the rotary table platform is established, as shown in Fig. 8. The print speed dictates the movement of the squeegee, pressing and transferring paste through the screen. The print stroke takes up the most time in the various steps and is therefore pushed up to gain throughput, at the cost of the desired fine line high aspect ratio.

Over the last decade the design of screen printers and their cell handling were improved such that throughputs of more then 1200 cells per hour became possible. Although some current screen printers can do ~1500 cells per hour [16], this still limits total throughput of the manufacturing line, since other, full inline equipment can easily double that number. As a solution two parallel lines of printers and dryers – and sometimes firing furnaces – are added. Today even triple lanes of screen printers are available, thus increasing throughput to ~4000 cells/hr [16]. A multi printing lane approach is also beneficial for the extra attention that screen-printing needs in terms of throughput and yield. Stopping one machine for screen exchange, for example, will not have to affect throughput.

The printing of two cells, which was selectively used for some time, has recently been introduced in commercial equipment, and, though it will double the throughput, it will not resolve the issue of stopping the printer for screen exchange, etc. It must also be demonstrated that printing two cells using one screen will not affect the desired fine line high aspect ratio printing.

To comply with the industry's needs, ECN Solar Energy carried out research into the applicability of rotary screen-printing for solar cell metallization. Rotary screen-printing is a well established technology for such processes as fabric printing. The method is a true inline process, and for PV application would easily increase throughput. Yet the special screens that are needed in this approach were found to be unsuited to realizing the required pattern definition.

RTP firing has been a topic of research for some time, and has shown encouraging results, but never made it as a real-world application due to its batch-type character. Firing in belt furnaces is a true inline process and throughput is not a real issue here. For cost purposes, the footprint, energy consumption and yield are important, but do not directly limit future manufacturing.

Future developments and outlook

Alternatives for screen-printing are under research and/or in the industrial test phase. The alternatives focus on improvement of the electrical front contact together with less shadowing, as well as high throughput. Fraunhofer ISE has carried out a large body of research on a hybrid method of metallization that involves deposition of seed layers with additional plating [17]. Industrial prototype equipment, such as various types of ink-jetting, is currently undergoing industry testing, as is research on full plating of the front-side contacts. Ink-jet seems perfect for the in-line depositing of fingers. Although the substrates can move inline and continuously, the method is still semi-continuous because of the stopping and starting of the deposition of paste at the beginning and end of a finger. A second process step is needed for the application of the busbars perpendicular to the fingers. Non-orthogonal patterns, such as the ECN pattern for metallization wrap-through cells (MWT), are difficult to align to the ink-jet approach [18].

The greatest challenge with these alternatives is that the equipment has to comply directly not only with the high throughput demands of the industry, but also with the accurate positioning of the cells for e.g. selective emitter-type cells, but also for the fine-line high aspect ratio requirements for both front-contacted cells and rear-contacted cell demands.

Together with the development of new approaches and equipment, the overall solar cell concept is evolving. New concepts, such as IBC, MWT, etc. apply back contacts, and lead to different requirements for metallization. Opening the dielectric layer with lasers can lead to other contact schemes such as direct plating, sputtering and laser contact firing.

A very important aspect of all new metallization development and other process steps is that it will not only have to increase efficiency of the cells, but also throughput at increased yield and at overall lower costs.

Conclusions and outlook

True inline processing of silicon wafer-based solar cells is not currently available for all processes. Inline processing could become very relevant when wafers get very thin and fragile and any wafer handling should be avoided. Particularly for vacuum processes such as PECVD of dielectric coatings and the metallization process, a full inline process will not become available in the near future.

It is likely that more processes will be performed on the same tray; for instance, the wet chemical cleaning step might be replaced by a dry cleaning step. In this case, the same tray could be used during diffusion, cleaning, coating deposition, and maybe even metallization. For new cell designs such as IBC, full inline processing is even more difficult since processes are needed that at the moment cannot be performed inline, such as boron diffusion, inkjetting, and laser processing.

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Ingrid Romijn studied physics at the Leiden University where she received her Ph.D. on metal-insulator transitions in conducting polymers and composite materials. She joined the ECN Solar group in 2004, where she started working as a researcher on passivating (SiN_x) layers. Recently, her work, both as scientist and as project leader, has been focused on new solar cell concepts using rear surface passivation and full back contacting.

Arno Stassen has worked as a research scientist in ECN's Silicon PV Technology group since 2006, addressing chemical etching, oxidation and cleaning of silicon wafers. As project leader, he is responsible for the ECN pilot line process. Stassen studied chemistry at the Radboud University Nijmegen and obtained his doctorate at Leiden University in 2002. From 2002 to 2006, he worked as a post-doctoral research fellow at the Technical University of Vienna, Leiden University, Technical University of Delft and ETH Zurich.

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Laser-assisted selective emitters and the role of laser doping

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ABSTRACT

Laser doping is often discussed in relation to silicon photovoltaic cell efficiency enhancement. However, the specific use of lasers for dopant diffusion falls within a broader category of 'Laser-Assisted Selective Emitters.' Understanding the benefits enabled by laser tools here is important not just in explaining what laser doping is, but why laser processing features in most selective emitter concepts.

Introduction

High-efficiency crystalline-silicon (c-Si) concepts command top-priority within research institutes and manufacturers' R&D departments [1]. Ideally, such proposals are accompanied by decreased manufacturing costs (thinner wafers) within 'standardized' process flows. While there are different high-efficiency options (defined by Mason as "technology that, in mass production, gives average performance greater than 17% efficiency" [2]), the most cost-effective involve efficiency-enhancement modification to 'standard' cells. ('Standard' in this case refers to the c-Si cell process that involves applying screen printed front side contacts on top of a PECVD SiN_x layer and a full-area aluminium back-surface-field (BSF) on the rear side.)

Among the new processes, the most eagerly pursued are 'selective emitters.' These feature a heavily-doped contact area underneath the metallized region and a lightly-doped emitter area between front fingers [3]. But even here, different schemes are proposed, each with unique processes and equipment. One equipment type common to most is a laser-based tool, performing selective material modification during emitter 'formation' [4,5,6,7]. Besi-Vetrella et al set the scene: "The laser technique adds the advantage of highly localized steps, meeting the requirements of selective emitter formation" [4], which was substantiated by Abbott: "The application of laser doping to crystalline solar cell fabrication to date has been fairly limited. This is surprising considering the numerous advantages to the technique and the proven ability of laser processes in high-throughput environments... Laser doping is the most underutilized of all laser processes currently used in solar cell fabrication" [8].

Laser doping research began during the 1960s, with application to solar cells gaining prominence in the late '70s and early '80s, generating "spatially localized doping patterns" in "efficient Si solar cells by laser photochemical doping" demonstrated by Deutsch et al [9]. The broader use of lasers to assist selective emitter formation was pioneered at the University of New South Wales (UNSW) during the mid-1980s [10], and through EU-funded programs called 'Low-Therm-Cells' [4] and 'Light-Print-Cells' [11] which featured "the use of spin-on techniques and laser assisted treatments to get selective emitter structures."

This article explains what functions lasers play in assisting selective emitter formation within advanced cell concepts by: classifying the laser/material interactions involved; outlining where laser processing occurs during production; and explaining how to choose optimized laser sources and tools. Emphasis is placed on laser doping, with three processes identified into which current research is assigned.

> "Selective emitters feature a heavily-doped contact area underneath the metallized region and a lightly-doped emitter area between front fingers."

Why selective emitters?

Forming selective emitters confronts inherent limitations of the traditional homogeneous emitter and screen-printed metallization process:

- Front surface metallization, which "requires a heavily diffused emitter to achieve both a sufficiently low contact resistance and adequate lateral conductivity" [12].
- Top surface metal shading losses resulting from linewidth limitations (typically 120-150µm).
- Poor surface passivation [ibid.] "as a result of the large metal/silicon interface area and the lack of a selective emitter to more effectively isolate this high recombination velocity interface from the active regions of the cell."

Many selective emitters are 'hybrid,' in nature; introducing selective emitters while retaining some form (or modified version) of screen-printing. Before discussing selective emitters, here are a few reasons why selective emitters (or high-efficiency cells in general) have not yet featured prominently [2]:

- Screen-printing offers "simplicity and low [investment] cost" [13].
- "Creating a selective emitter simply isn't easy" [14].
- Challenges justifying immediate return-on-investment (ROI) of new cell concepts (especially for 'pure-play' cell makers).
- Availability of standardized (high-throughput) production line equipment for new cell concepts.
- Requires patterning of the doped regions and "a very exact alignment of the front side metallization" over the heavily doped areas [15].
- Historically, strong sector growth put cell manufacturers in a comfortable position; priority was typically afforded to financing capacity of 'standard' lines with efficiencies ~14-16%.

Different types of selective emitters

Firstly, a basic outline is required for each selective emitter type, as well as an indication of where laser processing (including laser doping) is featured. The most common selective emitter types are grouped into five categories (below), linked directly to Table 1, which assigns labels for laser steps as 'Essential,' 'Optional', or 'Extra'.

1. Etch-back
2. (Screen-printed) phosphorous-doped paste
3. Buried contacts
4. Diffusion masking
5. (Single-step) laser doping.

The first two methods do not, by necessity, require laser-based equipment. *Etch-back* (1) typically involves performing a single heavily-doped, $POCl_3$

Selective Emitter 'type'	Essential use of lasers	Optional use of lasers	Extra laser steps possible	Sample references
1. Etch back	None			17, 18, 20
2. (S-P) P-doped paste	None	Ablate openings Scribe grooves		16, 19-21, 23
3. Buried contacts	Scribe grooves		Laser Doping	11, 2-24, 42
4. Diffusion masking	None	Ablate openings	Laser Doping	15
5. (Single-step) Laser Doping	Laser Doping		Scribe grooves Ablate openings	4, 5, 8, 9, 11-13, 13, 24 27, 29, 30, 33-38, 47

Table 1. A variety of laser-based processes (scribing, ablating, and doping) feature in the different selective emitter types. Laser processing can be categorized as 'Essential,' 'Optional,' or 'Extra' depending on the importance within each scheme. Within (3)-(5), options exist for multiple laser processing stages or combining the scribing/doping or ablation/doping within a single laser step.

emitter diffusion step at the front-end with a sheet resistance < 50Ω/Sq, creating an etch 'barrier' (or 'mask') typically using a screen-printed or photolithography-defined pattern with the same image as the subsequent metalized contact pattern, and then etching-back exposed regions between the emitter locations (grid fingers) for light-doping at ~100Ω/Sq. As expected, both plasma [16] and chemical etching [17,18] methods feature prominently. For the *(screen-printed) phosphorous-doped paste method* (2), two variants have been reported [19,20,21]: (i) screen-printing a dopant paste with the same pattern as the metallization, firing the paste and then printing the metallization over the highly doped pattern (requiring alignment of the two patterns); and (ii) adding dopant to the metallization paste to increase the doping density under the metal contact.

> "Diffusion masking – when combined with electroless plating – is a refinement of buried contacts: shallow 'openings' compared to deep 'grooves'."

For *buried contacts* (3), the default approach uses lasers to form narrow and deep grooves; characteristic of 'LGBC' proposed by UNSW [22] and championed by BP-Solar's 150MW of high-efficiency cells [2]. LGBC scribes inherently define a diffusion/plating mask. The standard method for selective emitter formation in LGBC is a heavy (second) diffusion stage into the grooves – overall 'double-diffusion,' while other methods have been proposed. Gee and Hacke [23] suggested combining LGBC with method (2) above, for "simultaneous doping and formation of a metal contact in a buried contact solar cell [by] disposing a self-doping contact material within the groove." Other versions include "laser enhanced diffusion [doping] within the grooves" [11,24].

Diffusion masking (4) must not be confused with etch-barrier mask formation for front-surface texturing of mc-Si cells [44], which is a front-end process followed by etching and by diffusion. In diffusion masking, laser processing occurs upstream ('preparatory'), creating selective (dielectric ablated) openings in the SiN_x/SiO_2 AR/passivation coating for subsequent heavy doping and metallization (screen-printed or electroless-plated). In this case, material removal can extend to ablate several microns of the underlying silicon, making this closer to 'scribing' than 'selective-removal.' The mask-opening step is called dielectric (or selective) ablation (or removal) [7], and is of equal prominence with or without subsequent selective emitter formation. This is also an essential step within most next-generation ('advanced') metallization techniques [25].

Following the mask-opening step, an optional damage etch may be required (generally only if non-optimal laser parameters are applied), followed by a second (heavy) phosphorous diffusion. Diffusion masking – when combined with electroless plating – is a refinement of buried contacts: shallow 'openings' compared to deep 'grooves.' Raabe et al touch on this topic: "this process sequence is utilized in the buried contact cell process [and] also used by the semiconductor-finger concept" [26]. While most diffusion masking schemes require double-diffusion, a single-step process was proposed by Raabe et al, where "a thin mask serves only as a diffusion 'suppressing' layer."

Laser-assisted selective emitters

In each selective emitter, laser/material interaction should be understood before identifying tools for production [7]. Morilla et al reiterate this: "One of the key points in transferring laser processes into production is the selection of the most adequate laser source and processing conditions" [27]. Indeed, selective emitter formation places demanding tolerances on laser tools (a comparison between edge isolation [28] and dielectric ablation [25] provides some guidelines).

To clarify, the term 'laser doping' refers to any step where a laser induces heating/melting that results in dopant-diffusion. Laser doping does not 'form' a selective emitter per se: it is merely one of several process steps which when put together form a selective emitter. The title of this article borrows from a more appropriate phrase introduced in a paper by Ventura et al in 'Therm-Cells' and 'Print-Cells'; Laser-Assisted Selective Emitter [29]. Table 1 introduces the three relevant laser processes:

- Laser scribing (scribe grooves)
- Laser dielectric ablation (ablate openings)
- Laser dopant diffusion (laser doping).

In laser scribing, 'deep' grooves are formed as recessed (buried) locations for front fingers. The most prominent example is LGBC, which remains the flagship of laser-assisted selective emitters today [22]. Scribing removes micron-level depths of material (through dielectric, P-layer, bulk silicon). Laser scribing tool requirements are analogous to laser edge isolation [28].

Laser dielectric ablation removes (ideally) only the dielectric, while minimizing damage to the underlying P-layer [25]. Most research in this area has been as a prerequisite for (two-step) electroless metallization, but other sophisticated approaches have garnered interest, such as combining dielectric ablation and laser doping within a single step [13,27].

> "Laser dielectric ablation removes (ideally) only the dielectric, while minimizing damage to the underlying P-layer."

Laser dopant diffusion

Laser dopant diffusion (laser doping) relies upon "lasers' ability to heat locally a semiconductor surface [which] can be utilized in processes like annealing and dopant incorporation" [5]. When performed as a single step, this is best illustrated by diffusion from 'residual' phosphorous-containing material such as the PSG layer, as explained by Carlsson et al: "the P-glass is a possible source for doping atoms" [30], while championed by Besi-Vetrella et al as "laser overdoping of contact regions by writing the grid pattern using a laser" [4]. Using lasers for doping has received widespread acceptance, clarified by Tjahjono et al: "one of the main advantages of using a laser as a means to induce doping is that it only imposes localized heating on the wafer, and sparing the rest of the area from high temperature process" [13]. Morilla et al commented: "laser technology enables the possibility to substitute high temperature furnace driven processes by low thermal budget, locally selective and highly flexible processes offered by lasers" [27]. Doping actually happens during the melting 'phase' of silicon, with "depths varying according to the used wavelength, ranging from 20nm to 1μm" [5].

While laser doping dates back 40 years [31], a succinct (solar-specific) categorisation was provided by Abbott (Chapter 5 in [8]), used as the basis of Fig. 1 (additional inputs from Duley [32]). Within this classification, laser doping within solar research is assigned to one of three laser processing types: (a) 'dry' laser processing with solid films; (b) 'wet' laser processing with liquids; (c) gas-immersed laser processing.

Most initial work (less favoured today) falls within category (c), also known as Gas Immersion Laser Doping (GILD). Here, deposition comes from a gaseous precursor (often flowed over the substrate). Further details can be found within pioneering research conducted in the late-'70s and early-'80s [9,33]. Laser doping via wet laser processing with liquids/chemicals (b) requires a dopant-containing carrier fluid. Early research by Stuck et al in 1981 had the cell immersed within a dopant-contained organic 'bath' and the laser incident from above [34]. A variant reported by Kray et al [35] has the laser beam guided within a chemical acid jet fired at high pressure onto the wafer surface: the dopant contained liquid incident from above but with simultaneous laser scribing of bulk silicon. Similar to GILD, wet laser doping imposes challenges within a production environment; how to achieve fast wafer throughput, having to deal with chemicals remaining on the wafer surface, and incremental operating costs owing to greater process complexity.

Currently favoured techniques fall under (a) dry laser processing of solid films, and are variants of an established process known as LIMPID (laser-induced melting of predeposited impurity doping) [36]. There are two approaches: (over-) doping of a residual phosphorous-containing layer (e.g. PSG), championed extensively at the University of Stuttgart [30]; or by introducing an extra dopant 'film' or layer (Narayan et al [37], Abbott [8], Guo et al [24], and Horiuchi et al [38]). 'Dry' laser processing with LIMPID is the only laser doping method not requiring extra gases or liquids, a factor that increases considerably the prospects of laser-based tooling entering production for laser doping.

Laser doping can be done as a single-step, or with simultaneous front-surface scribing (SiN_x/dopant-film and bulk 'grooves/pits') or ablation (SiN_x/dopant-film only). For dual processes, a plating-mask, suitable for electroless (or electrolytic) plating, is automatically patterned providing metallization (screen-printing or electroless) self-alignment [39]. It should be noted that laser doping has been confined in this article to (front-surface) emitter formation, but the discussion is equally valid for the base (e.g. PERL/PERT cells [40]) or for boron doping of n type cells [37,38,41].

Laser source and tool selection

Guidelines can be reached on optimized laser tooling for production. Each laser/material interaction is reviewed as a standalone laser-assisted selective emitters process, before 'dual' laser-based processes introduced above are discussed.

For laser scribing, laser source (and tool) selection is provided by way of production qualification by BP-Solar for LGBC [42] and from equipment optimization for laser edge isolation [28]. Collectively, this promotes high-power (10W+), nanosecond pulse-duration, diode-pumped solid-state (DPSS) lasers at wavelengths in the green (532nm) or UV (355nm) ranges. Fast throughput, aligned with c-Si requirements at 1,500 wafers per hour (or higher), suggests higher average powers (e.g. 2 x 45W green DPSS lasers) within multi-wafer process tooling [43]. Scribing several microns deep (and into the bulk c-Si) has the least stringent tool requirements of the laser-assisted selective emitters discussed, and the widest process windows [44]. Post-process damage etching can be eliminated when scribing 'shallow' grooves by diligent choice of laser parameters (correct wavelength, pulse-width) [45,46]. Nearly all laser tools used for scribing today in production involve dry laser processing coupled with fast galvanometer-mounted scanning mirrors for short process times and high throughput rates.

"Laser-based dielectric ablation shows excellent promise and increased adoption will clarify final laser source selection, as a stand-alone process or with laser doping."

Dielectric ablation (selective removal of SiN_x or SiO_2 layers without damaging the underlying P-layer) is one of the most exciting applications for lasers in solar; an overview can be found elsewhere [25].

More stringent demands on laser sources (compared to 'scribing') highlight shorter wavelengths (at or below 355nm), possibly shorter pulsewidths (of picosecond duration) and potentially uniform (homogenized, flat-top) beam profiles [ibid.]. The optimum choice of laser source and beam-delivery system may be influenced by the exact film thickness, by the material type (SiN_x or SiO_2), by the level of damage which can be sustained sub-surface, by dopant layer

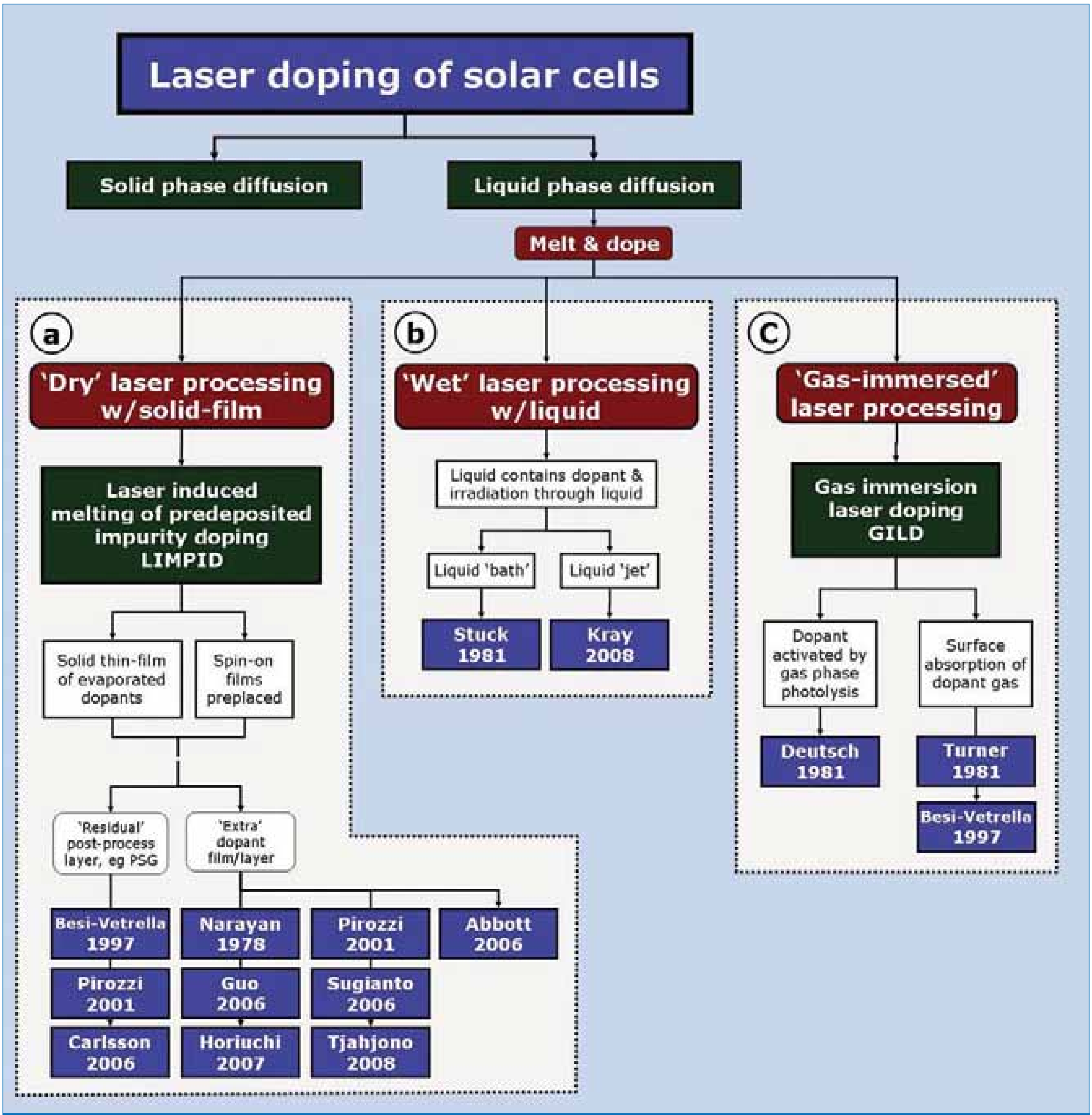

Figure 1. Classification of different schemes using laser doping for selective emitter formation. Abbott stated that solid-phase diffusion "forms extremely narrow junctions (< 0.1µm) for application in the IC industry and [is] not of interest to solar cell fabrication... In liquid-phase diffusion processes the laser energy causes the silicon surface to melt, and dopant atoms [then] enter the silicon in the liquid phase" [8]. Three different types of laser doping are identified, labelled (a), (b), and (c). Most research has focused on (a), 'dry' laser processing with solid films using the LIMPID technique.

concentration levels in fully-processed cells, and when considering tooling throughputs and ROI. However, laser-based dielectric ablation shows excellent promise and increased adoption will clarify final laser source selection, as a stand-alone process or with laser doping.

Laser doping (as a single process step) has been demonstrated with a range of lasers (different pulsewidths, wavelengths, energies, beam-shapes). This serves to illustrate the concept of using a laser to induce diffusion with "the potential of the laser-doping process as a simple selective drive-in process" [30], but most reports have also (not surprisingly) flagged up problems if non-optimal laser parameters are applied [15,47]. Mostly, this simply reflects a limited range of laser types available within any given research lab. Laser doping invariably demands lasers that provide strong localized absorption near the surface (promoting UV wavelengths), whose pulses have relatively low-energy (to avoid material damage) and operate at a fast speed (high repetition rates, or 'quasi' continuous-wave operation). Guidance dates back to 1997, when Besi-Vetrella et al used a laser "adjusted to obtain a fluence necessary to melt silicon, and to furnish a doped, smooth track, about 30 microns wide" [4].

The most topical 'dual' laser-process step combines dielectric ablation with laser doping, introduced succinctly by Tjahjono et al: "A particularly effective but simple way of achieving a selective emitter is by using laser doping to selectively remove the anti-reflection coating [dielectric

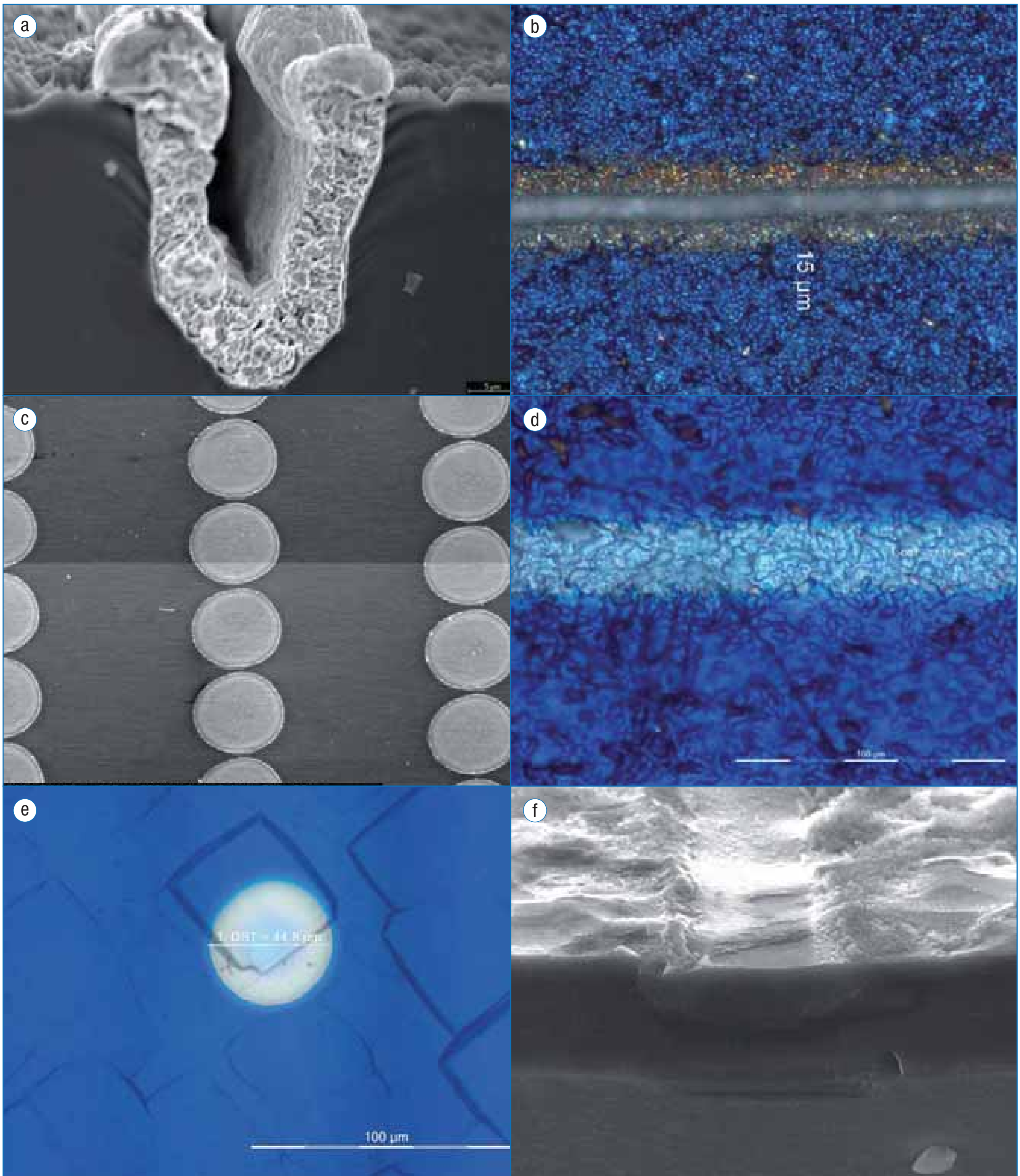

Figure 2. Front surface and cross-sectional images from various laser processes used within laser-assisted selective emitter schemes. Top to bottom, the images show laser scribing, SiN_x removal and SiO_2 removal. Images courtesy of: BP-Solar (a); Coherent, Inc. (b), (d) and (e); NanoGram, Inc. (c) and (f).

Figure 3. Coherent laser sources used for each of the selective emitter formation schemes, all within 'dry laser processing': (a) AVIA (scribing and ablation); (b) Paladin (ablation and dopant diffusion); (c) Talisker (ablation); and (d) LPX (ablation).

ablation] and simultaneously melt the underlying silicon while incorporating dopants into the melted silicon creating a heavily doped region...automatically providing a self-aligned mechanism for plating the metal contacts" [13]. Morilla et al stated: "laser-based ablation and doping are among the processes under development that may help to reduce the complexity and cost of the standard LGBC cell" [27].

Laser tool selection requires combining lessons learned from standalone dielectric ablation and laser doping processes: short wavelengths for localized absorption; sufficient average powers to activate the heat-generated dopant diffusion; fluence levels to ablate passivation layers while avoiding sub-surface damage downstream; short pulsewidths to reduce heat-affected zones. As explained by Tjahjono et al, "laser conditions were chosen since they provide adequate melting to sufficiently dope the silicon without causing ablation that can potentially result in more recombination sites [damage] and junction shunting" [13]. Morilla et al [27] sums up the issue nicely: "An important challenge is the development of a damage-free ablation process...the reduction or total elimination of damage or laser-induced defects in the silicon material... as expected, induced laser damage is highly dependent on the laser wavelength. V_{oc} drop [damage] was significantly reduced and almost nonexistent when operating the laser at the UV (355nm). A compromise between low damage and effective doping can be found..."

> "Laser tool selection requires combining lessons learned from standalone dielectric ablation and laser doping processes."

Conclusions

Laser-assisted selective emitters represent a class of high-efficiency cells which can be implemented directly within standard lines, as proven by BP-Solar's pioneering LGBC 'Saturn' production [42]. By 2010, selective emitter-based cells may account for 300MW out of 2.3GW of high-efficiency c-Si cells [2]; numbers are expected to grow as high efficiency becomes a necessity, not a luxury, to compete with lower-cost yet lower-efficiency thin-film PV cells. By categorizing the different schemes and material interactions, guidelines for laser source and tool selection can be established, thereby assisting cell and production line manufacturers specifying next-generation tools for high-efficiency cells.

Acknowledgements

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PV in the SPOTLIGHT

The International Solar Technology Awards, dubbed the Cell Awards, were created to provide an independently judged platform upon which the most successful and esteemed technologies and potentials in the solar industry can be placed in the spotlight, shining light onto some of the best technologies in the PV industry. The programme is based around seven awards; each award category is judged by a panel of industry experts and the industry public who voted online for their preferred candidates.

After each award category was decided for the 2009 event, the voting began. An online poll counted for 20% of the overall vote, while the majority decision of 80% of the overall vote went to the specialists, a panel of industry experts from some of the most highly regarded photovoltaics companies in the world. The Industry Choice Award was the only award voted for by 100% popular vote.

Once the voting had finished, and the winners had been decided, the entrants were held in suspense until the Intersolar Munich event 2009 where the awards ceremony took place. Here each winner was awarded with the unique Cell Award trophy, presented to each representative by some of the most important names in the industry.

Judges:

Fraunhofer ISE · Deutsche Solar · EPIA · Suntech · China Sunergy · Q.Cells · moserbaer

BEST PROCESS TECHNOLOGY FOR C-SI CELL MANUFACTURING LINES

Bates Marshall, SiXtron's VP of Sales and Marketing, accepts the award from ersol President Holger van Hebel at the Cell Award 2009 event in Munich.

The nominees for the Best Process Technology for c-Si cell Manufacturing Lines were: SiXtron's Sunbox, Advent's Ventura and BTU International's Meridian In-Line Diffusion.

And the *Winner* is:

SiXtron - Sunbox

SiXtron's SunBox is a silane-free coating system for front-side antireflective and passivation coating processes in c-Si solar cell manufacturing. Using a unique silicon carbide-based chemistry, the SunBox is a 'plug & play' solution for crystalline silicon cell manufacturing lines that matches the efficiency of today's most advanced antireflective and passivation coating systems while completely eliminating the significant safety, reliability and cost issues associated with pyrophoric silane gas. SiXtron's SunBox's core technology is based upon a unique solid polymer source material that is safe to handle, ship and store.

- SiXtron is the first company to provide a PECVD-based AR and passivation coating system that delivers the performance of today's silicon nitride coatings without the use of silane gas.
- Up to 50% reduction in installation cost of AR coating systems for new manufacturing lines; up to 50% reduction in total operating cost of AR coating system; reduced maintenance costs.

Runner Up

Advent Solar
Advent Solar's Ventura Technology is a comprehensive cell-to-module solar architecture that combines Emitter Wrap-Through (EWT) back-contact cells designed to eliminate grid obstruction with Monolithic Module Assembly (MMA) – a fully automated module assembly process. Ventura Solar Technology is designed to achieve the optimal balance between efficiency and cost – maximizing module energy output with minimal interconnect resistance, based on efficient, repeatable manufacturing processes to reduce costs.

BTU International
BTU International's MERIDIAN In-line Diffusion System combines the company's latest second-generation phosphorus coating technology with its flagship quartz-lined diffusion furnaces. The system is comprised of a direct spray phosphorus coater integrated with a conveyor belt diffusion furnace for processing silicon solar cells. The coater includes backside, topside and drying capability, which can translate into improved cell efficiency, while tight temperature uniformity enables uniform sheet resistance values.

BEST TECHNOLOGY FOR SILICON FEEDSTOCK AND WAFER PROCESSES

tec5's Steffen Piecha receives the award from Jerry Stokes, President of Suntech Europe

The nominees for this category were: tec5 with its VINSPEC SP Inline process control for ARs on PV wafers and Solaicx's CZ manufacturing process.

And the *Winner* is:

tec5 - VINSPEC sp inline process control system

VINSPEC SP is designed to provide reliable contactless inline quality measurement for thickness of antireflection coating at PV wafers directly after the coating process. VINSPEC SP offers MES logging of all process and measurement data in conformity to SECS/GEM. VINSPEC SP is a joint development of tec5 from Oberursel/Germany and VITRONIC from Wiesbaden/Germany.

- Fast spectroscopic technology allowing for short sampling intervals.
- Direct method of measuring physical properties of one or more coating layers.
- Shorter cycle times, a more detailed layer characterization and more information to react to changes in product quality.

Runner Up

Solaicx
Solaicx's proprietary continuous Czochralski (CZ) manufacturing process produces low-cost, high-efficiency silicon ingots five times faster and 30% longer than competitors employing equipment adopted from the semiconductor industry. The Solaicx method sees a continuous re-supply of fresh polysilicon maintain constant melt height in the crucible, and thus ingot length is determined by the height of the building or length of the pull chamber.

BEST REGION FOR MANUFACTURING SOLAR TECHNOLOGIES

Dorrit Koebke-Friedrich, Senior Manager of IMG Saxony receives the award from Nick Sarno, Senior Vice President of Manufacturing for LDK Solar.

The nominees for this category were: IMG Saxony Anhalt - Solar Valley; Silicon Border, Mexicali and the State of Oregon.

And the Winner is:

IMG Saxony - Anhalt Solar Valley, Germany

The Solar Valley Center of PV Industries houses almost 16% of global production capacity. It provides the possibility for rapid project realisation with a skilled and flexible labour force as well as generous investment incentives.

- Solar Valley unifies all PV technologies and is home to around 60 of the world's leading PV companies.
- The "Made in Germany" brand quality.
- Highest R&D support within the EU, and the lowest labour costs within Germany, despite a higher productivity rate (10% higher than German average).

Runner Up

State of Oregon
The State of Oregon generates interest from investors for its business energy tax credit, which covers up to 50% of the cost of a project; its low-cost hydropower; the state's proximity to California; and a semiconductor manufacturing work force that can easily transition into solar cell manufacturing.

Silicon Border, Mexicali
The Silicon Border could be described as the single largest application of PV systems in Mexico after electrification of rural communities. Over 500 luminaries have been installed, with PV panels of around 150W each.

GREEN SOLAR MANUFACTURING AWARD

The nominees for this category were: PV Cell Ribbon and Bus Bar Methodology from EFD, Cookson's Alpha PV ribbon and Komax's Xcell Stringer.

And the Winner is:

Linde - Flex F-80 Onsite Flourine Generator

Linde Electronics' Ian Travis, General Manager, Fluorine receives the award from Eleni Despotou, Policy Director and Deputy Secretary General of EPIA

Linde's On-Site F_2 Generator (pictured below right) has been installed at more than 20 semiconductor, LCD and solar cell production sites. Replacing NF_3 with Fluorine in a 500MW thin film Si fab results in elimination of NF_3 consumption with an untreated global warming potential equivalent to over 8 million tonnes of CO_2 per year. Linde's proven technology for generating F_2 on-site and on-demand eliminates the need for large volume storage and addresses all the safety requirements for handling this reactive material. In addition to its environmental benefit, F_2 reduces the time for chamber cleaning, thereby increasing plant productivity, through a more efficient etching process, and ultimately lowers cost per watt.

- Reduce cost per watt through reduced mass consumption, faster clean times, and reduced capital expenditure, with savings of 3c to 5c/W for a typical thin-film PV fab.
- 20% less F_2 is required vs NF_3; for less efficient activation processes, these savings can be significantly greater.
- Cleaning with F_2 can reduce chamber-cleaning times by a factor of 2 to 4, and therefore greatly increase the throughput on a critical step of thin-film PV production.

PV in the Spotlight
The Cell Award ceremony took place at InterSolar Munich, 2009

Runner Up

Edwards
Edwards' Spectra-Z 3000 provides an all-dry combustion abatement solution that meets many customers' needs, adhering to environmentally-friendly practices.

The Spectra-Z is a high-capacity combustion system that provides reliable, high-performance and cost-effective abatement of hazardous gases from solar cell processes that use large flows of silane (SiH_4). The Spectra-Z employs 4-stage combustion, an effective powder handling system and can be configured with up to six process gas inlets. It has low CoO, no water or oxygen required and is suitable for indoor or outdoor installation.

BEST TECHNICAL PRODUCT FOR MODULE ASSEMBLY

The nominees for this category were: PV Cell Ribbon and Bus Bar Methodology from EFD, Cookson's Alpha PV ribbon and Komax's Xcell Stringer.

And the Winner is:

EFD - PV Cell Ribbon and Bus Bar Methodology

EFD, Inc.'s Peter Lambert (right) receives the from Dr. Uroš Merc, CEO, Bisol Solar at the Cell Award 2009 event in Munich.

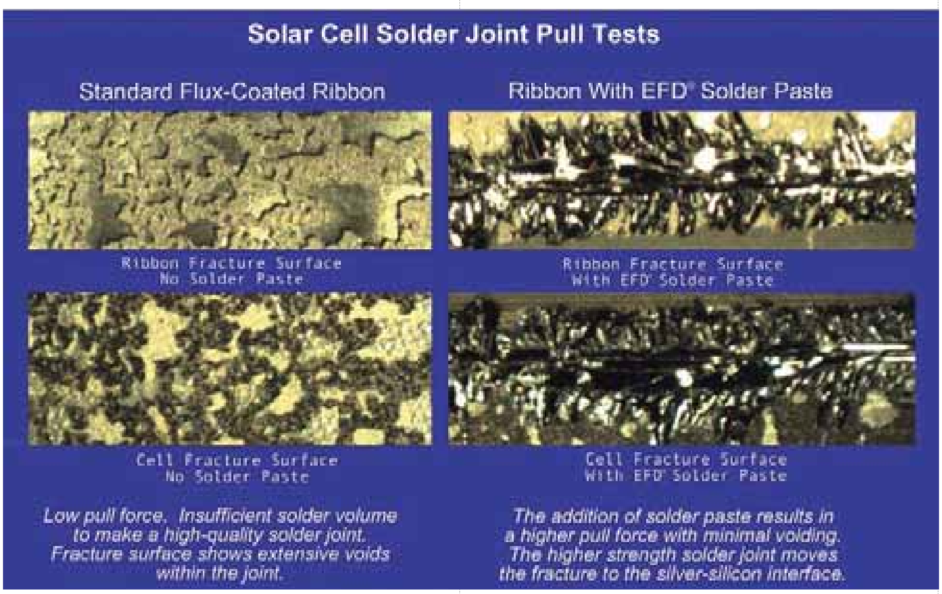
EFD's PV Cell Ribbon and Bus Bar Attachment Methodology is a point-to-point soldering process that uses a proprietary lead-free solder paste and flux mixture to attach string ribbon material to silver bus bars during module assembly. In addition to eliminating the need for pre-coating of ribbon material with liquid flux, the additional metal content augments the solder joint. The method is compatible with both manual and automated assembly operations.

- Additional metal content, used at specific locations in a point-to-point soldering process, has been shown to reduce the amount of microcrack formation and aid in the verification of solder joint formation during module assembly.
- Microcrack reduction could facilitate the use of thinner wafers and improve performance over the life of the module.
- Additional solder alloy increases solder joint toughness, consistency and durability (see below).

Runner Up

Cookson
Cookson's Alpha PV-Ready Ribbon increases throughput by eliminating costly maintenanceassociated with a separate fluxing operation. Major PV assemblers have seen enhanced solder joint reliability of the PV module assembly, demonstrated by significant improvements in peel test performance. The Alpha PV-Ready Ribbon is currently being successfully run on the production lines of major global PV module assemblers and is fast becoming the new standard in reliability and productivity in PV module assembly.

Komax
Komax's Xcell 3400 Stringer is the next generation of the company's automated stringer product line. Capable of processing all traditional mono- and polycrystalline solar cells up to 156mm x 156mm, with 2 or 3 busbars and a maximum throughput rate of 600 solar cells per hour, the Xcell 3400 Stringer is an excellent fit for solar cell stringing needs.



BEST TECHNICAL PRODUCT FOR THIN-FILM MODULE MANUFACTURING

The nominees for this category were, the KAI 1200 PECVD system (pictured right) from Oerlikon Solar, Applied Materials' Sunfab Line and Veeco's PV-Series Thermal Deposition Sources.

And the Winner is:
Oerlikon Solar - KAI 1200 PECVD system

Jürg Steinmann, Oerlikon Solar's Head of Marketing Communications, receives the Award from Dr. Uroš Merc, CEO, Bisol Solar at the Cell Award 2009 event in Munich.

The Oerlikon Solar KAI 1200 PECVD production system, originally used to produce TFT semiconductor devices in the LCD industry, deposits amorphous and microcrystalline absorber layers faster and at a better quality resulting in a significant reduction of the production cost of silicon thin-film solar modules. Based on

its research in partnership with the IMT in Neuchatel and the EPFL in Lausanne, dielectric lens compensation was invented which eliminates the standing wave effect. From the first concepts in early 2000, Oerlikon Solar successfully implemented this new type plasma source into mass production.

- The 40MHz VHF technology has considerably increased deposition rates and at the same improved the absorber layer quality.
- Oerlikon Solar's tool has doubled the deposition rate on its 1.4m² solar panels at best in class layer quality and improved the cycle time for the deposition of the amorphous absorber layer by over 30%.
- Amorphous single junction modules have shown an initial aperture efficiency of 9.6%.

Runner Up

Applied Materials
The Applied Materials SunFab Line offers customers a proven production solution to manufacture photovoltaic modules at a low cost per watt on substrate sizes up to 5.7m². The SunFab Line is capable of producing approximately 150,000 full-sized modules (2.2m x 2.6m) per year. A combination of low cost advantages will open the market to rapid expansion by moving solar from a niche solution to an economically viable alternative to traditional electricity.

Veeco
Veeco's PV-Series Thermal Deposition Sources are installed on CIGS coating systems and are capable of depositing on substrates as large as 120cm. Veeco sources have become the production standard for CIGS manufacturers because of their large capacities, high temperature operation and long term stability - all critical factors in the CIGS deposition process. Providing the largest available capacities (from 65cc to 15,000cc), the sources enable long production uptimes, minimizing material loading cycles and system vents.

SOLAR INDUSTRY CHOICE AWARD

The nominees for the Industry Choice Award were: the Meridian In-Line Diffusion System from BTU International, IMG Saxony's Solar Valley and SiXtron's Sunbox.

LDK Solar's Senior Vice President of Manufacturing Nick Sarno (left) presenting the Industry Choice Award to BTU International's Oliver Wehner (right), Sales Director for BTU France

And the *Winner* is:

BTU International - Meridian In-Line Diffusion System

BTU International's Meridian In-line Diffusion System combines the company's latest second-generation phosphorus coating technology with its flagship quartz-lined diffusion furnaces. The system is comprised of a direct spray phosphorus coater integrated with a conveyor belt diffusion furnace for processing silicon solar cells. The coater includes back-side, topside and drying capability which can translate into improved cell efficiency, while tight temperature uniformity enables uniform sheet resistance values.

- Reduced wafer handling and greater through-put than traditional batch processing translates into lower breakage rates and improved yield.
- Coating application is accomplished via a nozzle-less ultrasonic spray system, eliminating clogging typically found in nozzle type spray designs.
- Capable of applying both topside and backside coating to promote impurity gettering from the wafer, which can yield and efficiency improvement. Initial test results in BTU's laboratory have shown a 60-65% average lifetime improvement.

Runner Up

IMG Saxony Anhalt
The Solar Valley Center of PV Industries houses a high density of PV supply-chain companies. With almost 16% of global production capacity located in the region, it brings the possibility of rapid project realisation with a skilled and flexible labour force as well as generous investment incentives.

SiXtron
SiXtron's SunBox is a silane-free coating system for front-side antireflective and passivation coating processes in c-Si solar cell manufacturing. Using a unique silicon carbide-based chemistry, the SunBox is a 'plug & play' solution for crystalline silicon cell manufacturing lines that matches the efficiency of today's most advanced antireflective and passivation coating systems while completely eliminating the significant safety, reliability and cost issues associated with pyrophoric silane gas.

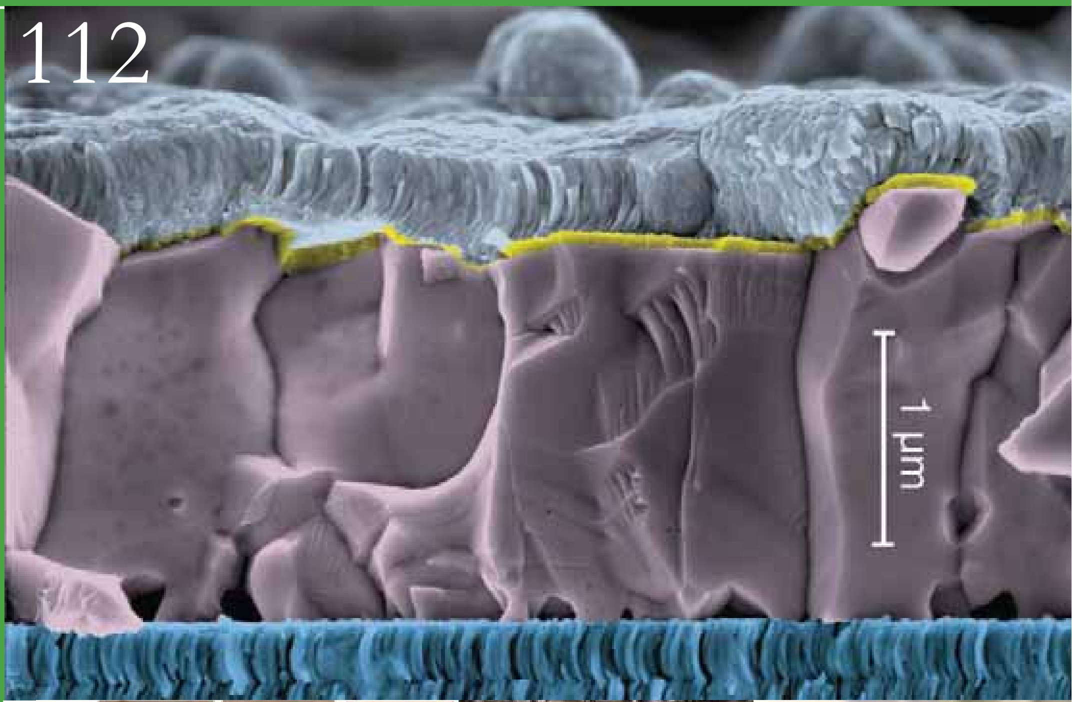
Cell Award 2010

In his closing address to the audience at the ceremony, David Owen, publisher of *Photovoltaics International*, encouraged the industry in these difficult times to reflect on current technologies that will help PV manufacturers achieve cost and yield goals now in the future, "It is vital that we continue to recognise and acknowledge new technical innovation in PV manufacturing now and in the future to encourage further technical developments."

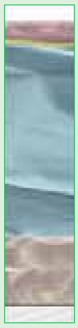
Entries for the 2010 Cell Awards will open on September 28th 2009.

Further details will be available on www.cellaward.com.

Thin Film



XsunX plots thin-film revolution with new cross-industry technology



In an attempt to attain the efficiencies of silicon solar cells coupled with the relative cheapness of thin-film manufacturing, XsunX has proposed a new TFPV technology that utilises the unused manufacturing capacity of the hard disk drive industry with the aim of mass production of cheap and efficient solar cells.

While current manufacturing techniques use the near-20% efficiency CIGS-based thin films, XsunX points out that this technology does not take advantage of the benefits of working with stationary, small area production technologies that can result in higher efficiencies. The company is working with a HDD equipment manufacturer to borrow small area deposition, material control and material transport technologies from the disk drive industry.

The company proposes a new manufacturing method that uses small area processing techniques on approximately 5" square stainless steel wafers. These techniques use the high rate processing techniques developed within the hard disc media industry, potentially increasing production, efficiency, factory yields and reducing cost.

XsunX is currently in the process of adapting high rate production tools from the disk drive industry and combining it with process knowledge from the thin-film manufacturing industry.

"Our approach to CIGS thin film, combining sophisticated high rate HDD equipment with proven CIGS processes that have been matured in the laboratory, offers XsunX an opportunity to differentiate by providing significant improvements and cost reductions for the use of solar power," commented Robert Wendt, Chief Technology Officer for XsunX.

The idea for the use of the HDD industry in this application came from the fact that, what with the economic downturn, the HDD industry has a glut of excess manufacturing capacity. XsunX has claimed that converting only half of the HDD industry would lend itself to adding nearly 3GWp per year of solar production capacity.

Potential applications for the wafers include the replacement of existing silicon wafers for this cheaper substitute; eliminating size constraints associated with monolithic thin-film technology; and various BIPV and residential applications and consumer products.

Image (above left) shows a sample 126mm stainless steel substrate. This sample depicts the flexibility of the stainless steel wafer format and development the backside contact Chrome Molly process. This work is being done to demonstrate the adaptation of high rate deposition techniques utilizing HDD equipment.

Research and Development News Focus

Significant advancement in dye-sensitized solar cells achieved

Researchers in South Korea have suggested a new approach to creating cost-effective and more efficient dye-sensitized solar cells, which will mean significant advancement in the thin-film market. So far development of this thin-film technique has seen one major setback; the efficiency of the cells has been half that of the more commonly used silicon-based cells, this new approach will improve the power consumption rates of dye-sensitized solar cells by at least 50%.

Park Nam-gyu, a researcher from the Korea Institute of Science and Technology (KIST), said his team has discovered a breakthrough method, which enables a sequential bonding of dyes in the thin, titanium dioxide (TiO_2) layers used in dye-sensitized solar cells.

Park said, "In the existing prototypes, the TiO_2 films bond with just one kind

Nano Solar Technology orders 120MW micromorph line from Oerlikon Solar

A Russian high-tech firm has ordered a 120MW end-to-end Micromorph line from Oerlikon Solar for the production of thin-film solar modules. Nano Solar Technology (NST) is a joint venture between Renova Group and the Russian Corporation of Nanotechnologies (Rusnano).

The project was first announced in May this year between Rusnano, a government industry body and Renova, owned by billionaire Viktor Vekselberg, which will control 51% of the venture.

The equipment will be delivered in 2010 to Khimprom OJSC in Novocheboksarsk town of (Chuvash Republic), the new site currently under construction. The start of production is scheduled for 2011. The order also encompasses a comprehensive multiyear service agreement, provided by Oerlikon Solar's global customer support team.

The facility is to be based on an existing chemical facility and will produce 1 million solar modules per year by the end of 2011.

Renova holds a 45% stake in Oerlikon Solar.

SCI Engineered Materials scores US$1M order for thin-film PV materials

SCI Engineered Materials has received a US$1 million order for thin-film photovoltaic products from an unspecified customer. The physical vapour deposition-related materials are expected to be manufactured and shipped during the second half of 2009, the company said.

SCI began developing additional products for the TFPV sector in 2006, following several years as a PVD materials supplier to the market. During the past two years, the Columbus, OH-based company says it has accelerated the acquisition of manufacturing equipment to scale its operations and also hired additional engineering and sales staff to specifically focus on thin-film PV. SCI says it is actively involved in the qualification process with several customers and has received a number of trial orders in 2009.

ECD to supply 15MW of Uni-Solar laminates to PV integrator Mercury

Thin-film photovoltaic manufacturer Energy Conversion Devices has signed a multiyear direct supply agreement with solar integrator Mercury Systems. Under the terms of the deal, ECD will sell Uni-Solar amorphous-silicon TFPV laminates to Mercury and will also provide technical training and aid in the design of future PV systems installed by the integrator's team.

Mercury, which expects to buy approximately 15MW of laminates over the course of the contract, will become a direct integrator of the products.

ECD has also recently signed multiyear deals with Inovateus and Johns Manville to supply PV laminates. In addition, the company is in the midst of closing its acquisition of one-time customer Solar Integrated Technologies, which uses Uni-Solar laminates in its building-integrated PV roofing products.

of dye, and developing techniques to allow the films to absorb dyes of different colours, thus allowing the solar cell to absorb and use a broader spectrum of daylight, has been a key issue... we were the first to achieve this by developing materials in both the mobile and stationary phase that enables the selective position of dye molecules with different absorption ranges. This could significantly improve power conversion rates that currently max at 11%."

The basic design of these dye-sensitized solar cells is based on a semiconductor formed between a photosensitized anode and an electrolyte. The cells are made of a porous film of tiny, nanometer-sized TiO_2 particles, which are covered with a layer of dye that is in contact with the electrolyte.

When contacted by sunlight, the dye injects a negative charge in the nano-particles and a positive charge into the electrolyte, thus converting the light into electrical energy.

The positioning of the dye molecules is critical in boosting power conversion rates, as it enables different absorption ranges in the TiO_2 films.

Ascent Solar passes 10% efficiencies on flexible CIGS thin film

Independently verified by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL), Ascent Solar says that its copper-indium-gallium-(di)selenide (CIGS) monolithically integrated 429cm^2 sized thin-film modules have reached 10% conversion efficiencies. NREL had also witnessed module efficiencies of 10.4%, all produced from Ascent's 1.5MW production line in Colorado.

"Ascent's high-volume 30MW commercial plant is scheduled to commence initial production at the beginning of 2010," noted Dr. Prem Nath, Sr. Vice President of Production Operations for Ascent Solar. "Module efficiency of 10% is a vital element for our low-cost-per-watt manufacturing goal in high volume."

Ascent Solar is also collaborating with NREL with the company's proprietary deposition process to use a zinc-magnesium-oxide (ZnMgO) layer to replace the standard window layer of a CIGS device. The ultimate aim is to replace all the top layers of the device.

Big glass passes: Applied Materials' large-area SunFab PV panels get IEC certification

Applied Materials has received International Electrotechnical Commission certification for both the single- and tandem-junction versions of the 5.7m^2 solar photovoltaic modules produced by its SunFab thin film line. Tests run by TÜV InterCert confirmed that the large-area amorphous-silicon panels meet IEC standards 61646 and 61730.

"Applied's 5.7m^2 modules are four times bigger than anything we've ever tested," said Feridoon Sergizzarea, President and CEO of TÜV InterCert. "We made modifications to the laboratory and added equipment to enable us to test modules this large. Creating a PV product of this size that can pass all of the IEC tests while maintaining mechanical and electrical integrity is an impressive feat of engineering."

The quarter-sized 1.4m^2 modules produced on the SunFab TFPV line received IEC certification earlier this year. However, a full-size 5.7m^2 panel designed to maintain high power output while subjected to years of exposure to sunlight, extreme temperatures, wind and precipitation was a new challenge.

Applied' says that its technology and engineering expertise in flat-panel display and architectural glass systems enabled it to deliver the critical uniform conversion properties required across large areas. An integrated bonded rail support structure strengthens the module, allowing it to withstand wind and seismic loads while enabling the reduction of installation costs by greatly simplifying the mounting structure.

"We expect 5.7m^2 modules to become the standard for utility-scale PV power," said Randhir Thakur, senior VP/GM of Applied's display and SunFab solar business group. "Applying SunFab technology to ultralarge modules creates an unprecedented opportunity to reduce both manufacturing and installation costs, transforming solar PV into a long-term solution to provide the world with affordable energy from a renewable source."

News

Centrotherm claims 12% efficiencies for turnkey CIGS production line

Based on results from its own pilot line, centrotherm photovoltaics has said that it has achieved CIGS (copper indium gallium diselenide) thin film module ($0.1m^2$ size) efficiencies of 13% and expects its first customer for its turnkey system to achieve 12% efficiencies with $1.5m^2$ sized thin film modules, in 2009.

"The efficiencies for thin film modules already achieved in laboratories demonstrate the potentials this technology holds. The challenge, however, is to make the leap from laboratory to mass production," explained Dr. Peter Fath, CTO of centrotherm photovoltaics. "Our advantage in CIGS technology lies in simple and robust process management, and selection process steps that can be transferred easily from small areas to larger ones."

centrotherm established a R&D centre in Blaubeuren, Germany at the beginning of 2008 for CIGS development.

Thin-Film Production News Focus

Switzerland's largest solar module production gets underway

The Pramac Group and Oerlikon Solar have announced that production has begun at the Switzerland-based solar module manufacturing facility. Oerlikon Solar's Micromorph end-to-end manufacturing solution enabled Pramac to reach production just seven months after completing its facility.

The plant, which is the largest in the country, near Locarno, will produce 30MWp of thin-film solar panels each year and create 150 high-tech jobs in the region.

ersol launches its micromorph thin-film module Vega-T on the market

ersol Thin Film, a subsidiary of ersol Solar Energy AG, has announced that it is launching its first micromorph thin-film module under the name Vega-T. Micromorph technology will enable initially an efficiency of approximately 8%, in comparison to the lower efficiency level that is achieved with amorphous thin-film modules, which is just 6%.

Over the next few years, companies such as ersol will work towards increasing the efficiency level of micromorph modules to 10% and higher; ersol is in the process of converting all of its modules from amorphous to micromorph, and the company says this transition will be complete in the next couple of months.

ersol has also been working with Schott Solar Thin Film, Jena, on a joint precompetitive development of the new micromorph thin-film technology. In contrast to the simple amorphous version, the micromorph thin-film modules have a double-layer structure consisting of an amorphous and a microcrystalline silicon layer.

ersol's micromorph thin-film module.

Xunlight wraps up 25MW roll-to-roll equipment installation

The first of Xunlight's 25MW wide-web, roll-to-roll photovoltaic manufacturing equipment lines has been fully installed at the company's 122,000-sq-ft facility in Toledo, Ohio, putting the operation on track to begin production of high-efficiency thin-film silicon PV modules. The company's proprietary roll-to-roll equipment, the first of four systems in the pipeline, has been shown to demonstrate uniform deposition of triple-junction thin-film silicon solar cells.

Xunlight module.

The recently completed installation is comprised of a 200-foot-long series of connected vacuum deposition chambers and will involve a PECVD process to deposit thin-film silicon solar cells on a 3ft wide, mile-long stainless-steel substrate. Once completed, four 25MW installations will bring the company's cell production to 100MW by the end of 2010.

ENN Solar's large thin-film modules receive TÜV and IEC certification

As the first Chinese thin-film manufacturer to produce tandem junction cells on a production line, ENN Solar Energy has passed another milestone with its receipt of certification from TÜV InterCert for its tandem junction silicon thin-film solar modules. This certification confirms that the modules comply with the IEC's requirements, and effectively passes the modules for sale in European and U.S. markets.

With this TÜV Certificate, ENN Solar becomes the first manufacturer in Asia to receive the certification for ultra-large size tandem junction silicon thin-film modules.

ENN tandem junction thin-film module.

The half- and quarter-size modules also received the certification, which concludes that all of ENN's module sizes are in compliance with the requirements of IEC 61464 and IEC 61730.

The $5.7m^2$ modules were produced on its 60MW Applied Materials 'SunFab' line, ramp-up of which took place in March 2009. EEN Solar has aggressive plans to ramp manufacturing capacity to 500MW by 2011.

JM's E3 company and ECD to deliver PV systems for commercial rooftops

Johns Manville, global manufacturer of energy-efficient building products, and Energy Conversion Devices, manufacturer of thin-film amorphous silicon-based PV laminates, have announced a multiyear agreement for ECD to supply Uni-Solar laminates to JM, which will market its capability through a new business entity, the JM E3 Company, or E3 Co.

There is no mention of what the megawatt supply levels will be for this agreement.

JM's thin-film modules.

Business News Focus

CIGS thin-film firm DayStar Technologies running out of money, could file for bankruptcy soon

DayStar Technologies, a copper-indium-gallium-(di)selenide thin-film PV developer based in Santa Clara, CA, is running out of money. Although the company posted a smaller net loss in its just-announced second-quarter results

than it experienced in the first quarter and the value of its net property and equipment has risen to $50 million because of increased investment during the period, its cash and cash equivalents have dwindled to $1.3 million.

As a result of its financial woes, DayStar says it will need "substantial funds in the near term" to continue operations, ramp its first production line, and begin shipping products, and a failure to raise such monies may result in the company declaring bankruptcy and possibly shutting down part or all of its operations.

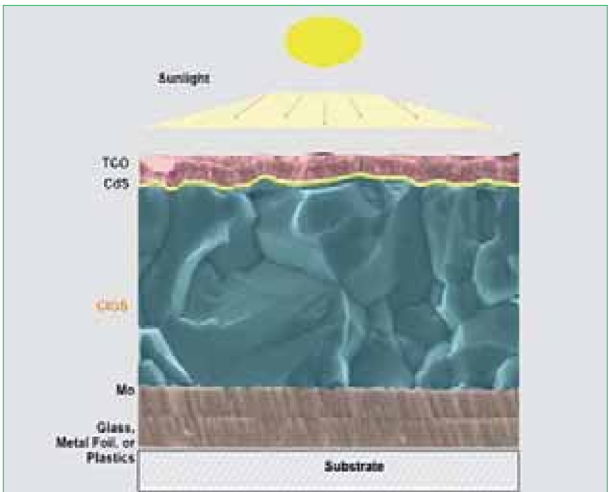
In DayStar's 10-Q report filed with the Securities and Exchange Commission, the CIGS firm says that "commercialization efforts, including the completion and ramp-up of the company's initial module production line requires significant additional capital expenditures as well as associated continued development and administrative costs. In order to continue operations, including its development efforts utilizing its preproduction line, fully build out its initial manufacturing line and commence commercial shipments of its product, the company requires immediate and substantial additional capital beyond its current cash on hand."

"To date, the Company has been unable to raise additional capital or complete an agreement with an investor or strategic partner," the filing continues. "Although the company continues to seek strategic investors or partners, in light of its current cash position, the company implemented a reduction in its workforce of approximately 30% during the second quarter of 2009 and may in the near term be forced to cease or substantially curtail operations."

"An inability to raise additional funding in the very near term may cause the company to file a voluntary petition for reorganization under the United States Bankruptcy Code, liquidate assets, and/or pursue other such actions that could adversely affect future operations," the DayStar 10-Q states. "Given current market conditions and available opportunities, there is substantial doubt as to the company's ability to complete a financing in the time frame required to remain in operation. A wide variety of factors relating to the company and external conditions could adversely affect its ability to secure additional funding and the terms of any funding that it secures."

DayStar has a proprietary one-step sputter process that it says can continuously deposit high-efficiency CIGS films over large-area glass substrates. The company claims the approach can meet the sub-$1-per-watt manufacturing cost threshold at a capacity scale of 100MW or more, including the achievement of commercial module efficiencies better than 13%.

The CIGS company has begun building out its first 25MW module production line and has a contract with solar PV integrator Blitzstrom to buy at least half of its production run through 2011, as long as the modules meet the proper performance criteria.



Cross-section of DayStar's CIGS film.

Product Briefings

Siemens

Siemens glass handling automation and drive technologies harmonize production and boosts productivity

Product Briefing Outline: Siemens automation systems group is offering a Totally Integrated Automation (TIA) solution for integration of process and manufacturing technology for large-scale, highly reliable and efficient automated production of c-Si and thin-film PV modules. Special cast and float glass are increasingly produced in dedicated lines that have a flexible design for both cell and thin-film applications. Siemens offers enhanced technical solutions for the integrated automation of all production levels – from raw material to the finished product.

Problem: Thin-film requirements for glass handling differ depending on the various technologies, such as vertical and/or horizontal, contact and/or contact-free handling as well as mechanical glass load management. Glass handling is not only a logistics issue in manufacturing of PV modules but is a growing requirement for increasing manufacturing capacity.

Solution: Siemens is working together with the PV industry on concepts to integrate process steps, to synchronize line sequences and to harmonize the handling processes. This increases the scale of automation, allows feeding different kind of process stations and reduces buffer and handling times. Track and trace, identification and authorization by Siemens are options to help support manufacturing intelligence. The result is a robust, integrated handling line concept for all kinds of thin-film technologies, which allows for faster ramps to volume production while improving yields and reducing costs. Siemens has worked for a long time with the glass industry and has developed solutions for the float and cast glass handling application, which today the PV industry can benefit from. Process control, motion control and technology are functions that were combined into one system and open up completely new possibilities for integrated glass processing and handling.

Applications: Thin-film glass handling including areas such as edge processing, cutting, sealing, drilling, milling, grinding and coating.

Platform: Key components of Siemens integrated glass handling approach include the Sinamics S120 modular drives system, Simotion and Simatics controllers S7, that build the integrated tool box. Modular hardware and software philosophy and standard engineering libraries allow 'easy to design' flexible and optimized solutions.

Availability: Currently available.

Product Briefings

ACI-ecotec GmbH

ecoContact from ACI-ecotec enables speedy thin-film module contacting

Product Briefing Outline: ACI-ecotec GmbH & Co. KG has introduced a fully automatic contacting system for the application of small pieces of adhesive tape in attaching bus bars to thin-film modules. In the dispensing module of 'ecoContact,' the conductive adhesive is applied using two dispensing heads at speeds of between 40 and 70mm per second. With continuous monitoring of the needles during application, the module process takes less than 40 seconds. As well as offering high speed and high contact quality, the system is said to be highly flexible and economical with materials.

Problem: Because of the large capital expenditure involved, production systems for thin-film photovoltaic modules must operate as efficiently as possible. In conventional contacting, adhesive tape is applied along the entire length of the bus bar, a process that can be wasteful.

Solution: ecoContact applies conductive adhesives using two autonomous dispensing heads. The conductive adhesive is applied via two dispensing heads at speeds of between 40 and 70mm per second, and the system performs ongoing monitoring of the needles. Any bumps or irregularities in the surface of the glass plate are automatically levelled out. Thanks to the controlled high-precision application, approximately one gram of adhesive is required for a substrate that is 1300 to 1400mm long. Because the CNC heads operate autonomously, the position, length and distance between the adhesive strips can be programmed flexibly, enabling the application of more than two adhesive strips without modifications.

Applications: Thin-film adhesive dispensing.

Platform: ecoContact comprises standard components for applying conductive adhesives, longitudinal and lateral contacting and soldering bus bars for the manufacture of all common thin-film module sizes.

Availability: Currently available.

Bekaert Advanced Coatings

Bekaert's one-piece AZO rotatable target delivers superior TCO layers

Product Briefing Outline: Bekaert Advanced Coatings has introduced a one-piece AZO rotatable target for thin-film photovoltaic applications. The new AZO rotatable target delivers TCO layers and back contacts for photovoltaic cells. TCO layers are essential building blocks for all thin-film PV (amorphous silicon (a-Si), cadmium telluride (CdTe) and CI(G)S) applications, where optical transmission and electrical conductivity are required simultaneously.

Problem: Thin-film solar cells rely heavily on the deposition of thin layers. Besides thin-film deposition of the absorbing semiconductor, the layer stack also consists of two thin-film electrodes: a transparent conductive oxide layer at one side of the absorbing semiconductor to let the light enter and a back reflector metal contact at the other side. Each of these layers has to be deposited with an accurate control of composition, morphology and thickness in a uniform way over ever-increasing substrate sizes.

Solution: The newly developed AZO target consists of one piece (no rings or segments, giving a more stable and better controlled sputter process). Directly applying the AZO material to the backing tube during production eliminates the need for bonding material that has a low melting point. This homogeneous bonding allows better cooling through optimized thermal conductivity and the ability to use higher sputter power densities. The new one-piece AZO rotatable target ensures high quality TCO layers, superior deposition rates leading to lower cost of ownership, and a firm stability over the lifetime of the solar cells.

Applications: TCOs in thin-film PV cells.

Platform: Rotatable sputter technology for PVD. Available in lengths up to 152 inches, in several thicknesses and in standard or 'dog bone' shapes. All conventional types of target fixations are supported.

Availability: Currently available.

Helmut Fischer GmbH

Helmut Fischer offers thin-film EDXRF in-line process control system

Product Briefing Outline: Helmut Fischer GmbH Institut für Elektronik und Messtechnik has introduced the 'Fischerscope' X-RAY Conti 5000 series, which uses energy dispersive x-ray fluorescence spectrometers (EDXRF) for in-line process control. Specially designed for continuous non-destructive analysis of alloys and measurement of thin layers and layer systems, the spectrometers are best suited to measure CIGS, CIS and CdTe in thickness and composition.

Problem: TFPV films are difficult to measure due to their special optical properties. The right thickness and composition of active layers is required to ensure performance efficiency and durability of the thin-film modules and to ensure only the correct thicknesses are deposited to control material and production costs.

Solution: Measurement of the photoactive layers can be performed on such substrates as glass panels, thin metal or plastic foils. For each application, the x-ray source and the semiconductor detector can be customized for best results. Simple integration into production lines is enabled by the Conti 5000's standardized mounting flange. Various modular build versions are available to measure in vacuum or ambient air. The additional cooling flange allows the measurement of very hot substrates with surface temperatures of up to 500°C. Calibration is said to be quick and easy, and due to a large aperture, state-of-the-art semiconductor detectors and a digital pulse processor, the Conti 5000 is claimed to produce excellent repeatability combined with an good longtime stability. The necessity for re-calibration is dramatically reduced, saving time and effort.

Applications: CIGS, CIS, CdTe thin-film thickness and composition measurement.

Platform: The entire operation, including analysis of the measurement signals and display of all information is carried out by an evaluation PC with the easy-to-use WinFTM software. Due to a versatile communication interface, all Conti 5000s are easily integrated into industrial process control systems.

Availability: Currently available.

Product Briefings

MonoVAT

MonoVAT transfer valve specially designed for roll coater systems

Product Briefing Outline: Vacuum valve specialist VAT has introduced a new transfer valve for roll to roll applications. One challenge for roll coater system designs utilizing loadlock chambers is to seal the process chamber entrance and exit openings while the web substrate (typically a metal band or plastic foil) remains in place. For this pinch seal configuration VAT offers the 3D MonoVAT sealing technology. Due to the linear motion 3D sealing technology, it is possible to clamp and seal the web without any deformation or damages.

Problem: The current disadvantage of roll-coater equipment is that in case of a web/ roll change the entire system needs to be vented to atmosphere and cooled down.

Solution: The MonoVAT transfer valve is placed between the front chamber, where the feed coil is placed, and the process chamber(s). A second MonoVAT transfer valve is used in the rear chamber where the take-up roll is placed. Once the web is completely coated the valves are closed onto the foil, the front and rear chambers are vented to atmosphere, the web is cut, the coils are replaced and connected with the ends of the web while maintaining vacuum and temperature in the centre process chamber(s). The result is a significant improvement in system availability, thereby increasing the throughput.

Applications: Vacuum-based thin-film roll coater systems (CIGS, a-Si, CdTe, organic cells).

Platform: The MonoVAT roll coater valve is available in slit sizes from height 15-50mm, length 300-1750mm. The valve is also available in aluminium or stainless steel with a wide range of options. This design flexibility of the MonoVAT transfer valve allows the valve to be adapted to meet the special requirements of some thin-film PV processes.

Availability: Currently available.

Umicore Thin Film Products

Umicore's ITO rotary sputtering targets reduces deposition costs

Product Briefing Outline: Umicore Thin Film Products has introduced high-density sintered Indium Tin Oxide (ITO) rotary sputtering targets for deposition of high-end transparent conductive oxide layers. These are suitable for use in both thin film and hetero-junction solar cells. Umicore produces a full range of Indium- and Zinc-based ceramic rotary sintered sputtering targets: ITO, AZO and i-ZnO.

Problem: In thin-film PV modules, the front contact (TCO) cost is typically between 5-10% of the total module cost. Hence, reducing that cost is a major factor in the race towards grid parity. Rotary sputtering targets have long been proven to significantly reduce total cost of ownership, but until recently, no industrial size sintered ITO rotary target was available on the market.

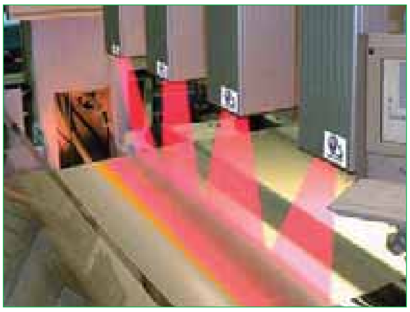
Solution: Use of Umicore's rotary targets typically results in savings of up to 30% per m^2 of ITO coated substrate when compared with processes running with planar ITO targets. This is due to higher utilization rate of the sputtering targets, high target thicknesses, elimination of nodule formation on the target surface, higher production yields and increased up time of the PVD equipment.

Applications: Any photovoltaic panel production process requiring ITO as transparent and conductive layer.

Platform: Sintered ITO rotary targets up to 4m in length with an integrated recycling program and in-house Indium refining. On-site free technical assistance is offered for first time users. All Umicore production sites are ISO certified.

Availability: Currently available.

i2S LineScan, Inc.



PV-4000 Vision system from i2S LineScan tackles thin-film defect inspection

Product Briefing Outline: i2S LineScan, Inc., a supplier of on-line and off-line camera-based vision systems for optical defect detection and feature metrology, has introduced its thin-film photovoltaic application-specific machine design, the PV-4000. Utilizing standard software, the inspection system can inspect glass panel, roll-to-roll metallic, or film substrates, and capture images of visual defects or out-of-dimension features.

Problem: As PV processes work their way out of the lab and into the manufacturing environment, one of the key requirements is to get the manufacturing costs down and the efficiencies up. This requires having real-time process feedback as corrections and enhancements are made. The PV-4000 can be used at multiple locations in the process to provide the required quality information.

Solution: Inspection, which happens after metallization and after scribing, can show up optical flaws in the substrate such as raw glass defects, metal surface defects and film defects. Further non-uniformity, pin-holes, and contamination in the metallization layers can be spotted, while scribe line spacing and edge deletion features can be trended. All defect data is stored or optionally offloaded to the factory-wide supervisory system. With real-time quality information, process engineers can correct out-of-spec conditions as they start and have a tool that provides instant feedback as they adjust the process to its optimum.

Applications: The turnkey system is networked into the factory database for glass panel, roll-to-roll metallic, or film substrates.

Platform: Resolution can be as fine as 5 microns using 8192 pixel linear array cameras and proprietary illumination. A free defect sample evaluation is provided upon request to document the detection sensitivity and performance guarantee.

Availability: Currently available.

First Solar tech talk: Thin-film PV leader says it will reach CdTe module conversion efficiencies of 16% and beyond

By **Tom Cheyney**

First Solar rarely allows its VP of technology Dave Eaglesham out in public, so his presence at the company's annual analyst day added a bit of welcome techie-geekiness to the proceedings. This was the first time that the thin-film market leader shared its conversion efficiency roadmap since its legendary IPO, providing him a chance to talk about, or in some cases "dance around," the details of First's technologies and how they align with its long-term mission.

The VP, whose banter was sprinkled with talk of a technological "horse race" and categorical "buckets" and numbers being "racked up," made it clear that the company is in constant technology assessment mode, externally and internally, with many irons in the fire to find ways to maintain its "sustained differentiation."

When First racks up other technologies against its own cadmium-telluride thin-film PV, it does so from a *really* long-term (as in 50-100 years) perspective, examining a tech's ability to scale in a prodigious yet affordable way. "We don't think that anything that's over a dollar per watt in terms of capex is going to have substantial legs in terms of its ability to go to scale," said Eaglesham.

As with anything to do with First Solar, cost is also paramount when it comes to technology evaluation. Unless a prospective improvement in the device, the process, the materials set, or whatever other bucket can match up with the company's aggressive cost-per-watt model, it won't make the cut.

"If adding the materials will improve the cost per watt or cost per kilowatt-hour that we produce, then it's something we're very interested in," company president Bruce Sohn said during our interview in late April. "If adding an exotic material will improve the wattage but the cost of doing so doesn't compensate appropriately, then it's not something we're interested in."

"Of course we have to evaluate that at scale," he continued. "Frequently that question might be asked and the answer to that question might be very different at 20MW than the answer at 1GW. We constantly assess that and run those models, [and ask], How much will this cost at scale?"

When Eaglesham and First Solar frame the technology horse race, it's always about how the other ponies do when they match up with the strengths of CdTe, now and into the future. Noting

Photo courtesy of First Solar.

David Eaglesham, First Solar's VP of technology.

how most employees think of themselves as working in a thin-film PV company first, and then CdTe, he went over the shared commonalities among TFPV technologies – lower bill of materials and capex than crystalline silicon, better efficiencies in low light (but lower efficiencies in good sun as well), etc. – and then cited a couple of CdTe's advantages, such as its sweet-spot band-gap in terms of the solar spectrum as well as its ability to be processed at a very fast film deposition rate.

For those who wonder whether First Solar might be getting into copper indium gallium (di)selenide (CIGS) or other thin-film or nano-thin film PVs, Eaglesham provided a bit of insight into how the company scrutinizes them. "When we look at how we rack up against other thin-film technologies and when we assess other thin-film technologies that we're interested in getting into ourselves, one of the primary issues that you have to face is that it is very difficult to find other semiconductors that you can deposit anywhere near as fast [as CdTe]."

Apparently First Solar believes CIGS has *some* fast-deposition and scalability potential. Several anonymous sources told me during the recent IEEE PV Specialists Conference that it's an "open secret" that First has a small team, led by former Solyndra chief scientist Marcus Beck, working on CIGS at an undisclosed California location.

Another key tenet in First Solar's cost-cutting and continuous improvement mantras is the ever-increasing conversion efficiency of its CdTe panels. Although it remains unclear just what the best-of-breed conversion efficiencies may be on First's top-performing "mothership" process development line at its Perrysburg, OH, site, it can be reasonably assumed they've already crossed the 11% bar.

Eaglesham shared data showing that since 2001, CdTe has closed the efficiency gap with poly- and monocrystalline silicon PV by about 3.3X, improving some 70% over the decade so far – a much brisker clip than the improvements shown by the c-Si siblings.

Part of that advantage results from what he called CdTe's "inherently faster cycles of learning" compared to bulk silicon. When you're dealing with cycle times where glass goes in one end of the line and 2 1/2 hours later a finished module comes out, technologists can get test results pretty fast.

He spoke of how First Solar does a lot of heavy analytical lifting to determine which efficiency components are higher risk and how to find multiple pathways to possible solutions to help mitigate that risk. Considering the 11% efficiency goal "looked like a big mountain to climb" when they were dwelling in the low 9s, the approach seems to have worked.

He also said he "felt lucky as a module technologist to have a direct line of sight

Photos courtesy of First Solar.

A First Solar module running through manufacturing.

to the installation and EPC businesses," which offers an "opportunity to really understand" what's going on in the field at a detailed level. And of course, the company's production scale and financial vigor don't hurt the efficiency improvement process either.

But for all its chest-thumping about the benefits of economies of scale, size also can have a detrimental effect. You could even call it growing pains.

Eaglesham admitted that "as the scale of the company gets larger, it does become more challenging to improve efficiencies," noting how "implementing improvements on a very large base" becomes more difficult. He noted the choice between retrofitting existing facilities with improved processes and doing so on freshly minted production lines, and admitted that "in many cases, you can implement on new capacity more readily."

For the near term, he said that First Solar doesn't just have "high confidence" it will reach the 12.5% module efficiency metric, it has "very high confidence," with all the concepts necessary to achieve that goal "locked in." The pathway will be through improving "light transmission into the existing device" and won't require any major changes to the basic design.

As he shifted into dance mode yet again, the VP discussed the "clear avenues" available to achieve this. Reducing the thickness of the cadmium-sulfide layer, a "significant loss mechanism," can help, but the challenge is do it in a manufacturable, controlled manner (since "thinner" doesn't necessarily mean "easy to manufacture"). The transparent conductive oxide films offer another area for improvement, and evidently First is working on some proprietary chemistries to "drive to best in class" capabilities. Glass transmission is another piece of the puzzle where continuous enhancements lead to more light getting to the existing device, he said.

But what of future conversion efficiency improvements, which might reach and even pass the storied 16.5% hero cell created by NREL?

Eaglesham ran through some slides on the theoretical limits of PV (30% for a perfect single-junction cell), the "top-down efficiency potential of CdTe" (21% is a reasonably established number for a theoretical device, then after factoring in module losses and production averages, a 16-17% production module seems plausible) and then "bottom-up efficiency potential" (largely the same conclusions as the top-down chart, but the production panels pop up to the 17-18% range). At the heart of the matter is "voltage," which he called "the biggest lever in closing the gap between 16.5% and 30%."

That's right, First Solar posits the average conversion efficiency of its CdTe panels

First Solar's production line in Perrysburg, Ohio.

– not champion cells, but *production modules* – nesting in the 16-18% range on the company's extended roadmap.

In discussing a slide titled "1000 pathways to >16% and beyond," Eaglesham pointed to a quintet of material science and device physics engineering avenues to get to the high teens: optical, contact, grain-boundary, band, and dopant.

These categories appear on every thin-film PV efficiency roadmap, he said, and taken together, they offer a "laundry list" of technical and engineering tricks that underscore one of his main takeaways: "CdTe still has lots of headroom for improvement."

The optical pathway, which offers solutions that "improve the given amount of light hitting the front side [of the cell] that winds up in that device," includes tweaking or directing the absorption of the light, enhancing the coupling, and using better antireflective films, he said.

Like all thin-film PV purveyors, First looks hard at the contacts, since both CdS and back metal "are significant in driving performance" and can be improved with more highly engineered, even combinatorial materials.

Along the grain boundary, a place near and sometimes not so dear to the hearts of CIGS and CdTe techies, figuring out how to "get minority carriers across the boundary is inherently difficult," he pointed out. To engineer that grain structure, researchers might add impurities to change the electric fields or alter process temperatures to get better behaving structures.

Band engineering, a familiar tool in the semiconductor process kit, involves playing with the composition of materials to produce different kinds of fields within the device and using energy bands to manipulate those carriers, he said.

He didn't mention any specifics about how dopant engineering came into play with CdTe, categorizing that as more of a concern for those working with micromorph silicon thin films.

"You can't drive to 16% devices by focusing on any one of them," Eaglesham opined, "you need to focus on all of them." Again, he reiterated the familiar First mantra of scale, how the company's resources allow it the ability to "invest across a wide portfolio" of potential approaches and to maintain its sustainable differentiation and its lead in PV's technological competition in the years ahead.

While Eaglesham's tantalizing propeller-head dance routine offered a peak into the First Solar technology vault and underscored how they "keep raising their own bar," it provided little true granularity of what they're doing in their labs to keep the conversion efficiency needle moving. (Single-walled carbon nanotube networks as next-gen transparent back contacts, anyone? An NREL team is working on that.)

Still, when the horse-race handicapper concluded by saying "we believe that 16-18% [efficiency] as a practical production potential is very achievable," it was clear that the First Solar team remain quite confident that they know how to get from here to there, and to continue moving forward with agility, despite their company's increasing girth and complexity.

(This feature is an edited version of two Chip Shots blogs originally published at PV-Tech.org.)

Characterization and monitoring technologies for CIGS

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ABSTRACT

Among the various thin-film solar module options available, Cu(In,Ga)$(Se,S)_2$ (CIGS) is especially interesting as it exhibits the highest efficiency potential. These chalcopyrite-based solar cells are manufactured on glass or flexible substrates using various thin-film coating methods for each layer. The central CIGS absorber layer is deposited by co-evaporation, selenization of elemental layers, and other methods. In order to achieve highest quality and reproducibility, the absorber properties must be properly monitored and characterized. In this contribution we shed some light on the most important analysis methods used for CIGS solar cell research, development, and production such as x-ray fluorescence, surface analysis, and Raman spectroscopy.

Introduction

Thin-film solar modules are expected to rapidly increase their market share by about 4% per annum in the coming years [1]. Key issues for their success are low materials cost, module integration, scalability of the manufacturing processes and visual design. Successful thin-film technologies like thin-film silicon, CdTe, and the chalcopyrite-based solar modules such as CIGS are already available on the market. Thin-film silicon has the longest market experience, but suffers from relatively low efficiencies for single junctions, although the a-Si/µc-Si tandems are best equipped to pass the 10% hurdle. CdTe is currently very successful, profiting from low-cost manufacturing and reasonably high efficiencies. Amongst the three thin-film technologies, however, CIGS exhibits the highest efficiency potential by far for lab cells – with the current world record at 19.9% [2] – and also for modules produced in large-scale manufacturing [3]. The current module record is 13.5% for a 3459cm² aperture area [4]. The typical thin-film layers of these solar cells are shown in the coloured scanning electron micrograph cross-section in Fig. 1. The CIGS layer is also known as the 'absorber' because the photons absorbed in this layer generate the charge carriers which are then used to generate useful electricity. The other layers form the contacts and the heterojunction diode.

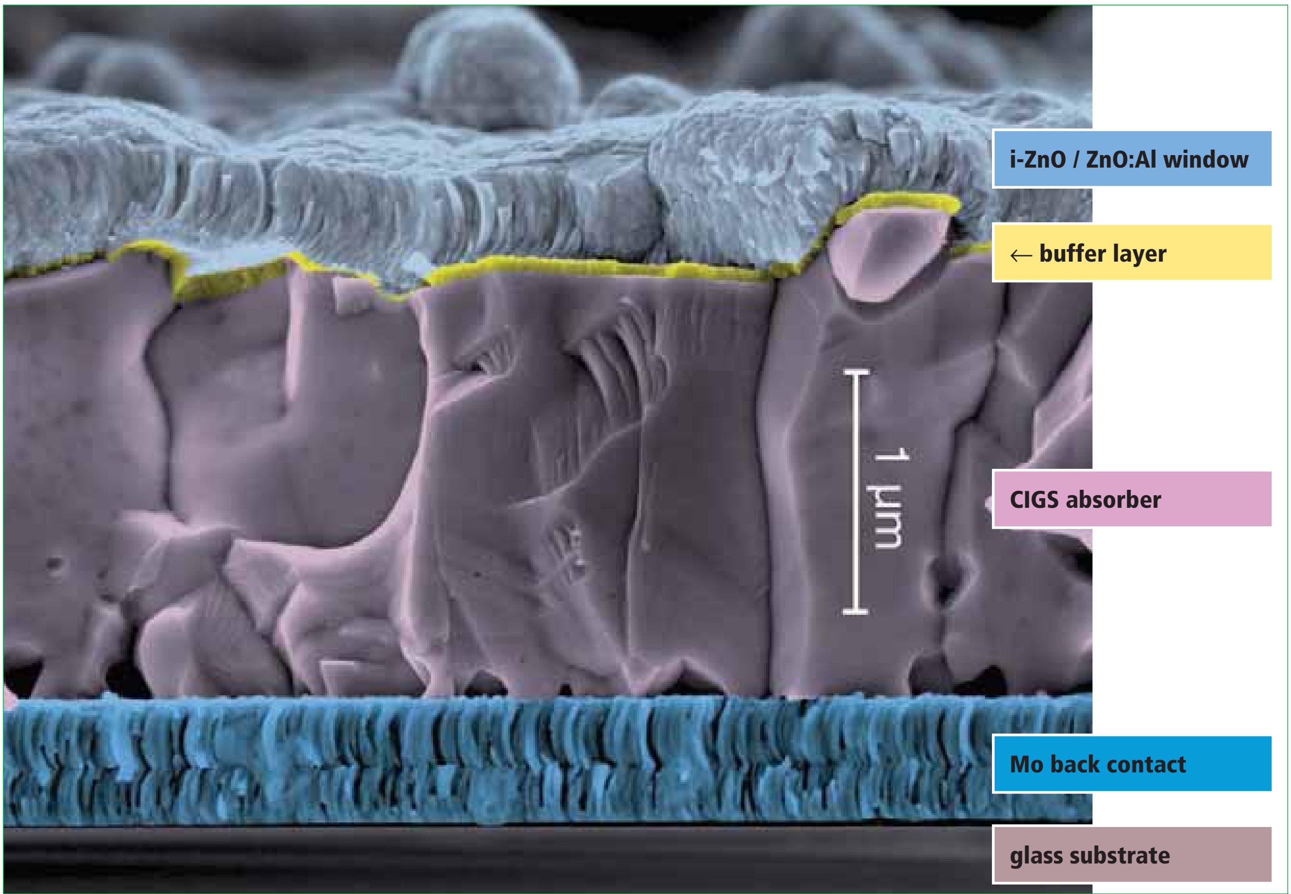

Figure 1. SEM cross-section image of the layer structure of a CIGS solar cell.

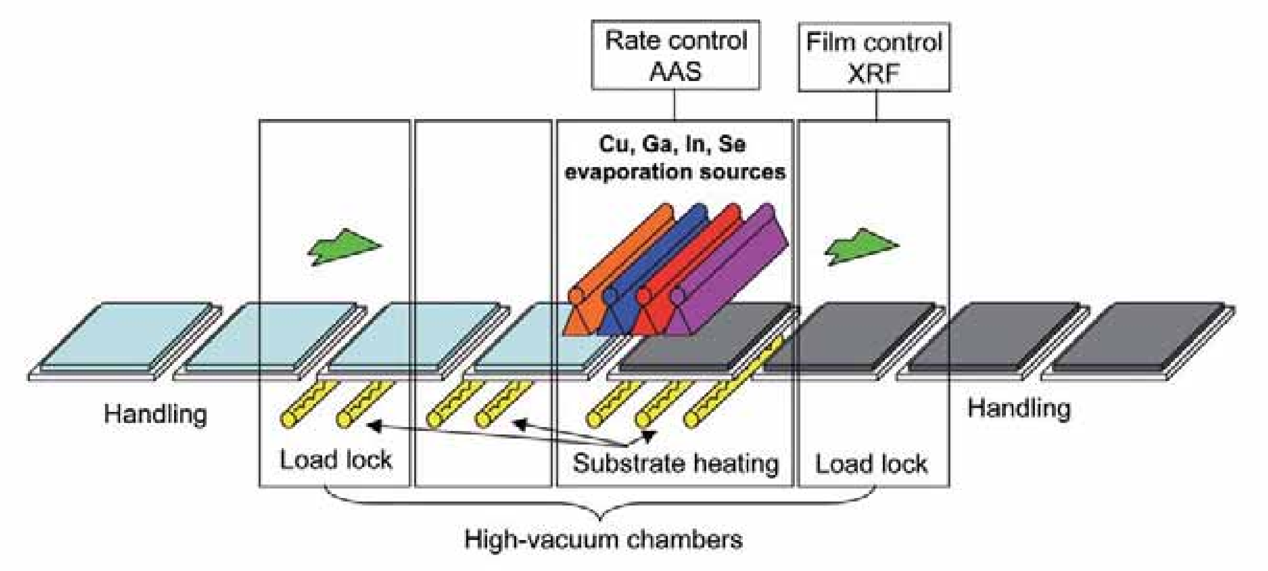

Figure 2. Schematic diagram of a CIGS coating plant indicating processing chambers and control systems.

The key to high-efficiency CIGS solar cells is the quality of the CIGS absorber layer itself, as it is the most complicated layer. CIGS is a quaternary compound semiconductor whose growth and composition must be carefully controlled in order to achieve highest efficiencies. The focus of this contribution is therefore on the characterization and process control of the CIGS absorber layer as used in the production, development, and research of thin-film chalcopyrite-based solar modules. The discussion will start by describing CIGS processing and the methods used in process control during production, and will then continue with special methods used in research and development to better understand and improve CIGS-based solar cells and modules.

CIGS production processes

There are several different pathways to manufacture CIGS absorber films. The main routes leading to the highest efficiencies so far are co-evaporation of the single elements or the selenization of stacked or intermixed precursor layers – mostly metal layers, which may be grown by standard coating processes like sputtering. Low-cost approaches generally avoid all vacuum processes using e.g. printing of nanoscale materials or electrodeposition. Usually, at least one thermal processing step is necessary for the film formation and to achieve sufficient quality. The ZSW has focused its expertise on the dynamic thermal co-evaporation process and runs a complete in-house processing line for the laboratory-scale production of 30cm × 30cm CIGS photovoltaic modules. Up to 19.6% cell efficiency could be achieved at the ZSW, the current European record, using the lab's in-line system [5]. Some of the process control methods applied in this system – which can be upscaled for mass production – will be described in the following sections.

Process control methods

Highest-quality CIGS deposition requires various growth phases for optimal film quality and phase composition. Laboratory research supports the development of growth schemes. In order to successfully implement the results in a production line, both the sources themselves and their integration into the system must be carefully designed. Finite element simulations helped in the profile optimization of line sources for these homogeneous films.

"The main routes leading to the highest efficiencies so far are co-evaporation of the single elements or the selenization of stacked or intermixed precursor layers – mostly metal layers, which may be grown by standard coating processes like sputtering."

Fig. 2 schematically illustrates a ZSW in-line CIGS vacuum coating system. The Mo-coated glass substrates are transported using carriers that are moved out of a preheating magazine along a heating passage into the process chamber. In the CIGS deposition chamber, the elemental metals copper, indium and gallium are thermally evaporated from separate linear effusion sources downwards onto the heated substrate. The homogeneity of the film in the transport direction is maintained by the constant substrate speed and constant evaporation rates. The metal evaporation rates are controlled using atomic absorption spectrometry (AAS), coupled into the chamber with optical fibers. With this method, the metal rates can be measured independently and very constant rates can be achieved. Sufficient selenium incorporation and film quality is only guaranteed when the selenium flux is several times higher than the metal rates. The final growth stage is carefully controlled, since the electronic quality of the photovoltaic device is particularly sensitive to the CIGS surface, where the metallurgical p-n junction is formed during later processing.

In addition, ZSW employs x-ray fluorescence (XRF) for the process control subsequent to the absorber deposition. This system is specifically programmed to be able to quickly determine both the integral film composition and the absorber film thickness. The results of this measurement are used as feedback parameters for a loop-back control of the evaporation rates. The XRF results also serve as a quality control measure to remove off-parameter films from the processing line and to provide parameters for correlating with the final module performance parameters.

Additional methods commonly used for process control are for example endpoint detection (laser scattering or thermal), in-situ Raman spectroscopy, and photoluminescence.

Analysis of CIGS absorber layers

A wide spectrum of additional methods is applied to study CIGS films for process development and scientific understanding. The following is a description of chemical, structural and morphological methods for the detailed analysis of CIGS thin films.

Chemical analysis

For the chemical characterization of CIGS films, scientists are generally interested in the film composition, either integral or in profile. As outlined earlier, the

XRF method can be integrated into a production line for process control. The energy-dispersive x-ray (EDX) method provides similar information with higher spatial resolution but requires an electron beam source. Raman spectroscopy is useful to gain information about phases and binding states. Furthermore, a wide array of profiling methods is available to investigate the distribution of elements through the depth of a film. Only the profiling methods are intrinsically destructive, since they involve sputtering through the film to acquire the depth profile. The other methods are limited by the size of the measuring chamber. The defining characteristics of these methods are outlined in the following sections.

XRF

In the XRF method, the sample is exposed to x-ray radiation, which knocks electrons out of the inner atomic shells. Upon relaxing, an x-ray is emitted whose energy is characteristic of the atomic element. The elements with atomic numbers from sodium up to uranium can be detected using this method. After calibration with suitable standards, XRF spectra can be quantified. XRF is a common method for determining the final CIGS composition either integrated into a production line for process control or externally for specific analysis. XRF systems can also be integrated into the deposition section of the coating plant, allowing the film composition to be determined after every step of a multistage process. Since the x-rays penetrate the entire film stack, the composition and thickness of each layer of a complete solar cell can be determined from a single measurement. Furthermore, XRF mapping techniques can be applied to investigate the lateral homogeneity.

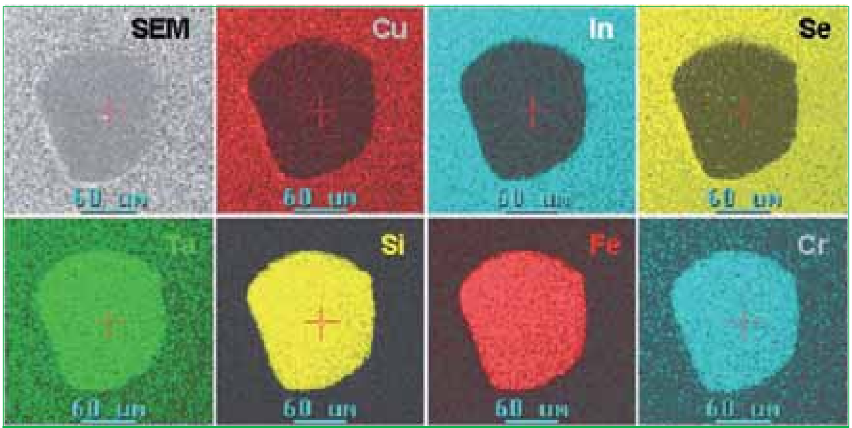

Figure 3. EDX mapping of a defect in CIGS deposited on chrome steel.

"Since the x-rays penetrate the entire film stack, the composition and thickness of each layer of a complete solar cell can be determined from a single measurement."

EDX

The EDX method is very similar to XRF in that it also analyses the characteristic x-ray energy spectra. The major difference is that an electron beam supplies the energy to remove electrons from the inner atomic shells. The penetration depth is lower than for x-rays, so the EDX method has a reduced information depth of about 0.5 to 2µm, which is also dependent on the element being analyzed and the acceleration energy of the bombarding electrons. Elements down to boron can be detected. EDX also has a higher lateral resolution down to 300nm, which makes it useful for the analysis of specific features and defects.

Fig. 3 provides an example of defect analysis on a CIGS film coated on chrome steel. A mapping procedure was applied in which a fast EDX spectrum was measured for each pixel. The grey image to the upper left illustrates the standard secondary electron image from the scanning electron microscope (SEM). The round defect in the centre of the image showed stronger signals from the underlying steel components due to the reduced CIGS film thickness at this location. The defect likely resulted from a loose particle that fell onto the substrate during the CIGS deposition process.

Raman spectroscopy

Raman spectroscopy provides information about the vibrational modes of the sample and can be used to identify

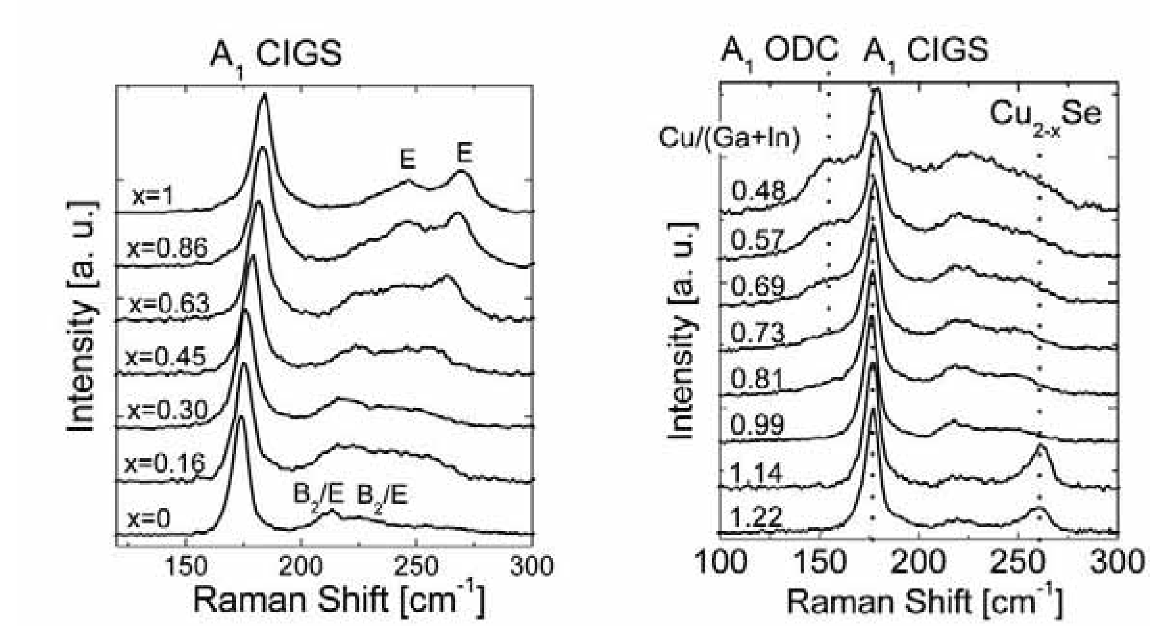

Figure 4. Raman spectra of $CuIn_{1-x}Ga_xSe_2$ layers with different Ga content x (left) and varying Cu content at a fixed Ga content x = 0.3 (right).

phases and estimate the film composition. Fig. 4 illustrates shifts of Raman modes related to film composition and additional modes related to secondary phases. The left diagram depicts Raman spectra of $CuIn_{1-x}Ga_xSe_2$ absorber films with various Ga contents x at room temperature. The frequency values of the dominant CIGS A_1 mode of the spectra increase linearly with the Ga content x. The B_2 and E CIGS modes are also labelled. Small frequency shifts of the A_1 mode are also observed in the Raman spectra of CIGS layers with various Cu contents from very Cu-poor to Cu-rich compositions at a fixed Ga content. They are illustrated in the diagram on the right of Fig. 4 [6]. A mode originating from a Cu-poor compound known as ordered defect compound (ODC) is apparent as a broad shoulder. $Cu_{2-x}Se$ appears in the Raman spectra of Cu-rich CIGS films. Furthermore, Raman spectroscopy can be used to determine the Se/S ratio when sulphur is incorporated into the absorber layer [7].

Raman spectroscopy is therefore useful for estimating composition and identifying secondary phases. It is a promising method for process control after CIGS deposition or even as an in-situ characterization method during the CIGS deposition process. When combined with a microscope, inhomogeneities can be investigated on the micrometre scale.

Depth profiling

The depth profiling methods are all surface-sensitive techniques coupled with sputter etching to measure through the depth of the sample. Entire photovoltaic devices can be investigated, whereby the sample is destroyed in the process. However, very useful information can be gained, for example about the gallium gradient in the CIGS absorber film.

> "Raman spectroscopy is a promising method for process control after CIGS deposition or even as an in-situ characterization method during the CIGS deposition process."

The ZSW employs SIMS (secondary ion mass spectroscopy) and SNMS (secondary neutral mass spectroscopy). The difference between the two is that with SIMS ionized atoms are detected by a mass spectrometer, while for SNMS the neutral atoms must be first ionized by a filament to enable their detection. SIMS enables extremely high detection limits in the ppb range, but can only be quantified for specifically calibrated cases due to matrix effects. SNMS, on the other hand, can be quantified, but is less sensitive with a detection limit of 0.01 at.%. The ZSW system can achieve a lateral resolution of 125µm for both methods as determined by the size of the sputter crater, and a depth resolution as sensitive as 1 to 3 monolayers. Typical SNMS depth profiles of CIGS with various Ga contents on Mo are shown in Fig. 5. This series indicates the effect of Ga content on the CIGS/Mo interface. Evidently, additional selenium is incorporated at the interface for low Ga contents.

GDOES (glow discharge optical emission spectroscopy) is a related technique used by other groups. Similarly to SIMS and SNMS, an ion beam sputters off atoms from the layer surface. These atoms are transported to a plasma where they are excited and emit light, the spectrum of which is analyzed. Furthermore, these atoms are ionized in the plasma and can be detected by a mass spectrometer. This is the principle of GDMS (glow-discharge mass spectroscopy). GDMS allows quantification comparable to SNMS at a detection limit from sub-ppb to ppt. ERDA, RBS and XPS, as described later, are normally used for surface analysis. By combining these techniques with argon ion beam sputtering, a depth profile can be recorded.

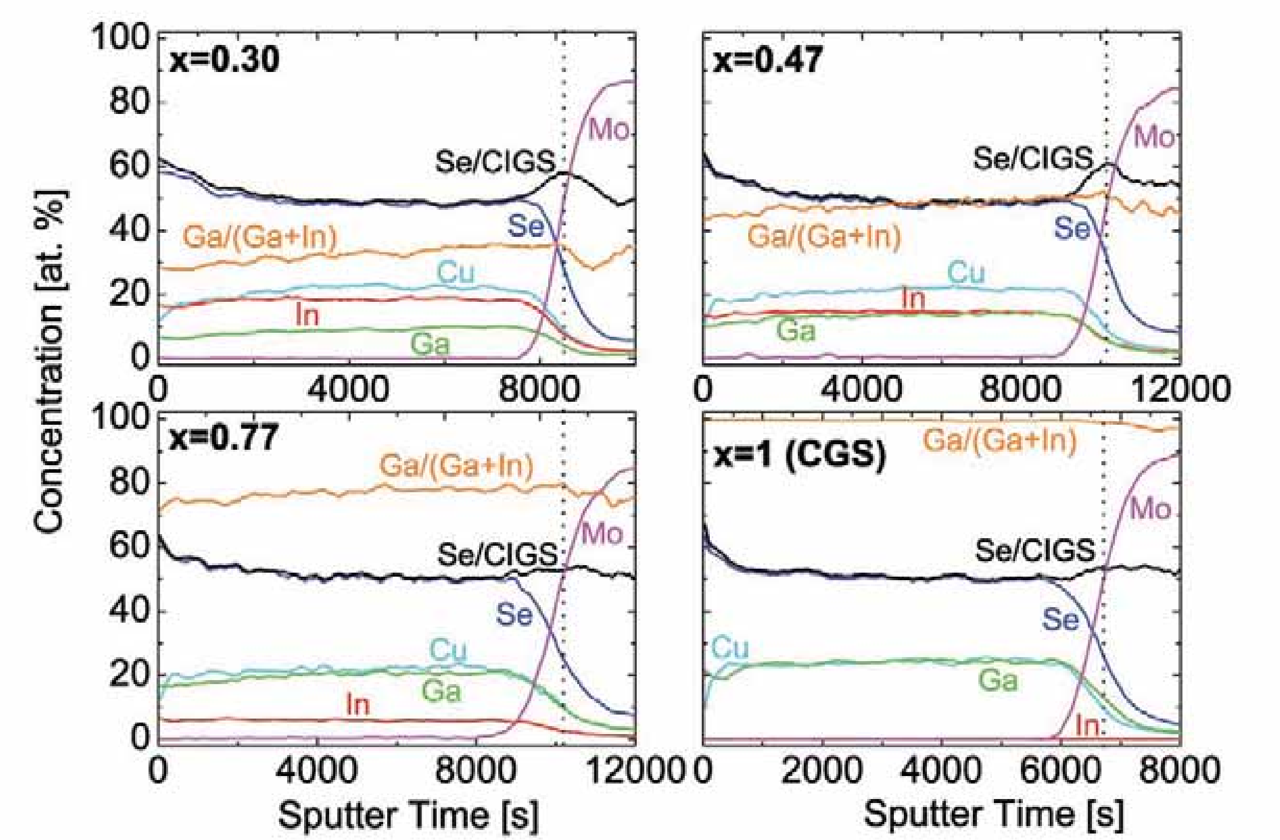

Figure 5. SNMS depth profiles for CIGS films with different Ga contents x as indicated. An increased Se/CIGS ratio is found at the Mo/CIGS interface for the lower Ga contents.

Surface analysis

The CIGS/buffer interface plays an important role in high-efficiency solar cells. The band structure at the interfaces affects charge transport. The so-called ODC surface composition of Cu-poor CIGS appears to provide a type-inverted surface, moving the region where similar concentrations of electrons and holes are present away from the defect-rich metallurgical heterointerface. Surface analysis methods are required to study only the CIGS surface layer. These techniques have a small depth resolution and include XPS, AES, UPS, RBS and ERDA. XPS is available at the ZSW. The principles behind them are described briefly in the following section.

For XPS (x-ray photoelectron spectroscopy), an aluminium or magnesium x-ray source is used to eject electrons out of the surface atoms. Measuring the kinetic energy of these electrons supplies information on the surface elements and their chemical binding states in the compound matrix. The depth resolution is about 1 to 10 atomic layers.

AES (Auger electron spectroscopy) is a related method in which an electron is ejected out of an inner atomic shell and is replaced by an electron from an outer shell. The energy released by this relaxation process ejects a secondary electron out of the atom, which is then analyzed. Unfortunately, Auger lines do not exist for all elements. AES is useful for further interpretation of XPS data, particularly when the energetic lines from different elements superimpose. XPS and AES measurements can also give spatial information through mapping.

UPS (ultraviolet photoelectron spectroscopy) applies ultraviolet light as the excitation source. Its main application is to detect the position of the valence band. Band structures of heterojunctions can be studied in this way.

RBS (Rutherford backscattering spectroscopy) and ERDA (elastic recoil detection analysis) require an ion beam as the source. In RBS the backscattered ions are analyzed. It is sensitive to heavy elements in a matrix of light elements. ERDA analyzes recoiled ions and is sensitive to light elements in a heavy-element matrix. H- or He-ion beams are required for these techniques.

Structural analysis and morphology

Structure, crystallinity, morphology, and thickness of the films can be determined using several specific methods. Only the film thickness as calculated from the XRF measurement can be integrated into a production line for process control. The other methods are mostly employed for research and development purposes. Besides the XRF measurement, film thickness can be measured over a step structure with a contact or optical profilometer or analyzed in cross-section in a scanning electron microscope (SEM). The latter also provides information about the crystallite growth, compactness, and other morphology aspects. Surface roughness can be determined e.g. with an atomic force microscope (AFM) or a confocal 3D microscope. X-ray diffraction (XRD) provides information about the phases and crystalline quality of the films as well as the orientation of the crystallites (texture) and strain. With the exception of the 3D microscope, all of these methods are available at the ZSW.

"By cleaving the sample and investigating the cross-section, the growth of the crystallites as well as their compactness and contact with the substrate can be investigated."

SEM

The scanning electron microscope has a high resolution for imaging the surface and microscopic defects. An EDX system combined with the SEM allows further chemical analysis of specific features. By cleaving the sample and investigating the cross-section, the growth of the crystallites as well as their compactness and contact with the substrate can be

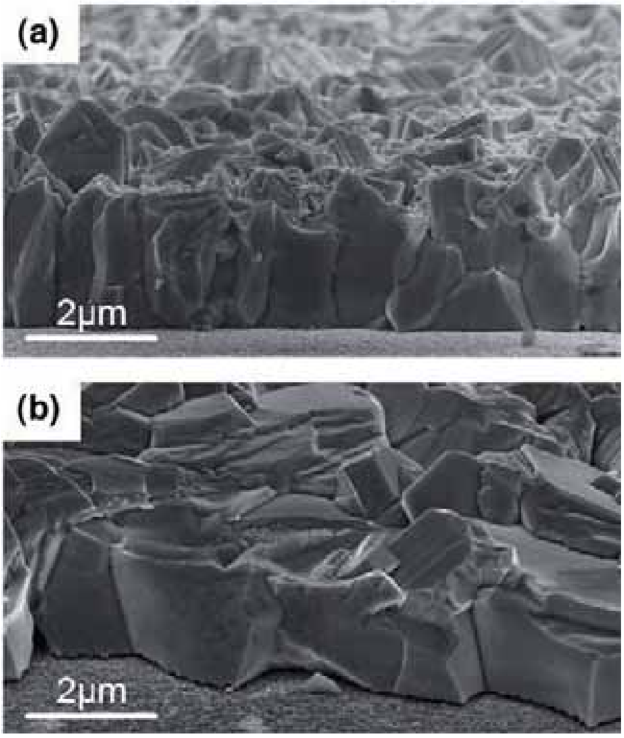

Figure 6. Scanning electron micrograph (SEM) cross-sections of $Cu(In,Ga)Se_2$ absorbers deposited in a standard (a) and a multistage (b) in-line process.

investigated. The thickness and growth of each layer can be studied for the entire solar cell. Furthermore, the conformality and degree of coverage of the extremely thin (20-80nm) buffer layer can be best imaged with SEM. Fig. 6 illustrates an example of the difference between the grain size and shape of 'standard' and 'multistage' CIGS films on Mo-coated glass. The multistage CIGS crystallites are more than twice as wide as the standard CIGS crystallites. Their surface also has a flatter morphology.

> "Whether or not the crystallographic orientation of the crystallites significantly influences the photovoltaic quality of the CIGS solar cell is a current subject of scientific discussion."

Profilometry/microscopy

A contact profilometer drives a sharp needle at a constant, low force over the sample surface. Masking or other pattering methods can create a sharp vertical step for measuring film thicknesses. A soft sample may be difficult to measure with this method due to indentation or movement of the sample material. The measurement also occurs only along one line, which is suitable for a step height measurement. An AFM uses a cantilever tip to scan across a two-dimensional surface area for extremely high-resolution 3D images and data on surface roughness. Variations of the AFM method also allow non-contact imaging. An optical profilometer or 3D microscope based on the confocal technique can not only measure step heights without mechanical contact, but also image surfaces with high-resolution height information. This data is useful for analyzing surface roughness. None of these methods are suitable for production line process control because they are slow and only image a very small area.

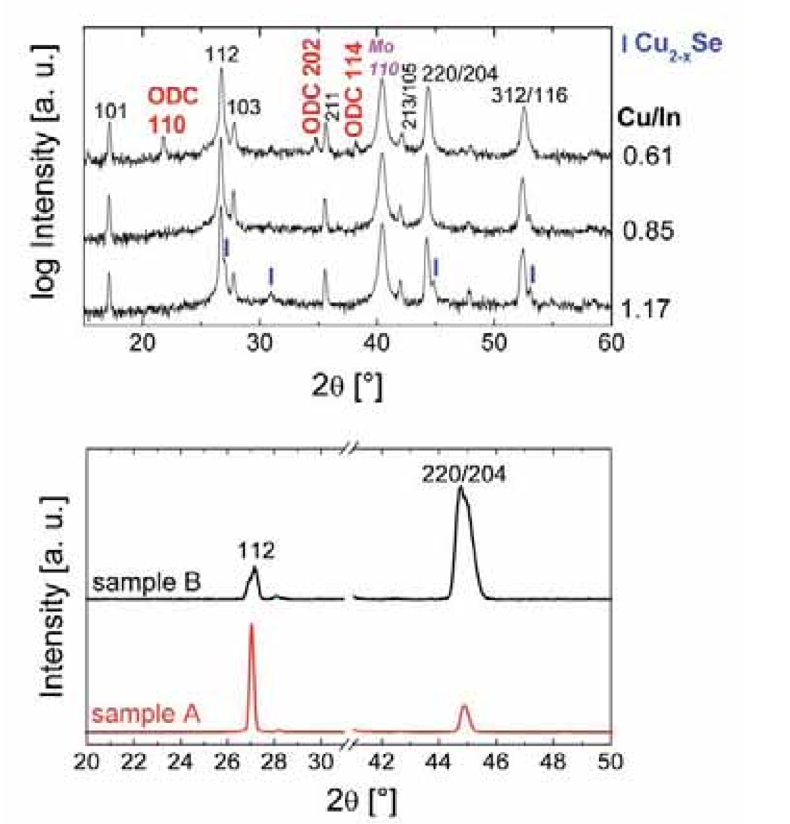

Figure 7. XRD patterns of $CuInSe_2$ thin films with different Cu/In ratios (top) and an example of texture in CIGS samples from different growth processes (bottom).

XRD

X-ray diffraction is a common tool for investigating phase composition. The sample is subjected to collimated x-ray radiation which diffracts on the crystal lattice. The method reveals the phases present in the sample, their crystallographic orientation, lattice constants and strain. The top diagram in Fig. 7 illustrates how additional phases can be identified using XRD. From top to bottom, the curves show measurements from In-rich to Cu-rich $CuInSe_2$, respectively. The In-rich compound known as ODC (ordered defect compound) is apparent in the In-rich film (red labels) and copper selenide is present in the Cu-rich film (blue ticks).

In polycrystalline samples, the crystallites can be randomly oriented, resulting in spectra similar to the powder spectra for the compound. However, polycrystalline thin films often demonstrate a preferred orientation or texture. Whether or not the crystallographic orientation of the crystallites significantly influences the photovoltaic quality of the CIGS solar cell is a current subject of scientific discussion. The bottom diagram in Fig. 7 illustrates how different CIGS deposition processes can lead to different crystallographic orientations of the films. The (112) reflex dominates for randomly oriented grains similar to sample A. In contrast, sample B shows a clear (220/204) preferential orientation.

Summary

This article illustrates the large variety of characterization methods applied for the process control, development and research of thin-film $Cu(In,Ga)Se_2$ layers for photovoltaic modules. Methods that can be integrated into production lines and those that are limited to specific research and development purposes are indicated. Improved understanding of CIGS properties and growth processes has lead to increased performance over the years and is key to achieving best efficiencies.

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Understanding moisture ingress and packaging requirements for photovoltaic modules

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ABSTRACT

Outside of the challenges of fabricating state-of-the-art photovoltaic devices, further care must be taken to package them such that they can withstand environmental conditions for an accepted lifetime of 20-plus years. Moisture ingress is a big adversary to hermetic packaging. The diffusion of water through barriers and edge seals can be minimized by careful choice of materials and package/barrier architecture. However, at present, there exist no solutions for extremely water-sensitive materials for flexible applications. Presented in the following is a review of the physics of permeation, the means of measuring permeation, current architectural strategies for semi-hermetic packages, and a brief evaluation of some common encapsulant materials.

Packaging schemes are often described as 'hermetic'; however, other than airtight, no quantitative definition apparently exists. For foodstuffs with little sensitivity to moisture, airtight means something very different than when describing photovoltaic modules. Even glass/glass and metal/glass seals that are often considered hermetic have some permeation, but on a geologic timescale for molecules like water. For any system in which leakage can be measured, but is on the order of the desired lifetime, the term 'semi-hermetic' is perhaps more appropriate.

"As moisture can cause significant degradation, it is important to understand the physics of its ingress."

When examining packaging requirements, the time over which the package needs to succeed in preventing ingress must be defined, as well as what contaminants should be excluded. It is important to separate steady-state behaviour from transient response. In this paper, the term 'semi-hermetic' will be used to describe systems in which effectively all moisture is excluded for at least 20 years. As moisture can cause significant degradation, it is important to understand the physics of its ingress together with the terms that describe it, general packaging strategies to limit it, how to appropriately measure it, and the limits of commonly used materials. This article will touch on each of these, while referring the interested reader to more in-depth reviews where appropriate.

Fickian physics, WVTR, lag time and breakthrough time

Moisture ingress is inherently a diffusion problem. In PV modules, moisture may diffuse both through the barrier and the edge seal (Fig. 1). Designing a module to make it semi-hermetic requires knowing information about the barrier and the sealants used. Some properties are material dependent like diffusivity and solubility, while others depend on how they are incorporated into a module design (e.g. physical dimensions and how they are dried prior to use) like water vapour transmission rate (WVTR), breakthrough time (t_b), and lag time (t_{lag}).

Diffusivity (D) is defined as the proportionality constant between the gradient in the moisture's concentration field (∇C) and the flux (J) as

$$J = -D\nabla C \qquad (1)$$

The change in concentration with time is thus represented as

$$\frac{\partial C}{\partial_t} = -\nabla J = (D\nabla C) \qquad (2)$$

If the diffusivity of a material is not dependent on concentration, the material is referred to as Fickian, which simplifies Equation 2 as

$$\frac{\partial C}{\partial_t} = -\nabla J = (D\nabla^2 C) \qquad (3)$$

In the special case of permeation of water through a thin membrane, the flux is one-dimensional and is referred to as the water vapour transmission rate. Assuming a Fickian material, the WVTR, as a function of time, through an initially dry membrane that is dry on one side and held at a constant concentration (C_s) on the other, can be modelled as [1-3]

$$WVTR(t) = \frac{DC_s}{l}\left[1 + 2\sum_{n=1}^{\infty}(-1)^n \exp\left(-\frac{Dn^2\pi^2 t}{l^2}\right)\right] \qquad (4)$$

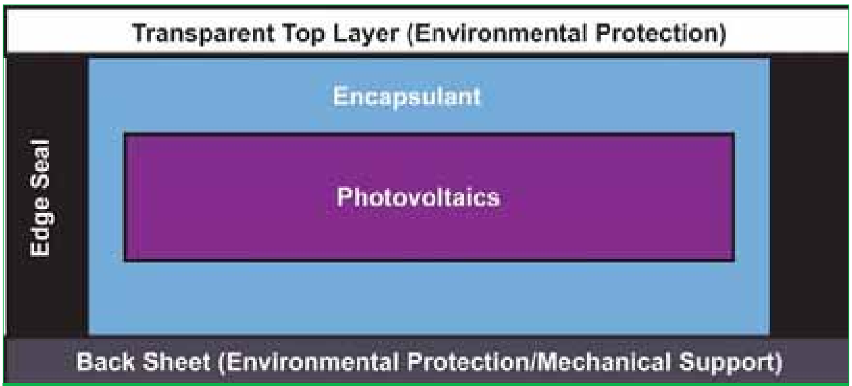


Figure 1. A photovoltaic module and its relevant packaging elements.

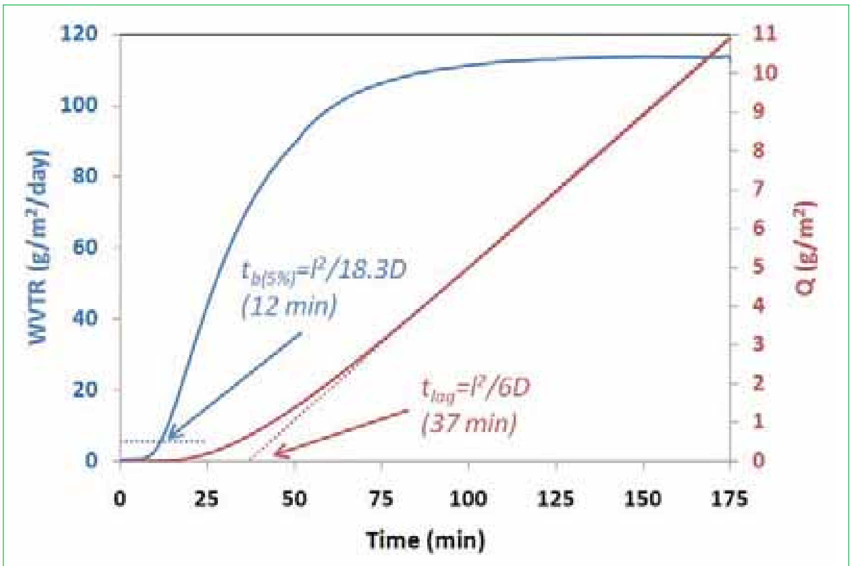


Figure 2. Graphical representation of transient breakthrough and lag time for a 2.84mm-thick EVA film at 85°C with saturated water vapour on one side and dry N_2 on the other.

$$Q(t) = \int_0^t WVTR(t)dt = \frac{DC_s}{l}t - \frac{lC_s}{6} - \frac{2lC_s}{\pi^2}\sum_{n=1}^{\infty}\frac{(-1)^n}{n^2}\exp\left(-\frac{Dn^2\pi^2 t}{l^2}\right) \qquad (5)$$

where t is time and l is the thickness of the membrane. Similarly, the total amount of permeate (Q) as a function of time can be modelled as [4].

Inspection of Equations 4 and 5 indicate that there is a delay before significant moisture begins to permeate a membrane, followed by a steady state condition (Fig. 2). In both cases, the steady state condition is determined by the value of the ratio DC_s/l, and the characteristic time for these processes is given by D/l^2. When $Q(t)$ is measured, a line drawn through $Q(t\rightarrow\infty)$ intercepts the time axis at a time called the lag time (t_{lag}) which is related to the diffusivity by

$$t_{lag} = \frac{l^2}{6D} \qquad (6)$$

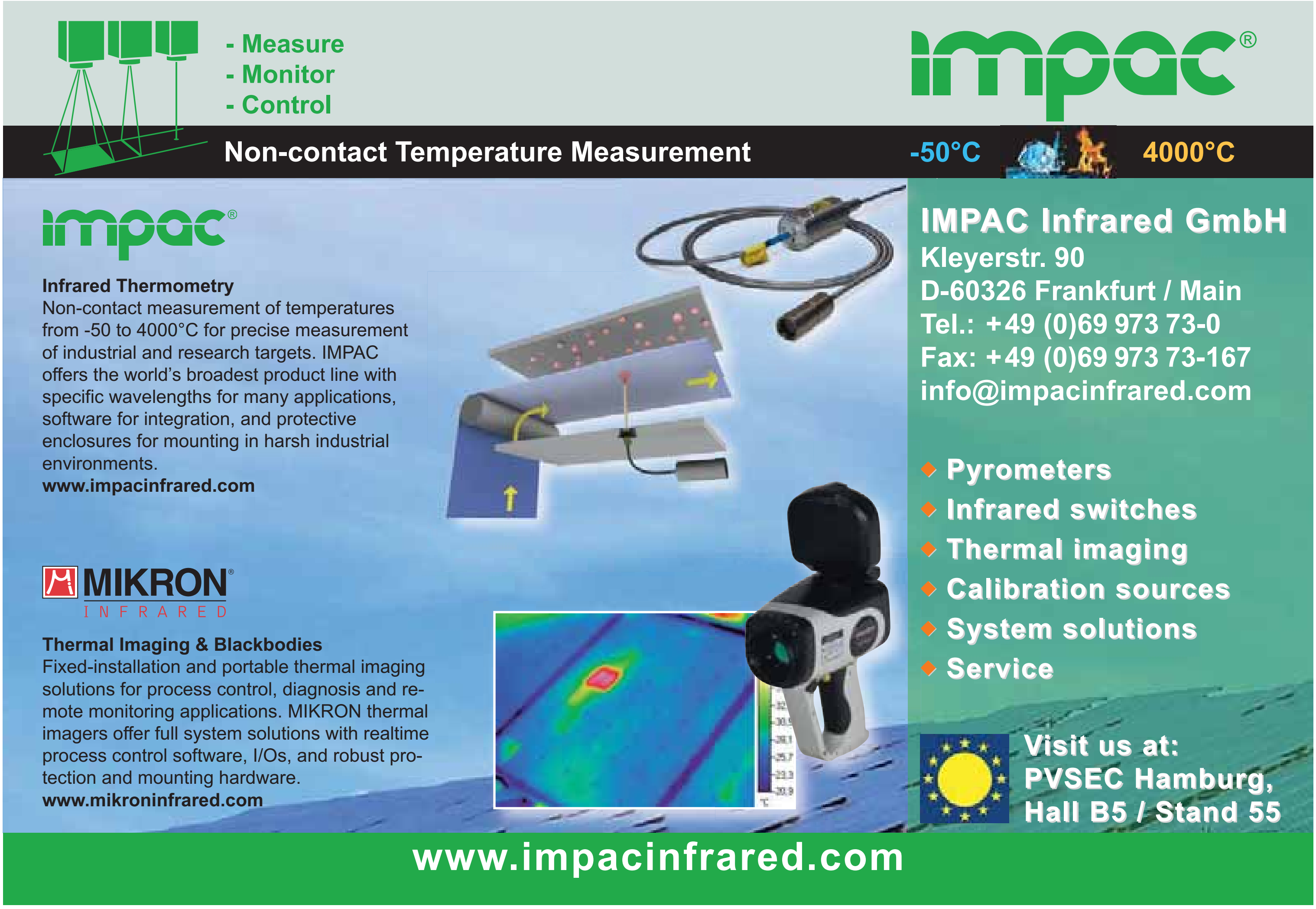
When $WVTR(t)$ is measured, the characteristic time can be related to the breakthrough time (t_b), which is the time taken to reach 5% (or any other desired number) of the steady state WVTR, by

$$t_b = \frac{l^2}{18.3D} \qquad (7)$$

Thus, the breakthrough time describes the time required for moisture to begin permeating significantly.

Edge seals

Edge seal materials consisting of a low-diffusivity material with desiccant are being investigated and developed by several manufacturers. These materials are typically used with impermeable front- and back-sheets (typically glass) which restrict moisture ingress to the edge of the modules and through the J-box (Fig. 3). Because permeation through the edge seals is essentially a 1-D diffusion process,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similar to the permeation through a membrane, the breakthrough time for a PV module edge seal can be determined by replacing l^2 with the width of the edge seal (w^2). For non-Fickian materials, often with fillers and desiccants, this breakthrough time is related to the diffusivity and width of an edge seal by [1, 5]

Thin Film

$$t_{b,NF} = K\frac{w^2}{D} \quad (8)$$

where K is a material-dependent constant [6].

Some PV modules do not use glass or metal foil as front- and back-sheets (barriers), in which cases the permeation of the barrier must be taken into account. Assuming uniform moisture concentration in the encapsulant (requiring the encapsulant's diffusivity to be much greater than the barrier's), and that the WVTR across the barrier is related to the change in concentration $\Delta C = C_{E,Sat} - C_E$, then the moisture concentration changes as a function of time as

$$\frac{dC_E}{dt} = \frac{WVTR_{B,Sat}}{C_{E,Sat}\, l_E}\left(C_{E,Eq} - C_E\right) \quad (9)$$

where B refers to barrier, E refers to encapsulant, and Sat refers to saturated conditions. Integrating Equation 9 yields the water content as a function of time of an initially dry module exposed to fixed environmental conditions

$$\frac{C(t)}{C_{E,Eq}} = 1 - \exp\left[-\frac{WVTR_{B,Sat}\, t}{C_{E,Sat}\, l_E}\right] \quad (10)$$

From this, we can obtain the characteristic half-time for equilibration of [2].

$$\tau_{1/2} = 0.693\,\frac{C_{Sat,E}\, l_E}{WVTR_{B,Sat}} \quad (11)$$

For example, typical values for EVA have C_{Sat}= 0.0021g/cm^3 at 25°C with l = 0.46mm. This leads to the product $C_{Sat,E} l_E \cong$ 1g/m^2. Thus, back-sheet materials with WVTR's ~1 g/m^2/day lead to an equilibration half-time of 17 hours. To achieve an equilibration half-time of 20 years (at 25°C) requires a WVTR < 10^{-4} g/m^2/day. If a WVTR this low is achieved, ingress through the edge seal becomes a concern. To put these numbers into perspective, a 1m^2 section of a material with a WVTR of 1g/m^2/day will see enough water diffuse into it each day to create a 1µm-thick layer of water over the entire square meter. Assuming that the water continues to collect (fortunately the water also diffuses out), by the end of 20 years this results in more than 7.3 litres of water. A material with a WVTR of 10^{-4}g/m^2/day would collect approximately a 1µm-thick water layer (or 0.73ml) after 20 years and a material with a WVTR of 10^{-6}g/m^2/day would result in an approximately 10nm-thick layer (or 7.3µl).

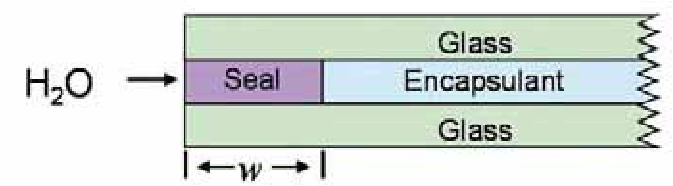

Figure 3. Schematic diagram of the edge of a module using a very low permeability edge seal to keep out moisture.

Packaging strategies

To create a semi-hermetic package, generally an approach like that shown in Fig. 1 must be used. There are four separate packaging elements: the encapsulant, the edge seal, and the front- and back-sheets. Standard encapsulants like EVA without an edge seal are incapable of creating a semi-hermetic package due to their high diffusivity and low solubility [7]. For instance, to achieve a 20-year, 10% breakthrough time with EVA at 40°C, a width of ~100cm would be necessary. In order to extend the breakthrough time to multiple decades while maintaining reasonable widths, poly-isobutylene (PIB)-based edge seals have been loaded with desiccant materials like molecular sieve. These effectively increase the solubility of the sealant retaining similar diffusivity in the polymer matrix, while temporarily trapping moisture in the desiccant. Still, semi-hermetic packaging at elevated temperatures and humidity requires significant edge seal width. In real applications, delamination effects that may be accelerated by moisture ingress and UV exposure must also be addressed, as adhesive failure of sealants is a common failure mode.

"PIB-based edge seals effectively increase the solubility of the sealant retaining similar diffusivity in the polymer matrix, while temporarily trapping moisture in the desiccant."

When a barrier like glass or metal is used with an edge seal, the most likely path of moisture ingress is through the edge seal and the J-box barring any damage to the barrier (Fig. 3). However, as flexible thin-film PV becomes more prominent, especially with its greater sensitivity to moisture/oxygen, flexible barriers with low permeation become more important unless a breathable back-sheet is desired. Currently there is no polymer-only material that can provide semi-hermetic barrier performance for PV applications (<10^{-4}g/m^2/day).

Strategies attempting to address this problem generally involve the incorporation of inorganics to reduce permeation. Permeation in these systems tends to be defect-dominated by either grain boundaries or pinholes of the inorganic layers [4, 8]. While reducing the defect densities has been attempted, stacks called 'dyads' of inorganic/organic materials have also been investigated to decouple defects between inorganic layers and create a 'tortuous path' between defects [4]. This not only improves the steady state transmission of the barrier, but can significantly impact the breakthrough time with times of 20 years predicted to be achievable by 12 dyads with a defect spacing of 5µm [4].

Another approach is to deposit the barrier directly on the finished module, typically using a technique like plasma-enhanced chemical vapor deposition (PECVD). While this technique may suffer from the same problems with defects, it does remove the necessity of using any edge seal. Furthermore, if a pinhole develops in the barrier, the extent of the damage may be limited to a much smaller area.

Measurement of moisture ingress

There are a variety of methods that have been developed to quantify water permeation. Each has limitations either in sensitivity, throughput, speed, or capital outlay/cost. In general, they can be divided into two main categories: scavenger and diffusion cell methods. Scavenger methods, such as the calcium test or the gravimetric cup test, quantify the amount of moisture that is absorbed or scavenged by a material then relate it to permeation through $Q(t)$ (see Equation 5). Such tests can be set up in a variety of configurations and use a controlled surrounding environment to regulate the test temperature and relative humidity.

Diffusion cell methods, such as the radioactive tracer method, mass spectrometry method, or the isostatic test, measure the amount of moisture passing through the barrier directly. These


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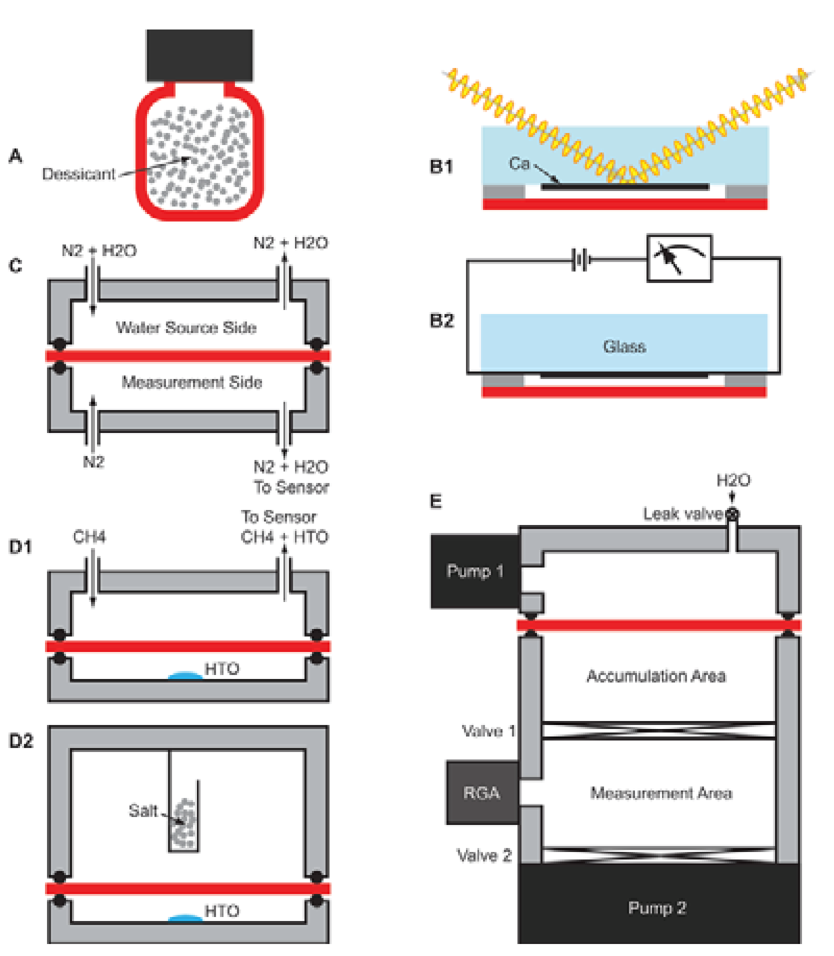

Figure 4. Schema of methods for measurement of WVTR through permeation barriers showing: A- gravimetric cup test; B- calcium test with B1 optical detection and B2 electrical detection; C-isostatic test; D- radioactive tracer test with D1 ionization chamber detection and D2 hydroscopic salt/scintillation detection; and E- mass spectrometry method shown with programmed valving.

tests are all set up similarly with the test barrier layer positioned in the middle of the diffusion cell, separating a water-rich source side from a dry measurement side. The relative humidity is controlled by the amount of water introduced to the source side of the cell, or liquid water may hold the space at 100% RH. Temperature is regulated by heating the diffusion cell. A brief description of these scavenger methods follows, illustrated for each case in the schematics in Fig. 4.

Scavenger methods

Gravimetric cup test

The most simplistic method of measuring WVTR (ASTM E96), sometimes referred to as the cup test, is used in the packaging industry (Fig. 4A). For these measurements, the test package, comprised of a test barrier material, is filled with a precisely measured mass of desiccant. The package is then sealed and placed in a controlled temperature and humidity environment. After an elapsed time (Δt), the desiccant is removed and mass change (Δm) is recorded. The WVTR is calculated from Δt and Δm (WVTR is assumed constant for Δt). This method is simple; the temperature and humidity can be easily controlled and many samples can be tested simultaneously. However, the breakthrough time cannot be easily determined from the data. Further, it is impossible to determine if the measured WVTRs are a result of diffusion through the barriers or through the sealed edges. Finally, the lower sensitivity limit of ~0.1g/m^2/day makes this test method unsuitable for PV and OLED barrier testing.

Calcium test

The calcium degradation test method (Ca test) uses a thin Ca layer to scavenge water that passes through a test barrier. There are two basic types of Ca test: an optical (Fig. 4B1) and an electrical method (Fig. 4B2). While the means of determining the amount of Ca degradation are different, the basic principles of the Ca test are the same. This test depends on the absorption of nearby water molecules by the Ca metal film to form CaO or $Ca(OH)_2$ via

$$Ca+2H_2O \rightarrow Ca(OH)_2 + H_2$$
$$Ca+H_2O \rightarrow CaO + H_2$$
$$CaO+H_2O \rightarrow Ca(OH)_2$$
$$2Ca+O_2 \rightarrow 2CaO.$$

While the relative rate of reaction between water and oxygen, to the authors' knowledge, has not been quantified at elevated temperatures, at ambient temperatures the rate of oxygen reaction relative to water is negligible as determined by isotopic labelling methods [9]. For the test assembly, a thin film of Ca metal is deposited by evaporation or sputtering onto the backside of the test barrier film, or onto an impermeable glass substrate.

The Ca film is then sandwiched between the glass substrate and the test barrier and the edges of the sandwich are sealed using an edge seal material. The structure is considered semi-hermetic with respect to the test barrier's permeation so that the only avenue of water transport to the Ca film is through the barrier film. This entire assembly is put in a controlled environment chamber, where the amount of Ca oxide present (or alternatively, the amount of Ca missing) is detected by either optical [10] or electrical [11] schema.

Optical detection methods depend on the transition from opaque Ca to transparent Ca oxide. UV-Vis and ellipsometric measurements have both been used (in both reflective, as depicted, or transmission modes) to determine the amount of Ca oxide present. Spectra are taken at the start and then periodically throughout the test by which the amount of Ca degradation is determined from the change in transmission or the shift in the refractive index of the Ca layer. This corresponds to *Q(t)* and can be used to obtain the WVTR (Equation 5).

The electronic detection method depends on the transition of the Ca film from a highly conductive metal to a non-conductive oxide. In this case non-corrosive (Au or Pt) contact pads are deposited onto the Ca film, so that the resistance of the film can be measured in either a two- or four-point configuration, and are then passed through the edge seal to the outside of the assembly. The amount of Ca remaining can be calculated from the resistance measurements (using an assumed bulk resistivity for Ca), and the WVTR can be calculated from the derivative of the change in conductance with time.

This test has good sensitivity (10^{-6}g/m^2/day) and can monitor transients as well as steady state WVTR [10, 11]. Using different (or adjusting) environmental chambers, it is possible to have many different temperature and humidity conditions. High throughput is also possible, especially with the electrical detection methods. However, to the authors' knowledge there are no commercial systems available and no ASTM standards for the Ca test. Additionally, the equipment required for initial setup is expensive.

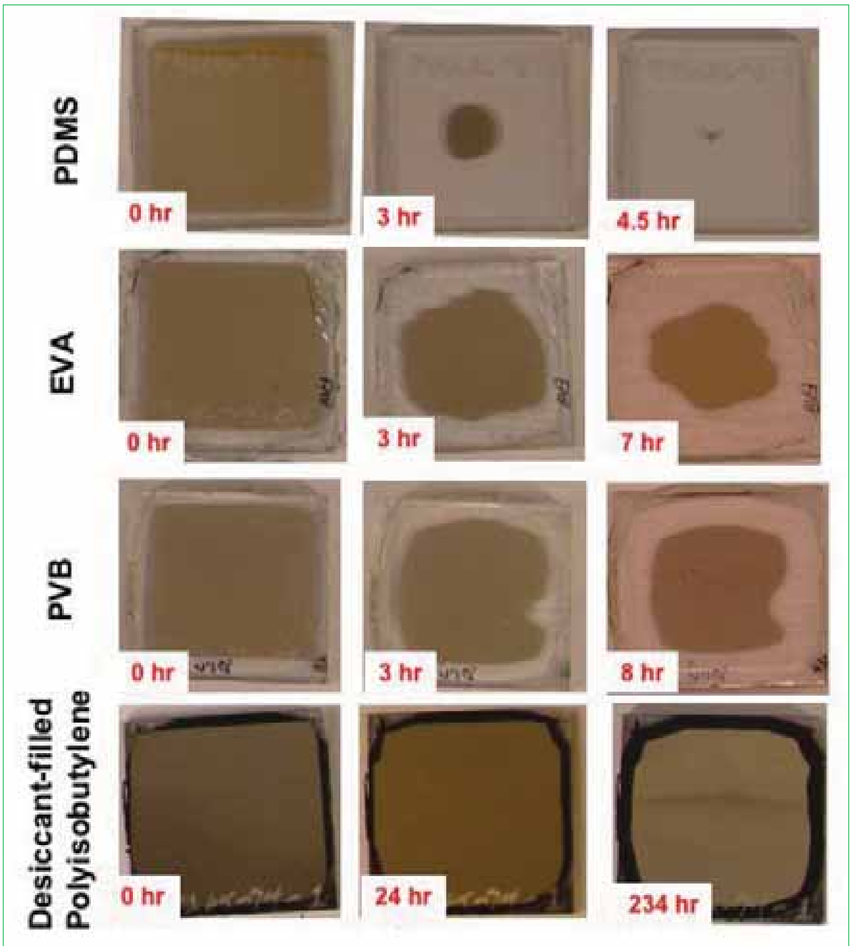

Figure 5. Photos of common encapsulant materials prior to environmental testing (0hr) and at demonstrative time points (indicated by time stamp), prior to complete degradation. Calcium's transition from opaque to transparent documents moisture ingress through the edges as illustrated in Figure 3.

Diffusion cell methods

Isostatic method

The dominant standard commercial instrumentation for WVTR measurements is the MOCON Permatron (ASTM-F1249). The MOCON instrument consists of a diffusion cell and an infrared sensor (see Fig 4C). From the gas stream on the measurement side of the barrier film, the infrared sensor measures the fraction of infrared light absorbed by the water, creating an electrical signal that is proportional in amplitude to the water concentration. The amplitude of the electrical sensor is compared to the amplitude of the signal from a calibration film with known WVTR properties to determine the actual WVTR of the test barrier. The more recently developed MOCON Aquatron uses a more sensitive coulometric detector that does not require a calibration standard.

The MOCON systems are some of the few commercially available WVTR instruments. More advanced models allow control over temperature and humidity, can measure up to six samples at once and can measure in real time to determine the breakthrough time as well as the steady state WVTR. However, the detection limits of the Permatron are 0.05g/m^2/day to 100g/m^2/day and the Aquatron limits are 5×10^{-4}g/m^2/day to 5g/m^2/day. Typically, systems are configured to only perform measurements on barriers up to 50°C without invalidating the warranty, although it is possible to configure them to test barriers up to 85°C using external test cells.

HTO/radioactive tracer method

The radioactive tracer method for measuring WVTR involves detection of water doped with tritium (HTO). Detection is done either directly using an ionization chamber [12] (Fig. 4D1) or indirectly by trapping any available HTO in a hydroscopic salt [13] (Fig. 4D2) and then measuring the tritium in the salt by scintillation methods. For both detection methods the water source side is a static HTO reservoir (RH100%).

In the case of the ionization chamber, a gas stream (usually methane) picks up any HTO that has penetrated the barrier film and carries it to the ionization chamber where the tritium is detected in real time. Using this method, the breakthrough time, lag time, and the steady state WVTR can be measured independently. The detection limits of the ionization chamber determine the limits of measurable WVTR, however, with adjustment of the barrier test area these limits can be extended. Theoretical lower detection limits are 2.4×10^{-7}g/m^2/day with practical detection limits <1×10^{-6}g/m^2/day [12].

> "There are a variety of methods that have been developed to quantify water permeation. Each has limitations either in sensitivity, throughput, speed, or capital outlay/cost."

In the case of the hydroscopic salt 'detector,' a salt source (usually LiCl) that absorbs any available water (including HTO) is situated on the measurement side of the barrier. The salt is periodically exchanged for new salt and the amount of tritium in the salt is counted with scintillation methods. To determine the WVTR, the measured tritium is averaged over the time since the salt was changed. For this reason, the salt method is only accurate in the steady state regime (i.e., after breakthrough). The detection limits are a result of the limits of the scintillation counter. With adjustment of the barrier test area and adjustment of the time between salt exchanges, these limits can be extended. Reported detection limits are ~1×10^{-6}g/m^2/day to 3g/m^2/day [13].

Since the HTO test is most commonly set up with a static HTO source, the test is only run at 100 %RH. The temperature is adjusted by heating up the vessel containing the source, barrier and 'detector'. It is also worth noting that, because the tritium is the detected species, this test method indirectly measures water. With the availability of a scintillation counter, the HTO test using the salt detection method can be set up quickly and inexpensively. Further, many samples can be run simultaneously. The ionizing detection method makes the initial setup more arduous, and is more difficult to multiplex. The major drawback of this method is the use of radioactive materials.

Mass spectrometry

Several methods for detection of WVTRs using mass spectrometry techniques have been reported [14,15]. For these measurements, UHV mass spectrometry techniques are used to measure the partial pressure of the water vapour permeating the barrier in a given integration time. This barrier bifurcates the UHV test chamber. While the upstream section of the chamber supplies metered water vapour, the mass spectrometer sits downstream to measure the WVTR. Both sections are evacuated (to ~1×10^{-8} Torr), then using a calibrated leak valve a controlled partial pressure is introduced and monitored in the upstream section of the chamber. The pressure differential on each side of the test barrier is controlled to minimize the mechanical strain on the barrier. The partial pressure of the water that has diffused through the barrier is measured above the background in the downstream section of the chamber.

Mass spectrometry-type methods have reported the highest sensitivities for an integrated measurement termed programmed valving mass spectrometry (PVMS) (instrumental setup shown in Fig. 4E). For PVMS, the downstream section is separated into three sections by valves: accumulation area, measurement area, and pump. The accumulation area is between the test barrier and the first valve. The measurement area, which houses the mass spectrometer, sits between the accumulation and pump valves.

During the measurement, the accumulation area is open to the barrier and the accumulation valve is closed, while the pump evacuates the measurement area to establish a baseline reading on the mass spectrometer. After a given accumulation time the pump valve is closed and the accumulation valve is opened, resulting in a jump in measured partial pressure, which in turn corresponds to the integrated partial pressure for the accumulation time. The whole downstream section of the chamber is then evacuated by opening the valve at the pump. This accumulate-measure-evacuate cycle is repeated; any measured change in partial pressure increases until a steady-state WVTR is established, thus the steady-state WVTR and the breakthrough time can both be measured. The reported lower detection limits for mass spectrometry WVTRs are ~10^{-7}g/m^2/day [14]. The most beneficial aspect of this method is its ability to measure other gaseous species in addition to water, though sample throughput is a major drawback.

Moisture ingress comparison of commonly used materials

A test of the moisture ingress using calcium's transition from opaque to transparent when oxidized (see Ca Test section) was performed on several different materials commonly considered as encapsulants and edge seals in PV applications. The results of the test are shown in the photo array in Fig. 5.

To perform the test, 3mm x 5cm x 5cm glass was outgassed in a nitrogen glovebox environment with less than 1 ppm O_2 and H_2O. After outgassing the glass, 100nm-thick calcium films were deposited on half of the glass squares. Each material was outgassed in the inert environment prior to assembly of the test structures. Overnight baking at 140°C was required to outgas the PIB edge seal material. The EVA and polydimethyl silicone (PDMS) were heated at 60°C while the PVB was heated at 100°C. Without sufficient outgassing, residual moisture in the encapsulants/edge seal materials rapidly degrade calcium. In assembling each structure, a heated mechanical press was used to evenly apply pressure to all structures except the silicone samples. A uniform separation of the glass squares was achieved by using a 0.25mm-thick release liner as a spacer. After assembly, samples were left in the glovebox overnight to ensure that all recorded calcium degradation was a result of ingress rather than interaction with the encapsulants.

> "The breakthrough time does not depend on the solubility for a Fickian material and is thus a qualitative measurement of the diffusivity or the effective diffusivity for non-Fickian materials."

Thin Film

After baseline measurements were made of each sample area and photographs were taken, the samples were stored in an 85°C/85% RH environmental chamber and periodically removed for monitoring. Time in Fig. 5 refers to the time spent in the environmental chamber, although effort was taken to minimize time in ambient conditions. It is worth noting that the environmental chamber takes approximately 5-10 minutes to stabilize after being opened.

The test illustrates the radically different rates of moisture ingress as the encapsulant is varied. The rate of ingress as determined by this test is essentially monitoring the breakthrough time for a very low percent of the steady state value. The percent of steady state WVTR necessary to produce the breakthrough profiles in Fig. 5 will vary from material to material, but this should not have a significant effect on the constant used in Equation 8. Therefore, as shown in Equation 7, the breakthrough time does not depend on the solubility for a Fickian material and is thus a qualitative measurement of the diffusivity or the effective diffusivity for non-Fickian materials. Thus, a method for comparison of the diffusivity (or effective diffusivity) of candidate edge seal materials has been established.

Conclusions

With careful consideration of encapsulant and edge seal materials and insightful packaging strategies, current PV technologies can withstand environmental conditions for the required 20 years. However, more research is required to develop materials for the more demanding and sensitive flexible and thin-film technologies. Many more reliability studies are required to measure and fully understand the diffusion properties of newly developed materials. While this paper has covered some of the underlying physics of moisture ingress as well as general packaging strategies including some of the principles and material properties that should be considered in module designs, putting them into practice effectively requires that attention is paid to several more details. These include ultraviolet (UV) stability, good adhesion/delamination, uniform assembly (i.e. control of edge pinch or flare), and mechanical stress. While a complete understanding of the effects of a single stress such as moisture, UV exposure, heat, or physical strain is always useful for continued improvement of particular materials, thorough knowledge of how coupled stresses affect a system is required for effective and reliable packaging.

Acknowledgements

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Rise of thin-film technologies

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ABSTRACT

Until the year 2002, wafer-based crystalline silicon solar cells were almost exclusively the solar cell technology used for large-scale power plants. Since then, steady growth in the market share for thin-film technologies has been observed, although crystalline silicon technology still remains the most important solar cell technology used in large-scale PV power plants. The market share of thin-film modules, especially CdTe modules, has been continuously increasing in recent years, most notably in the German market. However, other countries like Spain, the USA, Italy and France have seen some large-scale CdTe-based modules being installed in power plants recently.

Introduction

Crystalline silicon wafer-based modules are the most commonly used type of modules and are suitable for almost any application. Their advantage – a low area requirement in comparison to other technologies – is the main reason for crystalline modules being so well suited to tracking applications. Use of thin-film technologies is in most cases limited to fixed, ground-mounted or roof-mounted power plants. An estimated annual installed power capacity sorted by technology [1] for the period from 2000 to 2008 is presented in Table 1. Before the year 2000, nearly all installed power capacity was based on c-Si modules. The market share of thin-film modules has been continuously increasing in recent years; this is most notable in the German market (Fig. 1) where CdTe solar modules have reached up to 50% of market share in some states (Fig. 3). Some other countries – Spain, the USA, Italy, the Czech Republic, France and Thailand – have seen the construction of several large-scale power plants based on thin-film technologies in the past year.

The technologies discussed in this paper are divided into the following groups:

- Silicon (wafer-based) crystalline modules (c-Si), which include polycrystalline and monocrystalline Si modules;
- Other silicon crystalline modules, which include thin-film crystalline modules and microcrystalline modules (µc-Si);
- Amorphous silicon modules (a-Si), which include single-junction and multi-junction amorphous silicon modules (this group also includes a-Si modules on flexible substrates);
- Cadmium telluride modules, which include modules based on CdTe;
- Other modules, including CIS/CIGS modules, concentrator modules, etc.

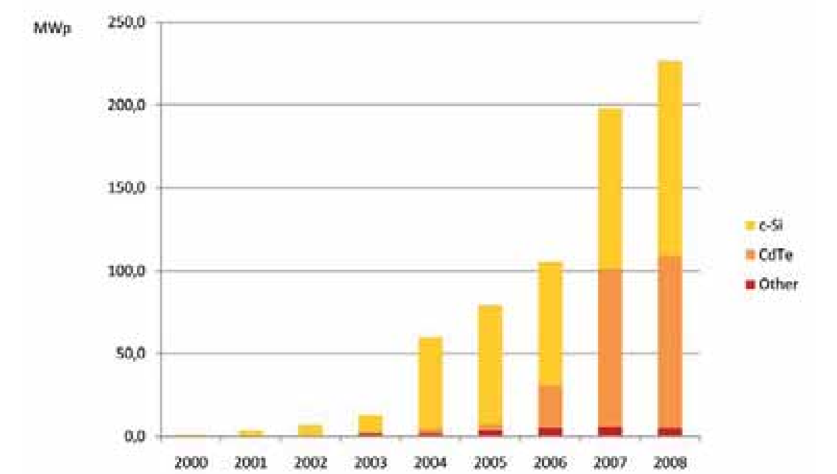

Figure 1. Estimated market shares of different technologies related to large-scale PV installations in the period from 2000 to 2008 (Germany) [1].

"Statistical data on technology market share related to large-scale PV power plants can be interpolated with a high degree of accuracy."

Market share

The combined market share of CdTe and a-Si modules is estimated to be close to 10% where CdTe represents more than 7% and a-Si about 2.5% of the market share related to large-scale PV plant installations. The estimated market share of solar cell technologies is based on available data (the technology used) from about 1,100 large-scale PV power plants [1], which is very reliable at least considering large-scale PV installations. The amount of information from these samples represents a relatively large part of large-scale photovoltaic power plants, so statistical data on technology market share related to large-scale PV power plants can be interpolated with a high degree of accuracy. The majority of solar power plants put into service in the year 2008 were based on crystalline silicon solar cells (modules). Other commonly installed technologies include a-Si, CdTe, µc-Si and copper indium selenide (CIS or CIGS) modules.

	2000	2001	2002	2003	2004	2005	2006	2007	2008
c-Si	5.2	9.5	19.6	25.9	77.6	103	155	453	2364
a-Si				3.2	1.9	4.8	10	12	>45
CdTe					3.0	3.2	29	110	190
Other						<1	<1	<20	<5

Table 1. Solar module technologies: estimated annual installed power capacity (MWp) in the period from 2000 to 2008 related to large-scale PV power plants (>200kWp) [1].

MWp	Country	Location	Description	System integrator
40	Germany	Brandis	Ground mounted, 550,000 CdTe modules	juwi
14.75	Germany	Köthen	Ground mounted, 200,000 CdTe modules	juwi
11.8	Spain	Zaragoza	Roof mounted, 85,500 a-Si modules	Veolia Environment
10	USA	Boulder City, NV	Ground mounted, 167,000 CdTe modules	First Solar
10	Germany	Helmeringen	Ground mounted, 135,000 CdTe modules	Gehrlicher Solar
8.5	Germany	Eckolstädt	Ground mounted, 115,000 CdTe modules	Beck Energy
8.4	Germany	Trier	Ground mounted, 112,500 CdTe modules	Conergy
7	France	La Narbonnaise	Ground mounted, 95,000 CdTe modules	EDF
5.9	Spain	Darro Granada	Ground mounted, 80,000 CdTe modules	Beck Energy
5.8	Germany	Igling-Buchloe	Ground mounted, 78,000 CdTe modules	Conergy/Epuron
5.6	Germany	Wörrstadt	Ground mounted, 76,800 CdTe modules	juwi
5.3	Spain	Villanueva de la Jara	Ground mounted, 75,500 CdTe modules	Phoenix Solar
5.3	Spain	San Clemente	Ground mounted, 75,500 CdTe modules	Phoenix Solar

Table 2. Some of the largest thin-film technology-based PV power plants constructed in 2008 [1].

Installed power capacity of other module types like Si microcrystalline modules or CIS/CIGS modules for example is low in comparison to other technologies – estimated to be less than 1%. A significant increase of market share was observed for other thin-film technologies like a-Si; however, while the market share of these technologies remains low in comparison with c-Si, 2008 saw much more power capacity being installed than ever before. The first large-scale power plants with thin-film arrays were constructed in 2003; with close to 3MW of power capacity, their market share was about 10%. Following the decrease of installed power capacity of large-scale power plants a year later, thin film's market share since 2005 has increased continuously.

It is estimated that – considering large-scale PV power plants – in 2008, about 50MW of power capacity was installed with a-Si and more than 190MW using CdTe technology (Table 1). The market share of CdTe modules increased in 2004, reaching about 10% two years later and increasing again to more than 15% in 2007. Because of a significant increase in the power capacity of c-Si installed in 2008, growth in the sector dropped to less than 10% in 2008. Nevertheless, it retains a firm hold on a large portion of market share for some regions (Fig. 2) and applications [2].

In Germany, market share of CdTe modules increased significantly in the last three years. CdTe modules represented a market share of about 25% in 2006, a figure that has jumped by up to 50% in the past two years. Due to competitive pricing, CdTe modules were used for several of the largest ground-mounted power plants [2] in Germany (Table 2); consequently such a large market share is not a surprise. An increase of CdTe market share was also observed in 2008 in other countries such as Spain, the USA and France.

Similar market share increases related to thin-film technologies have been observed in the Czech Republic and in Thailand, with a-Si remaining the dominant thin-film technology of choice in these countries.

Ground- and roof-mounted power plants

Thin-film modules are almost exclusively

Courtesy of Suravia

Figure 2. The Villanueva de la Jara PV power plant, Cuenca, Spain, consists of c-Si and CdTe modules, constructed by Phoenix Solar in 2008.

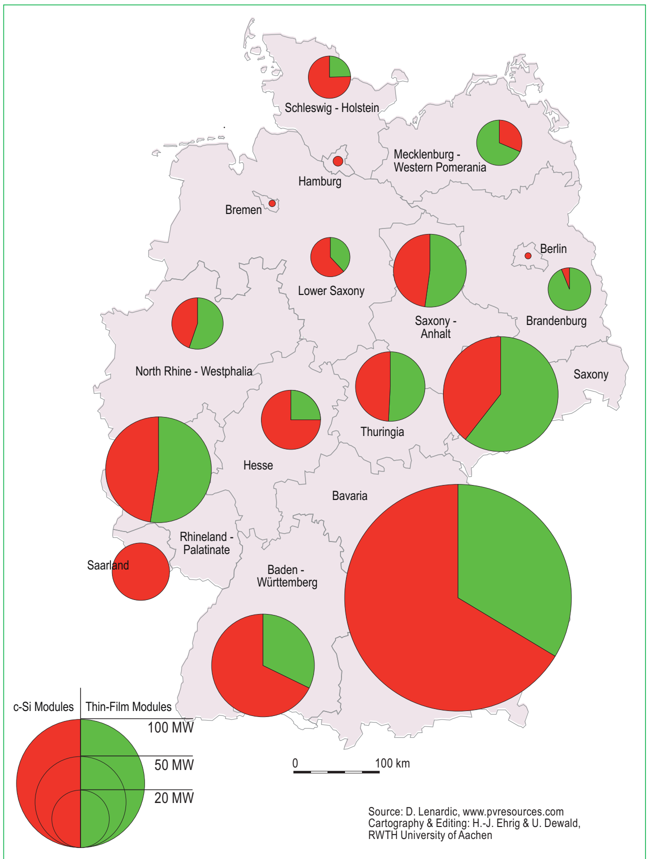

Figure 3. Estimated market shares of different technologies in German states as at December 2008 related to large-scale PV installations [1].

the technology of choice for use in fixed mounted arrays. Compared to 2007, last year saw about fourfold power capacity increase of a-Si and twofold power capacity increase of CdTe (Table 1). The most important markets for thin-film technologies are Germany, Spain and the Czech Republic. Meanwhile, CdTe has the largest market share among thin-film material in Germany (Fig. 1) and Spain, while in the Czech Republic (with about 20% of market share) a-Si is the dominant thin-film technology.

While several of the PV technology types can be used for roof-mounted power plants, crystalline silicon is the most common material used, although a-Si or CdTe are also used quite often. The market share of thin-film technologies – primarily a-Si and CdTe – has continuously increased since 2004, as shown in Table 3. Almost 25% of all large-scale roof-mounted power plants constructed in 2008 consist of thin-film modules. More than 20MW of large-scale roof-mounted PV plants were constructed using a-Si modules, with a slightly lower uptake of CdTe modules.

The past year not only showed the largest cumulative power capacity installed, but it also saw thin-film technologies take the highest market share. Owing to their list of advantages, thin-film technologies have a bright future. Market share will remain healthy, regardless of whether or not the technologies in use are based on silicon. One of the main concerns associated with all thin-film technologies is recycling. Developing and defining independent programmes for recycling modules and other components of photovoltaic systems are seeing intense

	2004	2005	2006	2007	2008
c-Si	29.1	51.2	59.1	62.8	109.3
CdTe	<1	<1	3.7	14.0	18.6
Other	<0.5	0.5	6.0	19.6	41.4

Table 3. Estimated annual installed power capacity (MWp) of roof-mounted PV power plants by technology type [1].


Courtesy of HiTech Solar

Figure 4. Ostrožská Lhota PV power plant was constructed in 2008 using c-Si modules. Ostrožská Lhota is one of the largest PV power plants in the Czech Republic, a country that has seen huge growth in recent months [4].

activity [3], and look set to represent one of the industry's main assignments in the coming years. Recycling cannot and should not be left to individual producers, but rather needs to be managed systemically and integrally, regardless of module type, technology, and manufacturer.

The data that represent the basis of this report is published at http://www.pvresources.com/en/top50pv.php and is available free of charge.

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Denis Lenardič holds a degree in electrical engineering from the University of Ljubljana, Slovenia. From 2004 to 2008 he served as chairman of the Slovene national section of IEC »TC82« Technical Committee, and has been systematically collecting data about large-scale photovoltaic power plants for several years.

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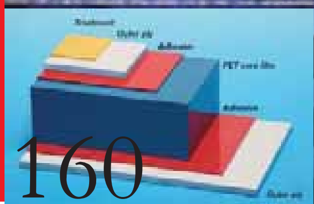
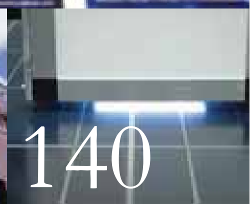
PV Modules





News

Bosch announces planned takeover offer for aleo solar

The management board of aleo solar has announced that some of the key shareholders, which together hold almost 40% of aleo solar's share capital, have signed agreements to sell their shares to Robert Bosch.

aleo solar modules.

The purchase price of each share is set at €9 in cash; this is 43% above the weighted average price of each aleo share in XETRA trading during the three months preceding this announcement, where the price was set at €6.31.

The selling shareholders consist of a group of investors including Marius Eriksen, the company's initiator and cofounder, as well as a company closely associated with Hannover Finanz, a financial investor in aleo solar since 2005.

Bosch intends to submit a suitable voluntary public takeover offer to the shareholders of aleo solar, with the aim of acquiring its remaining shares in connection with its acquisition of close to 40% of the shares of aleo solar.

Jakobus Smit, also cofounder and Chairman of aleo solar's management board, said of the deal, "We are ideally suited for supplementing its current activities in photovoltaics, which are essentially rooted in its acquisition of ersol Solar Energy AG in 2008."

Cofounder Eriksen said, "This confirms the strategy we've been pursuing for years. Bosch's decision to continue expanding the Prenzlau production site, as well as the Oldenburg location for both the German and international sales organization and marketing, under the present management constitutes a special recognition of the performance of all our employees and Management Board members."

Bosch has also entered into an agreement with the shareholders of Johanna Solar Technology to acquire a majority stake in the company; aleo solar will now no longer pursue its plan to purchase additional shares in Johanna Solar Technology if the voluntary public takeover offer and the acquisition agreements are executed.

This transaction is subject to the formal proviso that antitrust authorities approve it and that the minimum acquisition threshold of possibly 75%, which shall be fixed in the voluntary public takeover offer, is reached.

Module Production News Focus

Martifer Solar's 50MW automated module production line completed

The Portuguese company Martifer Solar and Spire, located in Bedford, Massachusetts, have announced their mutual satisfaction with the performance of the 50MW fully automated turnkey module manufacturing system developed for Martifer by Spire. The line uses robotic systems, subcontracted by KUKA Systems Germany, for material handling and processing.

Martifer's robotic systems.

Roger G. Little, CEO of Spire, said the following regarding the factory: "This line is completely automated, making it one of the most advanced module factories in the world. We combined Spire's process knowledge with our state-of-the-art manufacturing equipment and the latest in robotics and automation. The result is a high speed, high yield, cost-effective production line producing top quality PV modules."

Mecasolar 1-Axis seasonal Azimuth tracker system.

Mecasolar will produce trackers at new US site

Mecasolar will be opening a new production plant in San Francisco, which will start producing one- and two-axis solar trackers and fixed structures in the first quarter of 2010. This initiative reflects the interest of Mecasolar and the OPDE Group.

Mecasolar will exhibit two new products at Intersolar North America: its new fixed structures and new one-axis azimuth seasonal trackers. The fixed structures are designed for ground level installations and large solar photovoltaic plants.

With this expansion to its product range, Mecasolar said it responds to the needs of the PV market for installations at ground level. The company is moving on from the two-axis solar trackers, which it has been manufacturing since 2004.

The new range of products will be manufactured and assembled by production plants in Spain and Greece, as well as the new production plants scheduled to be started up in Italy and the U.S at the end of 2009. Mecasolar expects to reach a production capacity for fixed structures and single- and dual-axis trackers of 200MW/year by 2010.

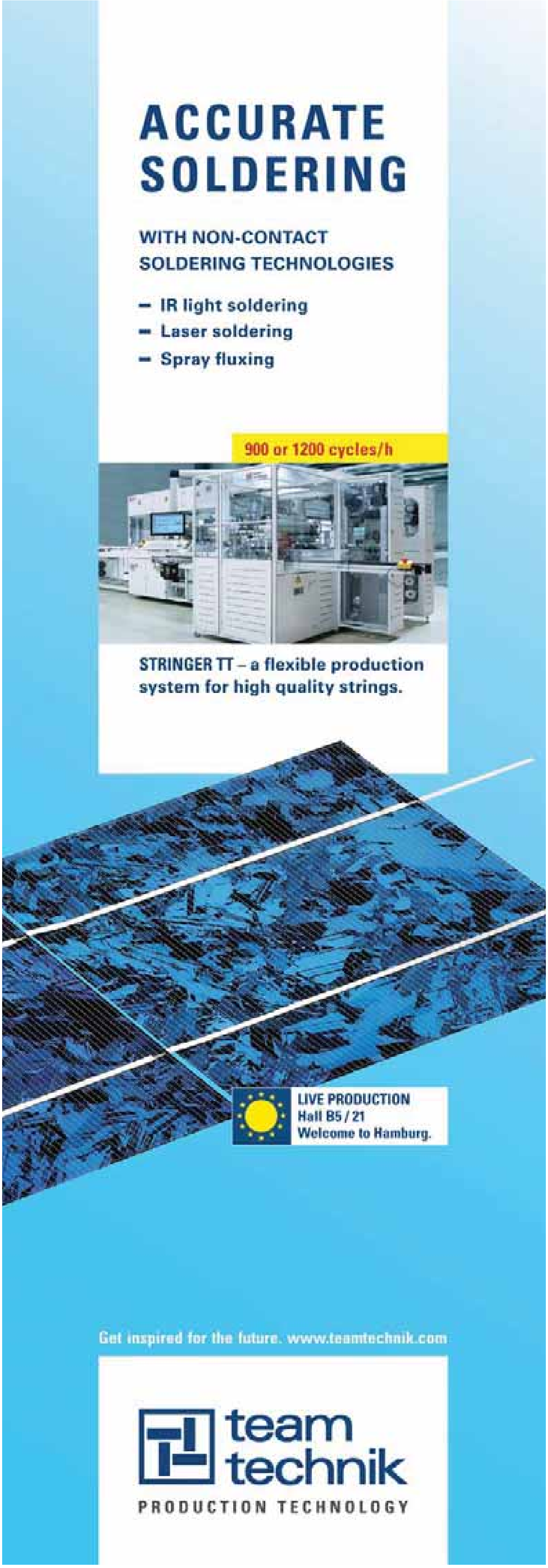
The distribution of both the fixed structure and the 1-Axis Seasonal Azimuth tracker will be performed exclusively by Proinso. Proinso is an engineering and distribution company that was already conducting the distribution of 2-axis Mecasolar trackers and also is a leader in the Trina and REC distribution modules, as well as being international partner of SMA in the supply of large PV plants.

Module Sales News Focus

aleo solar expands into northern Germany

aleo solar AG has announced that it is expanding a greenfield photovoltaic power plant in Südergellersen in the district of Lüneburg, Germany. The turnkey expansion project will boost the output of the existing solar farm from 530 to 1040kW.

The aleo 5,850 S_16 solar modules will save about 570 tons of CO_2 each year. Norbert Schlesiger, of aleo solar AG said,



"The high output of our solar modules means that greenfield solar farms can be profitable even in northern Germany."

Schlesiger's mention of profitability in north Germany points towards the fact that this area has not yet been a key area of growth. Projects such as this will produce a more important market for Germany, leaving room for future expansion.

The construction of this plant will begin in the third quarter of 2009, with solar modules expected to be connected to the grid by the end of the year.


Washer line at Solar EnerTech's production facility.

Solar EnerTech inks US$20 million, 10MW PV module supply deal with Solarzentrum Allgau

Solar EnerTech has signed a contract worth approximately US$20 million to deliver 10MW of crystalline-silicon solar modules to Solarzentrum Allgau, a leading German photovoltaic system integrator.

Module shipments are scheduled to begin immediately and will be delivered throughout the calendar year for deployment in solar installations in Germany.

Solar EnerTech, a solar cell manufacturer and PV panel designer, has its corporate offices in Menlo Park, CA, and production facilities in Shanghai as well as a joint R&D lab at Shanghai University.

BestSolar provides modules for 10MW Dunhuang City solar project

BestSolar Hi-Tech will be the sole PV Module supplier to the recently announced 10MW solar project in Dunhuang City, China. This is the first of a planned 500MWp of solar plants in the Duahuang region and is the first project to receive approval from the National Development and Reform Commission (NDRC) of People's Republic of China.

Dun Huang, China, commented Dr. Peng Fang, President of Best Solar, "This is a major milestone of Chinese solar industry. The achievement is through a strong competition process among all Chinese leading solar module manufactures, Best Solar has been selected as the sole supplier for this project, which indicates the affirmation from the Chinese Government and solar industry community on our manufacture system, quality and market position. We will supply the highest quality modules and ensure 25 years' reliable operation lifetime to set up solar power plant standard for the solar industry in China."

The consortium bid included Enfinity, CGN, LDK Solar and Best Solar. Their successful bid was electricity generation of 1.09 yuan/kWh.

Chinese consortium sets up new solar panel sales hub in U.S.

A consortium of 30 Chinese solar panel companies, collectively known as Centron Solar, has announced that it will be setting up a new sales hub in the Oregon, United States. Centron Solar brings with it 10 high-level managers as well as ambitious plans to expand to around 250 new employees in a year. The consortium sees an untapped module market in the U.S.

Recent sales reach 120MW for Canadian Solar

Fulfilling half of the existing 60MW sales agreement between the two companies, Canadian Solar has been tapped for 30MW of solar modules from Systaic AG for delivery to Spain. Added to this order is company's recent signing or reconfirming of sales contracts or extensions that bring the company's recent sales total to 120MW.

Distribution of the approximately 120MW of solar modules and solar products will see delivery to 24 customers in Europe, North America and Asia before the middle of the fourth quarter of 2009.

aleo solar enjoying "the photovoltaics buyers' market"

Aleo solar AG is recording a considerable upturn in business, which has continued well into the month of May. The group signed a number of new contracts at Intersolar 2009, totalling 5MW. Heiner Willers, part of the aleo solar Management Board, was happy with the results of the event: "Intersolar 2009 is the key photovoltaic trade fair for the European solar industry. As a participant in the last seven fairs, we have witnessed the huge growth in the industry. We can also see that quality and continuity are key factors for our customers – especially in a troubled environment. Even before the event, we were able to finalize contracts for 15MW with specialist dealers in Germany and Italy. These contribute to our current total contract volume of 65MW."

The above is helped, of course by aleo solar's 10-year product guarantee. Dealers and installers among others will notice that the new product guarantee completes the 25-year performance guarantee, which instils confidence in aleo solar's products.

Norbert Schlesiger, sales director at aleo solar, has also noticed the positive increasing revenue: "Revenue in May alone matched our entire first-quarter sales. We are highly confident that this positive trend will continue into the coming months. The photovoltaics market has finally turned into a buyer's market – rooftops in Europe are now the focus of the business. An own sales force, strong brand and premium quality will be the decisive factors for future business."

The construction of a European network with more than 800 specialist dealers across Europe highlights aleo solar's strengths as a distributor and led to above-average visitor interest at the trade fair.

Testing and Certification News Focus

Mage Solar extends its module and power guarantee

Mage Solar module production.

By using high-grade materials for module production, Mage Solar has been able to expand the product and power guarantee of its modules to 10 years and 30 years respectively.

Mage applies strict functional tests and international certifications in order to confirm the requirements for the reliability and durability of all Mage Powertech modules, by putting its modules through this process; the company is confident in extending its guarantees.

The company aims to attract a new customer base, as well as extending its existing orders, as local distributors and global partners alike will benefit from this move. The new guarantee terms apply to all crystalline modules with delivery date August 1st 2009 or later.

Spire delivers 12MW turnkey solar module production line to Sova Power factory in India

Spire has delivered a turnkey photovoltaic module assembly line to Sova Power, located in Durgapur, West Bengal, India. The semiautomated crystalline-silicon module manufacturing line can produce up to 12MW of PV panels annually and can be expanded as needed in the future.

The line will integrate Spire's key interconnect, lamination, and testing equipment, along with intermediate tooling stations. The Bedford, MA-based company said it will supply the process technology and training to operate the factory, as well as assistance in qualifying the factory's modules to international standards and certification.

Bürkle supplies Scheuten Solar with Ypsator laminator

Scheuten Solar Technology, the Dutch solar module and glass manufacturer, has announced an order for Bürkle's Ypsator laminator, which will increase the company's capacity by an estimated 50%.

The machine has a surface area of 1700 x 2200mm, a length of 17m and width of 7.5m working with six openings, and is designed for production of 12 solar modules per cycle. This corresponds to an annual capacity of approximately 50MWp. The investment volume including the conveying equipment is €1.6 million.

The multiopening technology has enabled Scheuten to double its production capacity using a Ypsator lamination line that only requires 30% of the surface of a traditional single-opening laminator.

The two-stage Ypsator is equipped with a hot press and a cooling press. During the lamination step, a membrane presses solar modules made of glass, a solar cell and foil with a pressure of up to 900 mbar. The line reaches a maximum operating temperature of up to 180°C.

Bürkle engineers and service engineers have had to define and connect the interfaces to the precedent and subsequent machines, one of which is the stringer which links the individual solar cells to electric circuits fully automatically.

The very exact temperature distribution and its reproducible processes determine this fully automatic lamination process. This means that the machine can create the required parameters such as vacuum, pressure and temperature in narrow tolerance ranges and with a very accurate repeat accuracy in each cycle.

Jenoptik Group gains new photovoltaics customer in Asia

The Jenoptik Lasers & Material Processing division is continuing to increase its presence as a PV production systems supplier in the Asian market. An unnamed Taiwanese manufacturer active in the renewable energies field has placed four separate orders for productive laser processing machines. These will be used for production lines for the photovoltaic industry, particularly thin-film solar cells.

Jenoptik is equipping the new production line with all systems required for structuring processes and laser edge deletion. Each of these will be fitted with functionality for selective deletion of the bus bar vias and with a laser-drilling unit for the junction boxes. The systems will be delivered to the customer in autumn – the first step in their expansion of capacity to 350MW per year.

TÜV SÜD America and RETC streamline PV certification

TÜV SÜD America, Inc. has combined efforts with Renewable Energy Test Centre LLC (RETC) – a partnership that will speed up the certification process for renewable energy technologies.

RETC will be certifying photovoltaics and renewable energy products with additional services such as third-party outdoor performance and reliability testing. RETC's location in Silicon Valley, its semiconductor-experienced engineers and process knowledge, in addition to the expected solar market growth in the US are all advantages it plans to use to the full.

TÜV SÜD has strived to offer one-stop shop capabilities for PV testing and certification services for many years and is a well-respected name in testing. It currently has IEC 61215, IEC 61646, IEC 61730, and UL 1741 accreditation and is looking to use this partnership to gain UL 1703 qualifications and establish an international presence.

Kuka Systems to supply, install turnkey solar PV module line for Solarwatt

Solarwatt has ordered a new automated turnkey production system for manufacturing crystalline-silicon solar modules from Kuka Systems. The line, which will occupy a production area of 3,800m^2 in Solarwatt's factory near Dresden, will increase the company's production capacity by 150MW when it comes online in the first half of 2010. Augsburg, Germany-based Kuka Systems designed and developed the new plant and is supplying the PV production equipment for the manufacturing line. The toolset includes automated modules for glass destacking and washing, film application, string layup and cross-soldering station, lamination, framing, performance testing, sorting, and packing.

The line also includes the complete conveyor equipment and control technology, as well as 29 Kuka industrial robots and the supplier's Robo Frame, Robo Trimm, and Robo Load automation systems.

In addition to supplying and installing the components, Kuka Systems will be responsible for the turnkey commissioning of the complete line, including the start of production. Once up and running, the module plant will operate in three shifts and produce a module every 28 seconds, according to Solarwatt CEO Frank Schneider.

TÜV SÜD America, Inc.


Solar Semiconductor modules.

Underwriters Laboratories grants certification to Solar Semiconductor

Underwriters Laboratories (UL), an independent product safety certification organization, announced its certification of Solar Semiconductor for the SSI-3SG6-220 family of photovoltaic modules. With facilities located in Kompally and FabCity in Hyderabad, they are the first manufacturer in India to be certified for the wattage range from 198 to 242W.

UL's Photovoltaic Technology Centers of Excellence are located in San Jose and Suzhou (China) where they both set standards and act as a third-party certification body in the Renewable Energy (RE) categories. Solar Semiconductor is a multinational company that produces PV products and services for the global solar PV market.


UL module testing.

Canadian Solar's PV Reliability Testing Center gains ISO/IEC17025 certification

One of the largest PV reliability testing centres in the world, Canadian Solar's test facility in Changshu, China has received accreditation from the China National Accreditation Service for Conformity Assessment (CNAS). The ISO/IEC17025 accreditation will build on the centre's credibility in the reliability-testing arena.

The state-of-the-art photovoltaic reliability-testing centre boasts a total combined indoor and outdoor testing space of more than 2,000m^2. Equipped with an array of cutting-edge test equipment including walk-in climate chambers, mechanical load and hail testers, pulse and continuous solar simulators, electroluminescence testers and first class infrared cameras, the tests carried out in the facility conform to the IEC61215 and IEC61730-2 standards.

Snapshot of spot market for PV modules – quarterly report Q2 2009

pvXchange, Berlin, Germany

ABSTRACT

Solar enterprises will each be faced with the occasional surplus or lack of solar modules in their lifetimes. In these instances, it is useful to adjust these stock levels at short notice, thus creating a spot market. Spot markets serve the short-term trade of different products, where the seller is able to permanently or temporarily offset surplus, while buyers are able to access attractive offers on surplus stocks and supplement existing supply arrangements as a last resort.

Introduction

A spot market always shows the up-to-date prices of solar modules, because it does not consider the long-term delivery contracts of the producers. These days, the spot market for PV modules is global, because the short-term satisfaction of local supply deficits is possible with short transportation times and relatively low logistics costs. pvXchange provides a closed online trading platform for sellers going 'public' with a short-term offer. Other participants of the market can decide if they want to buy the goods at that price, while potential buyers may post their interest and in turn be contacted by interested sellers. Each issue of *Photovoltaics International* will enable the tracking of spot prices of modules through statistics provided by the pvXchange trading platform.

> "The steady price erosion with consequent pressure on margins and obvious reluctance of customers shows unpleasant consequences in the industry."

Price reductions on a global scale

In the six-month period from January to June 2009, prices for Chinese PV modules on the spot market fell by approximately 30%, with European and Japanese manufacturers following suit and reducing their prices by about 23%. Even the otherwise rapidly expanding business of thin-film modules is not spared from a quick change to the buyer's market this year. Bearing in mind the different technology types, the spot market prices for thin-film modules have dropped by 15-22% since the beginning of the year. As the third quarter quickly approaches,

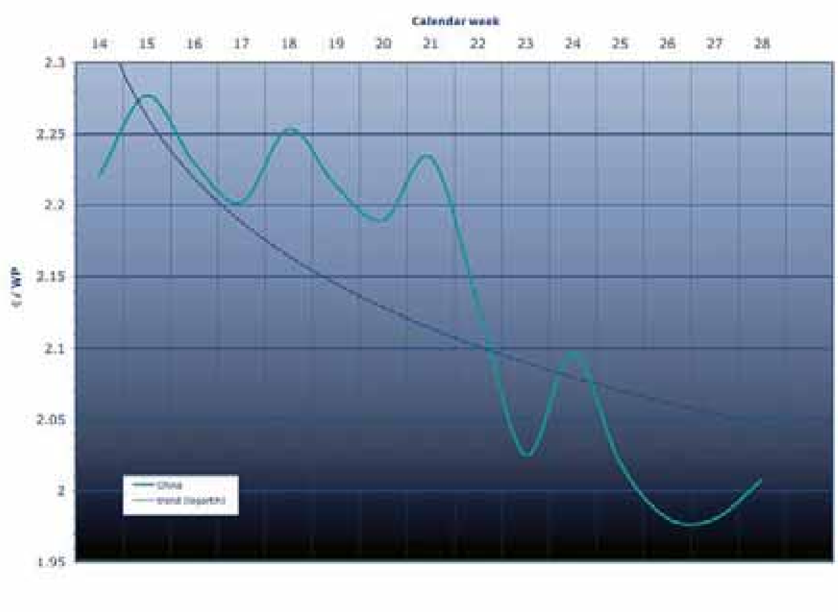


Figure 1. Development of market prices for modules produced by Chinese manufacturers from January 2009 to June 2009 (in EUR/Wp).

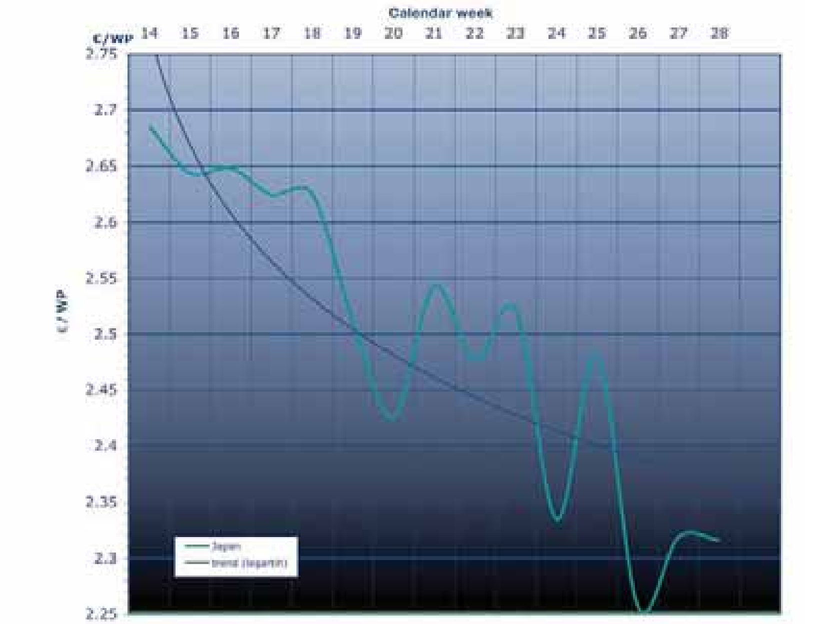


Figure 2. Development of market prices for modules produced by Europe manufacturers from January 2009 to June 2009 (in EUR/Wp).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the trend will endure across all technology types: prices will continue to fall!

The expectations of many of the actors in the industry that the price will hit bottom has not yet been confirmed in this, the second quarter of '09. The steady price erosion with consequent pressure on margins and obvious reluctance of customers shows unpleasant consequences in the industry. This has resulted in downward corrections of sales and earnings targets for 2009 by many large European companies. However, this price sag is not only visible in the spot market: contract prices for (even partially) crystalline modules were cut significantly around the world in April and May.

Despite this trend, each region features a manufacturer whose prices on the spot market are higher than those of most other providers, as is the case for Suntech Power, for example. Facing up to the price decline since the beginning of the year, these companies have for various reasons decided not to dip to the same price level as their competitors. Other companies such as Yingli and Solarworld remain optimistic, starting sales campaigns and modifying long-term contracts despite the strong decline in module prices. In addition, reductions in production cost are resulting in even more capacity being built in order to cope with the global crisis.

The industry is suffering acutely from a price war, the end of which is difficult to pinpoint. Meanwhile, as many companies from the old continent dream of sales increases, Asian players are gaining ground in Europe. Chinese manufacturers like CSI and Trina Solar have sold the bulk of crystalline modules on the PV spot market in the past months. In the thin-film realm, the spot market mainly saw modules from U.S. manufacturer First Solar changing hands.

> "Chinese manufacturers like CSI and Trina Solar have sold the bulk of crystalline modules on the PV spot market in the past months."

Besides Germany and Italy, Belgium has staked its claim as an attractive market and has gained mindshare in recent months. On the other hand, Spain has not seen an upturn in demand so far this year. Product oversupply will mean a difficult sales year for the country, as financing difficulties slow down the implementation of new projects. Despite the great potential of new markets such as Austria and Greece, some countries have lost the market connection amid the rapid expansion of photovoltaics.

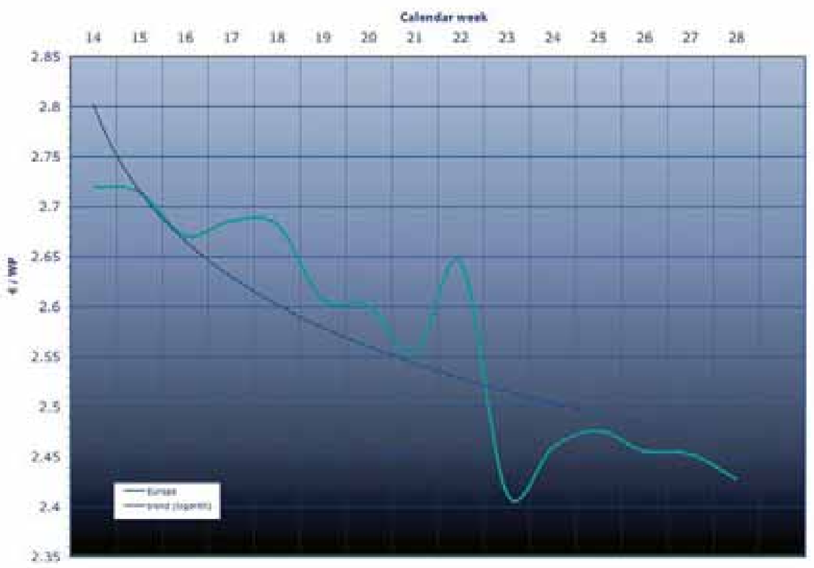

Figure 3. Development of market prices for modules produced by Europe manufacturers from January 2009 to June 2009 (in EUR/Wp).

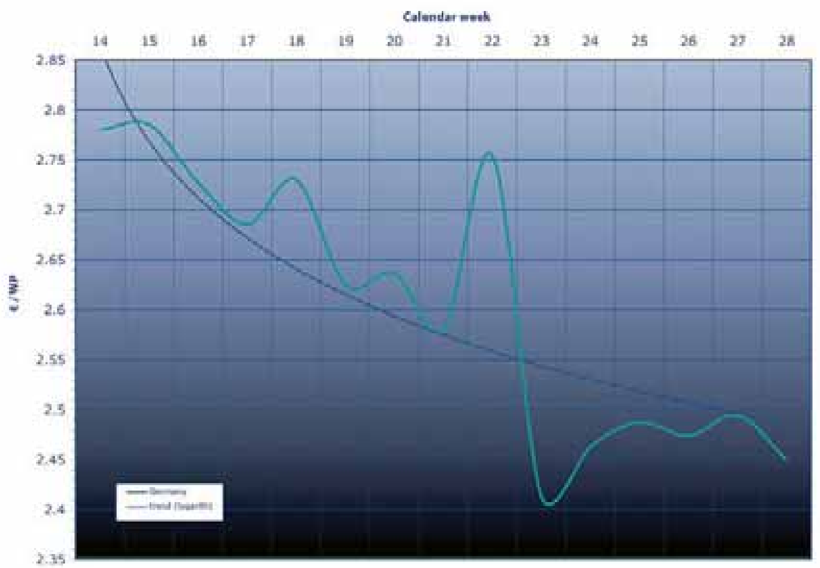

Figure 4. Development of market prices for modules produced by Germany manufacturers from January 2009 to June 2009 (in EUR/Wp).

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 2008, the company procured solar modules with an output of around 100MW. This represents a trading volume of approximately €300 million. With its international network and complementary services, pvXchange is constantly developing its position in the renewable energy market, a market which continues to grow on a global scale.

Based in Europe, pvXchange also has a presence in Asia and the USA.

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Product Briefings

United Initiators

United Initiators' organic peroxide initiators improve EVA performance

Product Briefing Outline: United Initiators specializes in manufacturing and supplying cross-linking agents to compounders and manufacturers of PVM encapsulates. Cross-linking with organic peroxide initiators adds many product and performance advantages, the chief of which is the improvement in stability of the encapsulate films produced for PV manufacturing. PV manufacturers rely on a special formulation of ethylene vinyl acetate (EVA) that includes peroxides to achieve dimensional and UV stability through crosslinking.

Problem: Some vertically integrated companies rely on EVA encapsulants tailored to their applications' needs. Others in photovoltaic manufacturing buy their materials from outside compounders and then assemble the materials into PVMs. While compounders are knowledgeable about peroxide initiators, United Initiators is often able to assist them in gaining performance with the cross-linking agents. A key problem is discoloration in the form of yellowing or hazing that causes a reduction in the sunlight that penetrates to the silicon wafer and the goal is to continue to reduce discoloration.

Solution: Stabilizing PVM encapsulates improves their performance, colour and cure characteristics. Solar encapsulates are typically made with ethylene vinyl acetate (EVA), which in sheet form is used to surround and protect silicon wafers and the PVMs' circuitry. Other benefits include better adhesion, reduced cell breakage and tailored flexibility. Cross-linking in PV manufacturing may extend performance of encapsulate sheet material to 20 or 30 years—a period as long as the product's lifespan. Cross-linking by peroxides has a positive effect on the properties of materials and results in a low compression set, improved thermal aging and elimination of discoloration.

Applications: PV module lamination.

Platform: Organic peroxides.

Availability: Currently available.

Amelio Solar, Inc.

Amelio Solar offers CIGS tandem module with 13% conversion efficiencies

Product Briefing Outline: Amelio Solar, Inc. has developed the 'PV Duo' tandem photovoltaic module, which combines a thin-film a-Si photovoltaic device and a thin-film CIGS photovoltaic device into one integrated module. The company claims demonstrated efficiency as high as 13% while retaining the important advantages of a-Si, including its ability to perform in high temperature and low light conditions.

Problem: Conventional solar panels are comprised of interconnected crystalline silicon (c-Si) semiconductor wafers, a highly processed material which is increasingly expensive due to its high manufacturing cost and a global supply shortage. However, thin-film photovoltaic modules are produced by coating a pane of glass (or other substrate) with a very thin film of (non-c-Si-based) photovoltaic material. The resulting product is claimed to cost 50% to 70% less to manufacture (per watt of module power output), performs longer each day and in lower light, and is more versatile than traditional photovoltaic modules.

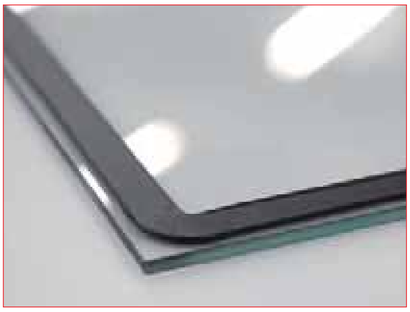
Solution: The PV Duo capitalizes on the construction of glass-to-glass encapsulated thin-film photovoltaic modules. As with the a-Si and CIGS, the PV Duo consists of a glass plate to which are applied the layers of material comprising the thin-film photovoltaic device. Unlike a-Si and CIGS, however, which have a second glass plate that serves as a blank, protective back cover laminated to the photovoltaic glass plate, the PV Duo utilizes the surface area of the second glass plate to create a second photovoltaic device. This device is initially CIGS-based, and is laminated to the first photovoltaic glass plate, initially a-Si-based, resulting in an a-Si/CIGS four terminal tandem module.

Applications: Rooftop, BIPV.

Platform: PV Duo offers its a-Si and CIGS products in $1.0m^2$ and $1.5m^2$ substrate sizes, and turn-key manufacturing systems for all products with either manual or optional automated glass plate-handling.

Availability: Currently available.

Komax



New hot melt sealing equipment by Komax enables precise and continuous application of butyl

Product Briefing Outline: Komax has developed new sealing equipment for thin-film modules that enables a continuous and precise hot melt dispensing of high-viscous butyl. The hot application of the butyl improves the adhesion and therefore the protection of the module against humidity. The higher accuracy of the hot melt butyl placement (compared to the commonly used butyl stripes) allows a simpler system for the EVA or PVB cutting and marriage. In addition, the dispensing out of barrels enables a 24-hour operation without material exchange.

Problem: Thin-film solar cells are sealed with butyl tape to protect the active layers from humidity. The commonly used butyl tape is extruded onto a liner and provided on a reel. However, the tolerances of the liner as well as of the tape are high and the small reels need to be exchanged several times per operating shift. In addition, the adhesion of the tape is very sensitive to the cleanness of the glass.

Solution: With the new hot melt sealing equipment from Komax, the butyl is not extruded onto a liner, but directly onto the glass. Through this method, one process step can be eliminated and material costs are reduced. The high-viscous butyl is pumped from a barrel to dispensing head. The shape of the butyl can be easily adapted to the required width and height. A 200kg barrel will be consumed in approximately two days, whereas a butyl reel lasts only for about one hour. In addition, the application with the hot melt dispenser leads to an improved adhesion and a higher accuracy. A higher accuracy enables the use of a simpler foil cutting and marriage equipment.

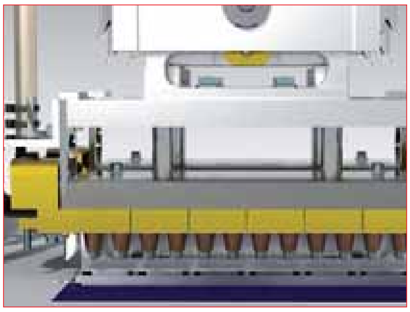
Applications: Thin-film photovoltaic modules (substrates as well as superstrates).

Platform: Komax supplies equipment for crystalline module production and for thin-film back-end module production.

Availability: Currently available.

Product Briefings

SOMONT



SOMONT pushes stringer throughput to 100MW per year with 'CERTUS' platform

Product Briefing Outline: SOMONT, a subsidiary of 3S Industries AG, has had success with the RAPID stringer and lay-up systems for high throughput cell stringing in module production with capacity ranges of 10-40MW per year. However, a new stringing system, CERTUS, has been developed for production capacities from 50-100MW per year.

Problem: The need to balance between higher level module capacity, to reduce overall manufacturing costs and to enable higher throughputs of individual tools while retaining the smallest environmental footprint requires a fresh approach to every process step in assembly production.

Solution: The CERTUS utilizes a modular concept to match the desired capacity requirements that integrates all the elements needed at the front-end of the module production line. New, state-of-the art technology for the stringer includes in-line string testing, matrix lay-up, interconnection, matrix testing and lay-up on the glass plate. It has a new technology that applies flux on to the ribbons. Improved cell handling and new temperature management for the unique soft touch soldering process are all help increase the throughputs. After cell soldering, the entire string is tested with a new, in-line test system consisting of a 3-D camera, flasher and dark current measurement. Only strings matching the required specifications are forwarded with a special transport system to the matrix lay-up station. After completion of the lay-up, the entire matrix is forwarded to the interconnection station that handles the required ribbons and soldering. The completed matrix is tested once again and carefully placed on the glass plate. The entire stringer is compact, with a sleek design.

Applications: Cell stringing in module production.

Platform: The new CERTUS can be configured with a series of options as well as integrated in existing module production lines.

Availability: Currently available.

teamtechnik

teamtechnik boosts stringer system uptime and reduces footprint

Product Briefing Outline: teamtechnik's high-throughput stringer machines for the global photovoltaic industry are designed to combine reliable large-scale series production with high levels of string quality. The standard stringers TT 900 and TT 1200 operate at respective rates of 900 and 1200 cycles per hour. The two units are the offspring of a singular modular construction system. Thus two TT 1200 stringers will operate at 2400 cycles per hour in a 50MW system.

Problem: Module assembly is one the most expensive steps in c-Si cell/module production. Fully automated and integrated tabber/stringer systems need to have high throughput and high yield to support PV manufacturers cost reduction strategies.

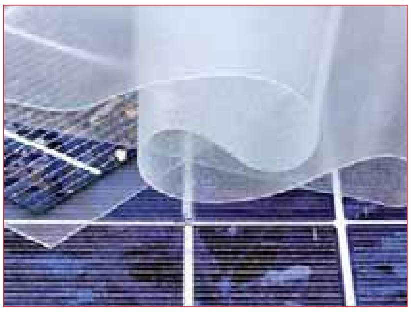
Solution: All TT stringers feature contactless, controlled soldering technology that relies on infrared light or laser, both of which are available for optional integration in every teamtechnik stringer. The laser technology serves as a valuable source of enhanced flexibility for dealing with different materials; it ensures optimal results when soldering an extensive array of cell, ribbon and flux combinations. The controlled process technology compensates for variations in cell material to minimize breakage while ensuring consistent string quality. Each of the heating zones in the TT stringer can be adjusted individually. It is also possible to specify the ideal thermal conditions for each cell type prior to, during and after the soldering process. A special hold-down device featuring the functionality of a positioning tool guarantees that ribbons are precisely positioned on the cells. The resulting strings offer convincing geometrical quality by combining improved alignment, linearity, length and cell intervals with excellent cell and ribbon positioning.

Applications: Standard and back contact cells (BC/EFG/film). Wafer thickness > 160µm with 2 and 3 bus bars.

Platform: The systems are designed as a flexible modular system and can be equipped with a wide range of soldering technology.

Availability: Currently available.

Wacker



Wacker's silicone-based elastic polymer sheet can be used with multiple solar cell types

Product Briefing Outline: Wacker is introducing 'Tectosil,' a silicone-based elastic polymer sheet, which is thermoformable and therefore a fast and easy encapsulant process. Tectosil provides solar cells with effective and long-lasting protection against mechanical and chemical stresses. It is non-corrosive and can be used with any type of module.

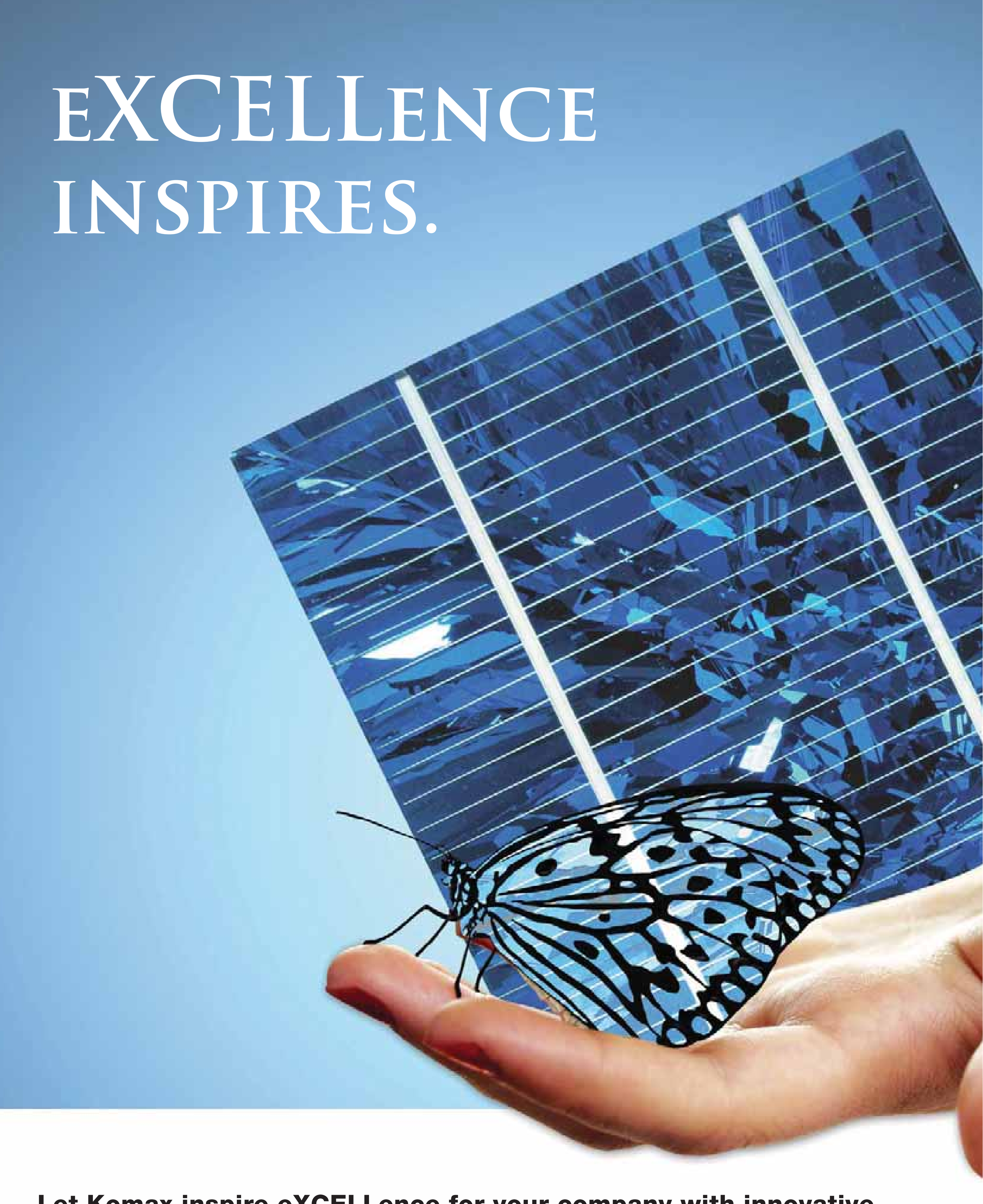
Problem: There is a growing need for new encapsulant materials as the PV industry continues to expand and traditional materials are in limited supply. However, new materials must perform in the same way and offer the durability required for a PV module's expected lifespan.

Solution: Tectosil is a flexible, highly transparent and electrically insulating sheet comprising of a silicone-organo copolymer. Because of its thermoplastic properties, this silicone-based polymer can be processed quickly and inexpensively – without curing or chemical reactions. The lamination process thus benefits from short production cycles and a high tolerance to local temperature differences within the laminator. Solar cells encapsulated in Tectosil are afforded optimum protection against mechanical and chemical stresses. The material bonds the components of a PV module into a stable laminate.

Applications: The material can be used to make any type of module and is suitable for either vacuum laminators or continuous processes.

Platform: When in contact with moisture, the chemically stable, catalyst-free sheet does not produce any substances that might initiate corrosion or damage surfaces. This allows the sheet to be used for encapsulating solar cells containing films of compound semiconductors (e.g. CIGS), or other highly sensitive chemical substances like transparent conductive oxides. The material absorbs almost no water, poses an effective moisture barrier and is permanently electrically insulating.

Availability: Currently available.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A new method for measuring cross-link density in ethylene vinyl acetate-based encapsulant

Zhiyong Xia, **Daniel W. Cunningham** & **John H. Wohlgemuth**, BP Solar International, Inc., Frederick, Maryland, USA

ABSTRACT
Among the different packaging materials used in photovoltaic solar modules, ethylene vinyl acetate-based (EVA) encapsulants play an important role during the lifespan of the module assembly. Prior to lamination, EVA is a thermoplastics polymer containing a number of additives. During the lamination process, EVA cross-links into a three-dimensional network structure, i.e., a thermoset, which provides protection for solar cells against detrimental environmental conditions. Since EVA has a very low glass transition temperature and melting points, proper cross-link density has to be achieved through the lamination process to prevent the EVA from cold flowing in the field. As a result, module manufacturers constantly monitor the cross-link density or gel content of EVA after lamination. This paper proposes a new method of measuring the EVA cross-link density value while avoiding many of the pitfalls associated with conventional cross-link density test method.

Introduction

Many of today's commercial photovoltaic solar modules carry a 25-year warranty. Significant efforts have been dedicated to understanding and improving the reliability and durability of the whole module assembly [1], the majority of these modules use ethylene vinyl acetate (EVA) as an encapsulation material. Evidence suggests that among the different module components, the encapsulant plays a critical role in ensuring the lifetime performance of the solar module [2-3].

The EVA encapsulant serves several key functions including: 1) holding/bonding the module components together; 2) optically coupling the glass and the solar cell; 3) providing the required barrier between the solar cells and the environment; and 4) maintaining electrical isolation. The most commonly used EVA encapsulant for PV modules is a block copolymer of ethylene and vinyl acetate (VA) with a VA content of about 33% by weight. The high VA content guarantees a greater than 90% light transmission onto the solar cells. Fig. 1 is the chemical structure of an EVA block copolymer.

Uncured EVA is a thermoplastics polymer that has a low glass transition temperature and low melting points. In order to be suited to PV module applications, EVA must be cross-linked (or cured) into a three-dimensional network structure such as a thermoset polymer. The curing is typically achieved through the application of cross-link agents activated during the module lamination process. Cross-link agents that are generally used to cure EVA are peroxides, such as 2,5-dimethyl-2,5-di-tert-butylperoxy hexane (Lupersol 101) and tert-butyl 2-ethylhexyl percarbonate (TBEC) [4].

During the standard module lamination process, the peroxide will decompose homolytically to generate a pair of oxy radicals. Each of these radicals can abstract a hydrogen atom from the EVA molecule and initiate the cross-linking in EVA. Research carried out at Jet Propulsion Lab [5] showed that the presence of VA functional groups is critical to the cross-linking of EVA, and that polyethylene without VA groups could not be cured at all with these peroxides under normal lamination conditions.

"During the standard module lamination process, the peroxide will decompose homolytically to generate a pair of oxy radicals. Each of these radicals can abstract a hydrogen atom from the EVA molecule and initiate the cross-linking in EVA."

Since EVA is an elastomer, achieving a proper cross-link density in EVA is essential to overcome the 'cold flow' of EVA and thus make the module durable for field applications. As a result, module manufacturers should constantly check the cross-link density of cured EVA. The most widely accepted way of measuring the EVA cross-link density is through solvent extraction [5], which must be operated at elevated temperatures for better solubility of EVA in the solvent. Some common solvents that have been used to extract EVA include toluene, tetrahydrofuran and xylene.

During the extraction process, the uncured EVA will be dissolved in the hot solvent, while the cured EVA will remain solid. The samples are weighed before and after the extraction with the ratio between the two weights representing the gel content. However, this solvent extraction method poses several drawbacks including health, safety and environment issues resulting from dealing with chemicals, long turnaround time, high test variability, and the potential for built-in inaccuracies as will be discussed later in this paper.

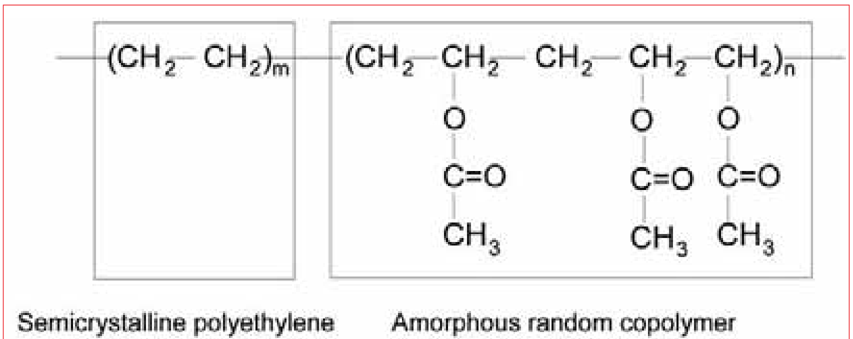

Figure 1. Chemical structure of an EVA block copolymer.

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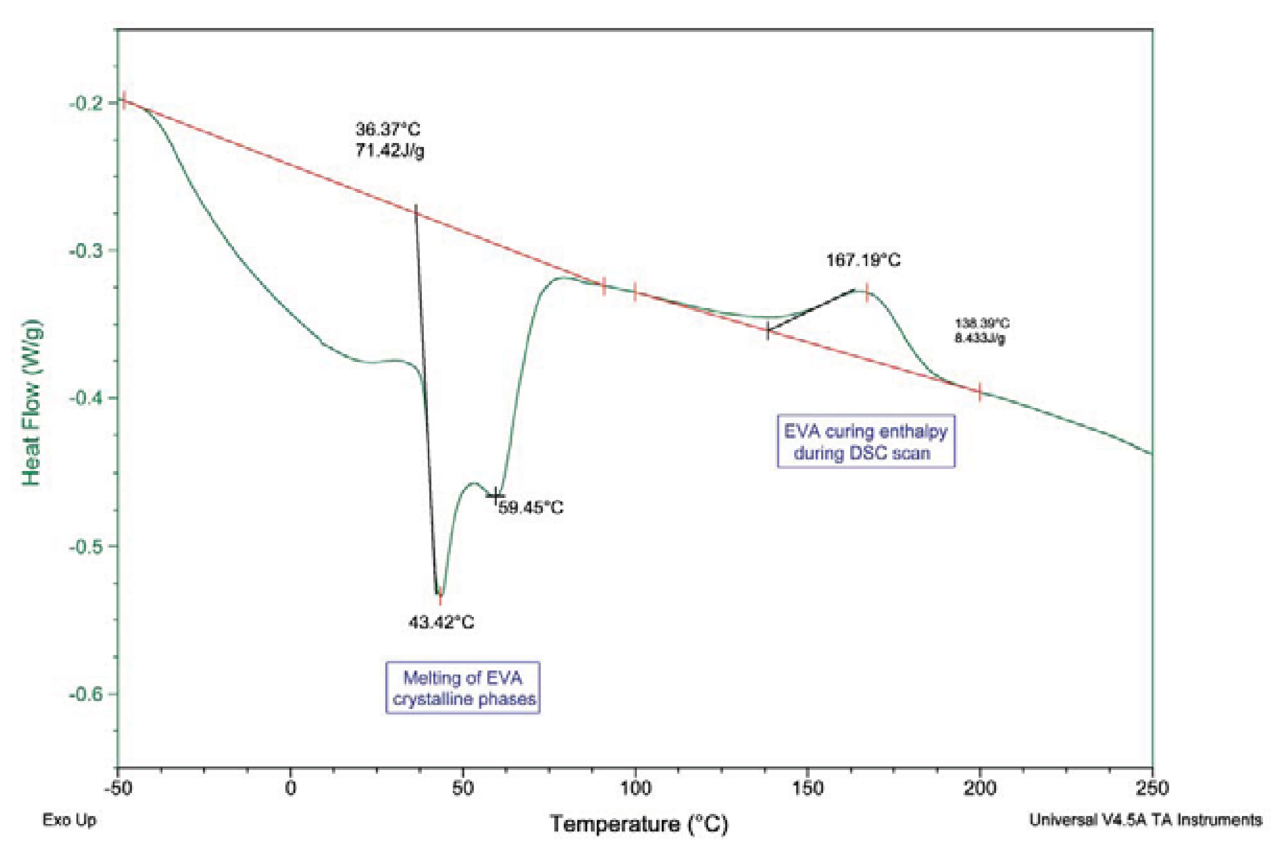

Figure 2. DSC trace of a partially cured EVA heated from -60°C to 300°C at 10°C/min.

Thus it is of great interest to the PV industry to develop an alternative method for measuring the cross-link density in cured EVA that can overcome the aforementioned shortcomings associated with the solvent extraction method. In this work, the feasibility of using differential scanning calorimetry (DSC) as an alternative method of measuring EVA cross-link density was evaluated. Compared with the solvent extraction method, DSC is a thermo-physical method, and can also provide structural information about the EVA formulation.

Experimental

The EVA used in this study was a standard fast cure EVA with 33 wt% vinyl acetate. The EVA was laminated under different conditions, after which process all samples were conditioned at approximately 23°C and 50% relative humidity for 48 hours prior to the DSC or solvent extraction test.

DSC tests were performed on a Q2000 modulated DSC equipped with an auto-sampler and Tzero aluminum sample pans with standard lids. During the DSC scan, an N_2 purge at 50ml/min was used to protect the sample from oxidation. The temperature range for the test was from -60°C to 300°C, with a heating rate of 10°C/min, which was chosen because the heating rate of EVA during lamination in this study was also around that range. The integration range for measuring the curing enthalpy was from 100°C to 200°C, and the samples weighed approximately 5mg.

Toluene solvent extractions were performed on the same set of samples that were analyzed by DSC. The extractions were carried out at 60°C for 24 hours. Samples were weighed before and after the extraction. The gel content was then calculated using the following formula:

$$gel\ content = \frac{final\ weight}{initial\ weight}$$

Key assumptions involved in this method are that uncured EVA dissolves 100% in hot toluene, and anything that is not soluble after the extraction will be counted as gel content. As will be shown in the results and discussion section, this method poses some key drawbacks, including over-predicting the EVA gel level if the solvent extraction is performed at temperatures lower than the high end of the EVA melting range.

Results and discussion

As discussed earlier, cross-linking of EVA is through the reaction between peroxide and EVA. However, under normal module lamination conditions, not all of the peroxide will be consumed in cross-linking EVA due to a number of factors including limitations in EVA-curing kinetics, the presence of antioxidants in the formulation, absorbed oxygen, ethylene chain branching, and un-saturation of the polyethylene backbone [6]. According to the research carried out by Ezrin et al. [7], there remains about 30% unused peroxide in a typical EVA module immediately after lamination. These residual peroxides will either further react with EVA in the field and/or decompose into by-products as a result of outdoor aging [7].

Differential scanning calorimetry technique

The residual peroxide within the partially cured EVA can be further reacted in a controlled manner using a continuous temperature scan. DSC is an ideal technique for this application. In a standard DSC set-up, there are two heating stages inside a furnace. During the test, two aluminium pans are placed on the two heating stages. One pan holds the test sample, while the other is empty and used as a reference. The furnace is heated and the temperature of each pan is monitored. If the test sample undergoes a thermal transition, a difference in temperature between the two pans will ensue. The DSC instrument converts the temperature difference into exothermic or endothermic heat flow data. Since the curing reaction of EVA gives off heat, when there is residual peroxide, an exothermic peak will appear in the DSC trace. By comparing the size of the exothermic peak in the uncured and the partially cured EVA, the relative amount of residual peroxide in the partially cured EVA can be quantified. In other words, the larger the exothermic peak, the more residual peroxide is left in the partially cured EVA, meaning less

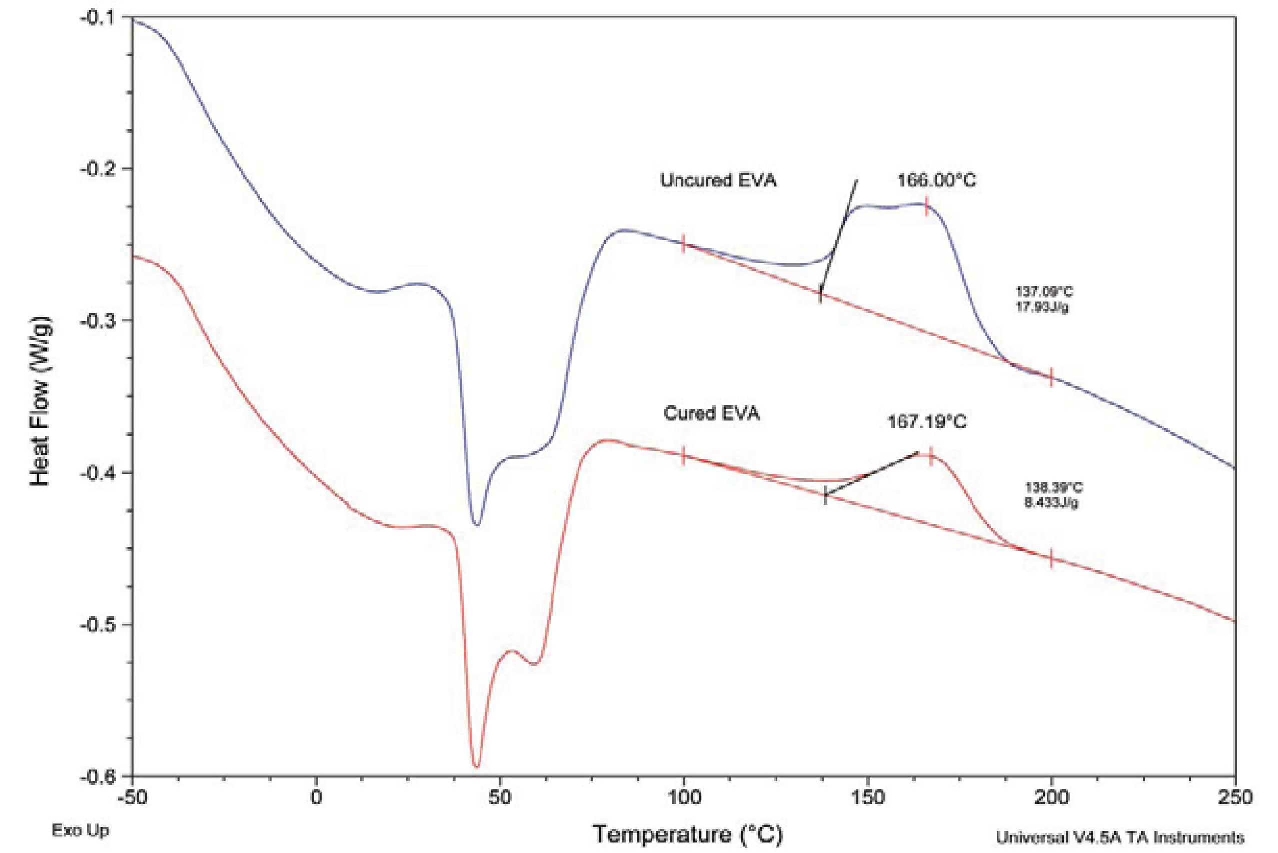

Figure 3. DSC traces of both uncured EVA (blue) and a partially cured EVA (red).

peroxide was used in cross-linking the EVA. Using the same rationale, one can also monitor the shape and position of the exothermic peak. The latter is especially useful to differentiate specific EVA curing packages.

Fig. 2 shows a DSC temperature scan for a partially cured EVA. As the sample was heated from -60°C to 300°C, a series of thermal transitions were observed. The two major endothermic peaks at 43°C and 59°C are related to the two crystal morphologies in EVA. The peak at 43°C is due to the melting of less perfect crystals, while the peak at 59°C corresponds to the crystalline phase of the better packed polyethylene chains. This complex crystallographic structure of EVA comes

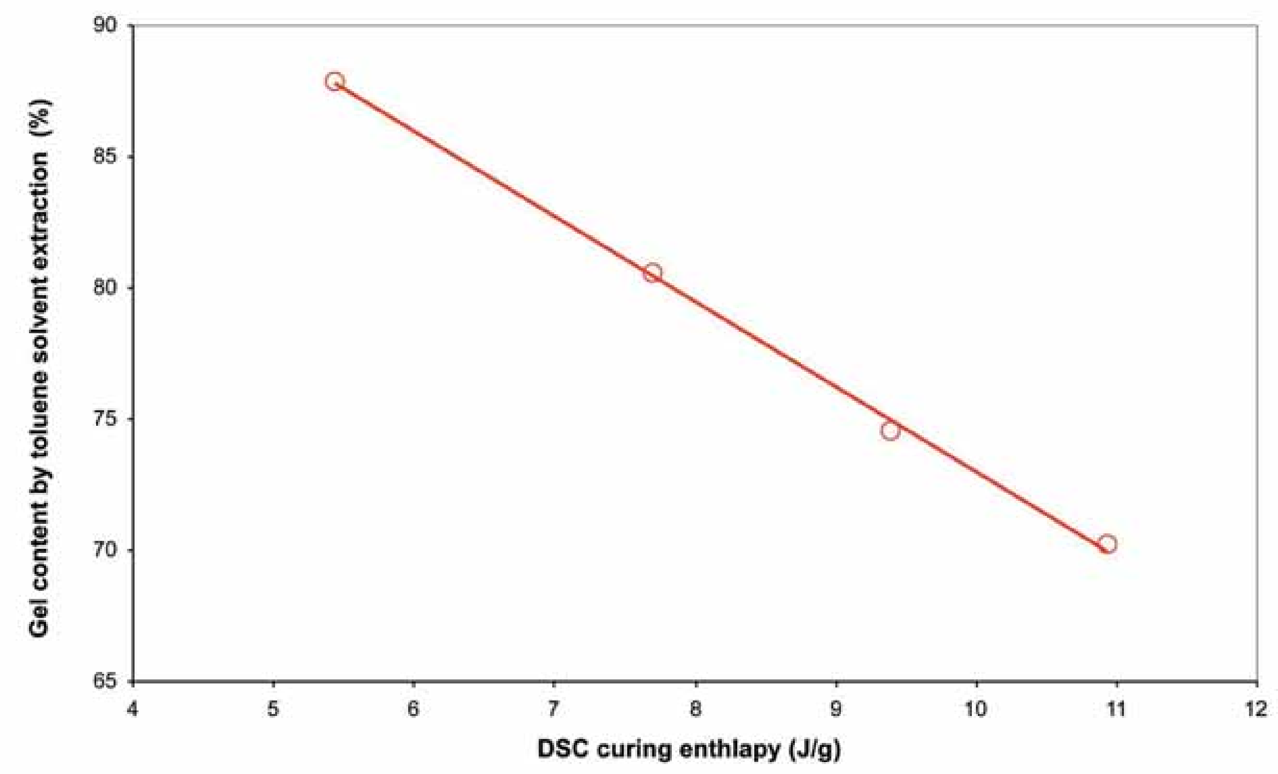

Figure 4. Correlation between DSC curing enthalpy and gel content measured by solvent extraction.

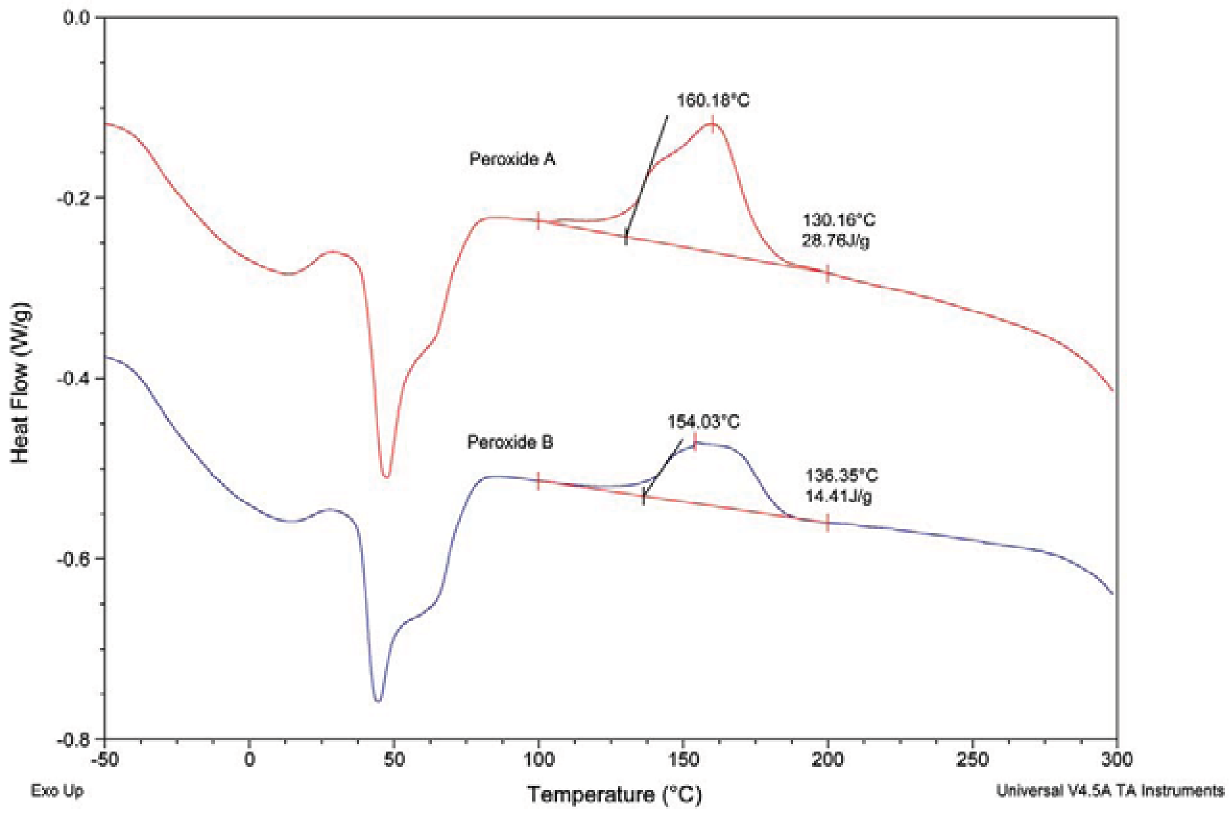

Figure. 5. DSC trace of EVA samples with different peroxide types and concentrations.

from the presence of VA functional groups [8], which in turn disrupt the regularity of the polyethylene chain, which leads to poor chain packing or poor crystal structure. The melting process continues until 75°C. It is worth noting that these melting points – which have also been reported in other studies [9] – overlap with the glass transition temperature of EVA.

As the temperature of EVA increases to greater than 100ºC, a major exothermic peak becomes visible – a result of the

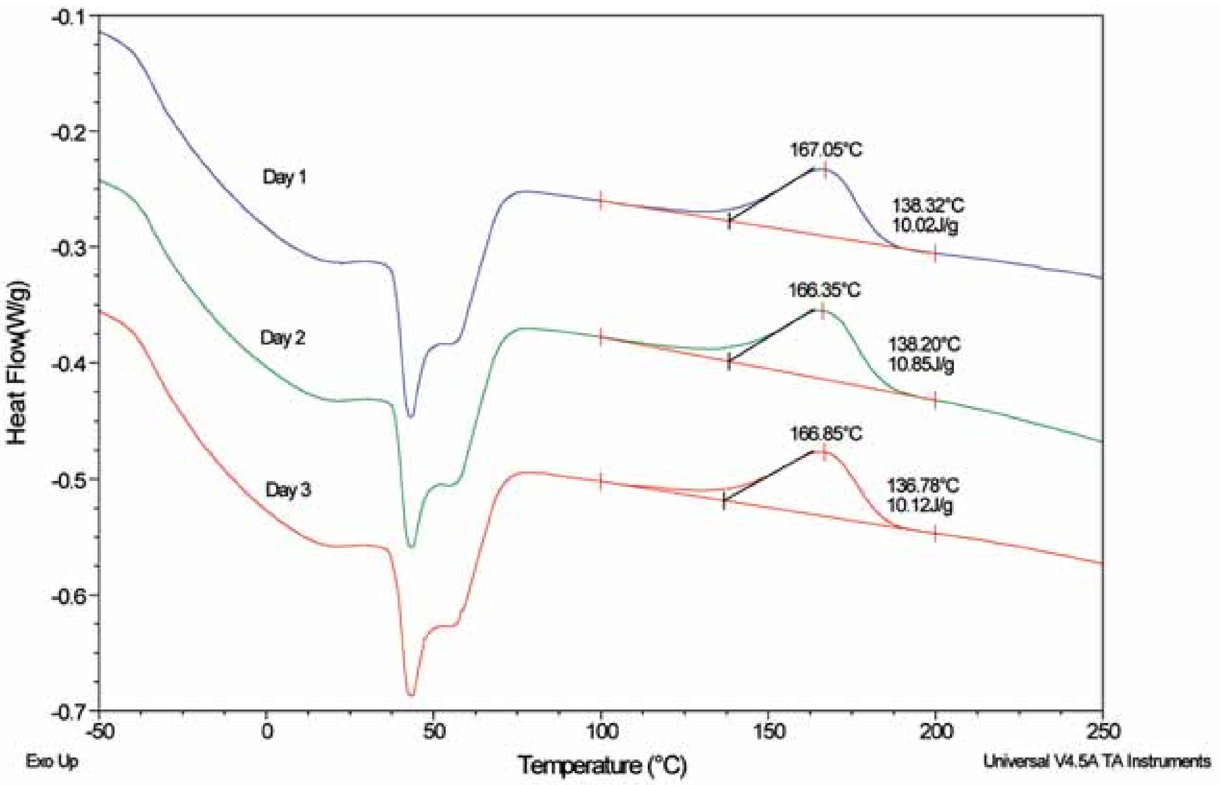

Figure 6. Repeatability check for DSC.

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	DSC	Solvent extraction
Pros	Fast turnaround time	More historic data
	Can provide curing kinetics	Widely used
	Physical process/no chemicals needed	
Cons	Relies on residual peroxide	Could over-predict EVA gel content
	Not applicable to EVA with no residual peroxide, or with unknown thermal history	Long turnaround time
		High variability
		Chemical solvent required

Table 1. Comparison of DSC and solvent extraction.

reaction between EVA and peroxide during the DSC heating process. The peak temperature centres around 167°C, and continues to about 190°C. Integration of this peak shows that the amount of curing enthalpy is 8.433J/g for this sample.

"By comparing the size of the exothermic peak in the uncured and the partially cured EVA, the relative amount of residual peroxide in the partially cured EVA can be quantified. In other words, the larger the exothermic peak, the more residual peroxide is left in the partially cured EVA."

In order to further understand the change in curing enthalpy during lamination, an as-received EVA sample (uncured EVA) was analyzed using the DSC method, the results of which analysis are depicted in Fig. 3. For comparison purposes, the partially cured sample in Fig. 2 is also plotted in Fig. 3. To determine the extent of cure, the total energy released under the curve is determined as J/g. In the case illustrated, the uncured EVA has a total curing enthalpy of 17.93J/g versus 8.433J/g for the partially cured sample. Based on these data, about 50% of the original peroxide still remains in the partially cured EVA, while the other 50% of the peroxide has been consumed in cross-linking EVA during lamination.

To get a direct relationship between the DSC curing enthalpy and the solvent extraction gel content values, EVA samples with different levels of cross-link density were prepared using different lamination conditions (time/temperature). The cured EVA samples were then analyzed by both DSC and toluene solvent extraction, the results of which are shown in Fig. 4. This illustrates that a good correlation has been established between the DSC curing enthalpy and the gel content measured by the conventional solvent extraction method.

A DSC dynamic temperature scan can also be used to determine the type and the amount of peroxide in EVA. Fig. 5 shows the DSC traces for two uncured EVA samples with different peroxide types and concentrations. The EVA with peroxide A (red line) shows a higher curing enthalpy than that with peroxide B (blue line). In addition, peroxide A begins to cure EVA at a lower temperature than peroxide B. Based on the DSC analysis, EVA with peroxide A will generate higher cross-link density than peroxide B if laminated under the same conditions.

To check the repeatability of DSC, three identical EVA samples were cured with the same lamination conditions but on different days and analyzed by DSC. Overall, very consistent DSC traces were obtained, as shown in Fig. 6. It was found that curing enthalpies for all three samples were not statistically different from each other, from which we can conclude that DSC has an excellent repeatability.

"In order to further understand the change in curing enthalpy during lamination, an as-received EVA sample (uncured EVA) was analyzed using the DSC method."

As Fig. 2 showed, the upper range of EVA melting extends all the way up to 75°C. Therefore, if the solvent extraction is performed at a temperature lower than 75°C, part of the EVA crystalline phase will not fully melt and will be mistakenly counted as EVA gels. This will over-predict the true gel content in partially cured EVA.

Of course, the DSC method has limitations too. Since the measurement is based on the residual peroxide continuing to cure EVA, this method is not applicable to samples with unknown thermal history, such as field return samples, where residual peroxides may not be even present anymore. Also, for filled EVA materials, the filler level needs to be determined first for accurate measurement of the curing enthalpy or the gel content by solvent extraction. Table 1 summarizes the comparison between the DSC and the solvent extraction methods.

Summary

DSC has been proved to be a fast and reliable method of measuring the cross-link density of EVA. Given the nature of the analysis, no chemicals are involved in the process. DSC takes a much shorter time than the solvent extraction method. Furthermore, with a well-controlled lamination process, it is actually a more accurate way of measuring EVA cross-link density. Compared with solvent extraction, DSC is not only able to predict cross-link density, but also is capable of determining the curing kinetics of different peroxides.

Acknowledgment

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About the Authors

Dr. Zhiyong Xia received his Ph.D. from Texas A&M University in materials science and currently works at BP Solar as a materials scientist. His major research area is encapsulation and packaging of solar cells. A member of ACS, SPE and IEEE, Dr. Xia holds three US patents, 18 US patent filings and has contributed to more than 30 technical publications in peer reviewed journals and conference proceedings.

Dr. Daniel Cunningham is Module Technology Manager at BP Solar. His responsibilities include product design, reliability and certification, and in the past he has served as Director of Technology for the company's CdTe activity where his R&D team produced a record module efficiency of 11%. He has extensive experience in silicon solar cell processing and crystal growth in which he has numerous publications. Dr. Cunningham graduated from Southampton University, UK with a Ph.D. in physical chemistry.

Dr. John Wohlgemuth earned a Ph.D. in solid-state physics from Rensselaer Polytechnic Institute and has been working at Solarex/BP Solar for more than 30 years. His PV experience includes cell processing and modelling, Si casting, module materials and reliability, PV performance and standards. Dr. Wohlgemuth is the convener of WG2, the module working group of TC-82, the IEC Technical Committee on PV.

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Trends and developments in the lamination process of PV modules (part 1)

Mark Osborne, News Editor, *Photovoltaics International*

ABSTRACT

The encapsulation of solar cells is one of the most enduring 'traditional' process steps in the fabrication of a photovoltaic module. The need to protect the delicate semiconductor active solar cell with protective material to ensure long-term operation remains a critical step in the module assembly process. However, continued development of the lamination process and materials used for encapsulation are required to meet increased demands of 25-year guaranteed module operation in the field, shorter cycle-times and lower production costs. In this two-part article, we look at the challenges these and other factors are having on the lamination process, the equipment required and the developments taking place to meet module manufacturers' requirements now and in the future.

Sticking with EVA

Since the early 1980s, the conventional ethyl vinyl acetate (EVA) material has become the workhorse of the PV industry with respect to providing the required electrical isolation as well as protection for the solar cell from the elements when the PV module is operating correctly in the field. Photovoltaic modules by design and function need to be exposed to sunlight as much as possible. Therefore the materials used to support and protect the modules must be of the right construction and operate consistently for many years.

The required characteristics of adhesion via an adhesive agent proven with EVA-based encapsulant has meant that the PV industry has been able to progressively offer longer-life warranties for modules, which now typically run for 25 years and whose lifetimes are expected to be extended further in the future.

Although other fabrication processes are regarded as more technically demanding, correct encapsulation of the solar cells considerably influences the life expectancy of a module. This has led to the situation whereby module manufacturers are extremely conservative with material choice and developments in the lamination process.

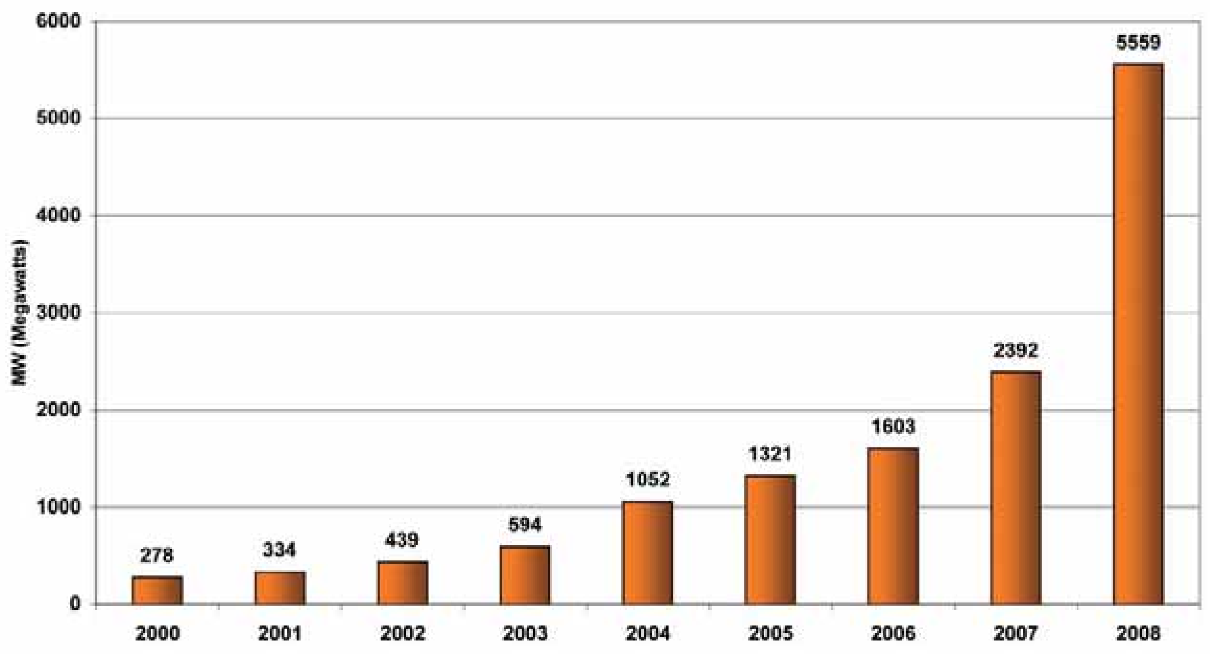
Market demands

The rapid growth in the photovoltaics market is clearly demonstrated in Fig. 1. Such growth has had the effect of creating material shortages for extended periods of time, most notably and well documented in respect to polysilicon. However, there have also been periods of supply constraint in regard to encapsulant materials.

Oil-based plastics such as EVA and PVB (poly vinyl butyral) require refining. As demand for oil increased significantly over the last decade due to the economic growth in China and other emerging economies, refining capacity has been under severe constraints and the price of oil-based materials has also been subject to major increases as a result.

When coupled to the rapid expansion of capacity in module production (see Fig. 2) and the expected capacity coming on-stream over the next few years, concern has increased over the PV industry's dependence on EVA-type materials and renewed efforts have been made to find long-term sustainable alternatives.

According to Karl-Heinz Brust, Technical Manager at Krempel Group, a noticeable shift has taken place since



Source: EPIA

Figure 1. Historical global growth of PV installations through 2008.

2008 towards actively seeking these alternative materials. Krempel Group is known in the industry for its 'AKASOL' family of polymer backsheet film materials engineered from combinations of PET, PEN, PC, PVF and PVDF.

"The key is maintaining the high-quality requirements well known with conventional materials when developing alternatives", noted Brust. "Collaboration with chemical suppliers, equipment suppliers, research institutes and module manufacturers is required. Typically a development time of three to four years is required."

Krempel's product offerings conform to IEC 61730-1 and IEC 60664-1. The laminates are UL-recognised components and are listed in the QIHE2 category (E 312 459) and are compatible with all encapsulation plastics of relevance, such as EVA, PVB and TPU.

However, Brust warns that laminates being classed as conforming to IEC specifications is not a guarantee that the material will support module life/performance expectations. In his opinion there is an increasing number of backsheet materials now entering the market that, while they are claimed to meet the supply and cost issues, they have not been active in the field long enough to have been fully evaluated.

"The question is what is the behaviour of different materials over 25 years in different climatic conditions?" asked Brust. "It is often not possible to physically see the quality differences in the material after module assembly; the problems only arise later. It is a problem in the industry that we do not have sufficient accelerated tests to qualify new materials... therefore it still takes experience working with these alternative materials to determine what works and what doesn't."

Not surprisingly, Brust went on to explain that at Krempel, considerable in-house testing is carried out to ensure the long-term reliability of the material over and above the false economy of significantly cheaper materials. Brust believes that a small cost saving may be achieved with the right material development while retaining the high quality required for such a demanding application. Unfortunately, any significant cost reduction strategy that dictates development can mean risky business for module manufacturers.

Interestingly, Brust feels that a return to supply-and-demand balance would not necessarily mean a reversion to traditional materials and brands on the part of module manufacturers. The competitive landscape has changed; Brust sees potential for greater diversification in the type of materials being used. They are being better developed and are more geared towards the product market and different end-user applications, while some materials are better suited to utility-scale markets than residential rooftop applications.

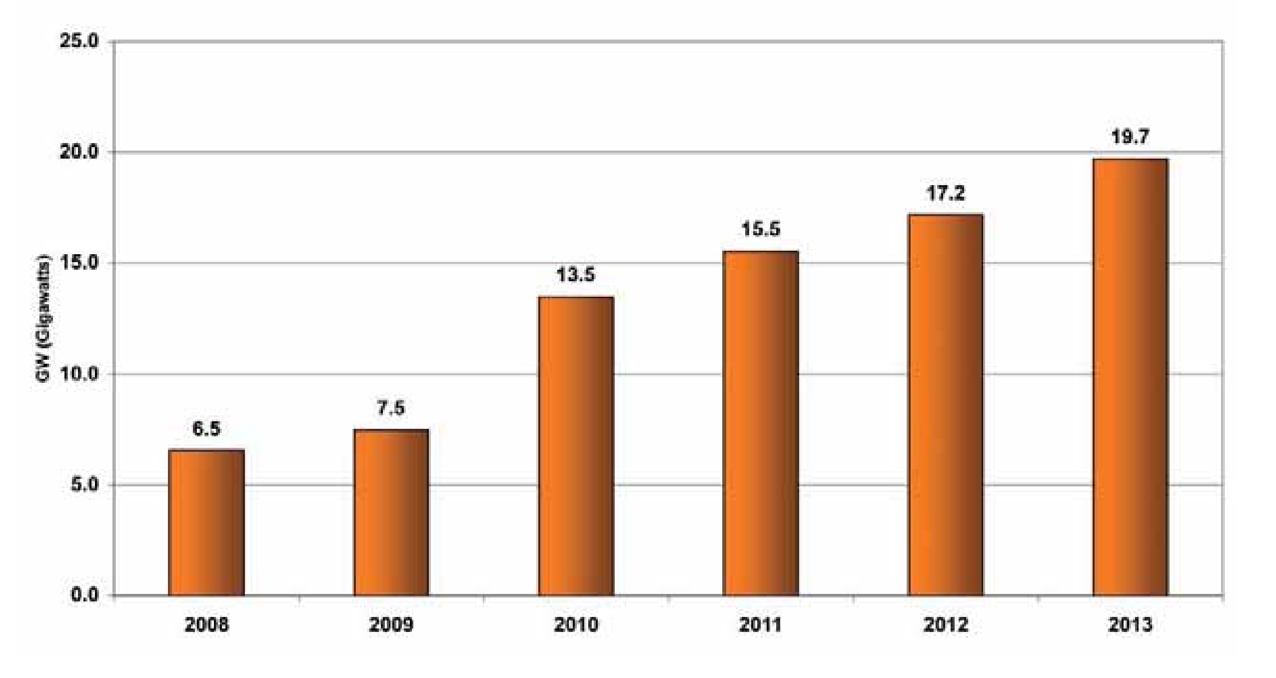
Although more research is required to establish which applications could use cheaper, lower-quality materials, this move could potentially prove a significant step in the right direction for a market that is considered conservative. Closer collaboration will be required with module manufacturers on all aspects of the specific applications for a given module, helping to bridge the gap between cost considerations and life-span requirements.

Materials developments are coming thick and fast from a host of suppliers, such as Coveme SpA's recent introduction of 'dyMat PYE', a new backsheet material. In co-operation with DuPont Teijin Films, Coveme has developed a high-grade PET inner layer with a lifetime claimed to be five times longer than that of traditional polyester.

Research has shown that improving the hydrolysis resistance of polyester is key to achieving better performance from backsheets. Due to water permeation of the outer layer, the inner PET layer suffers, losing its protective properties over time.

The dyMat PYE laminate is based on two layers of polyester film. The cell side is treated with a special thick primer that provides high bonding capability to EVA. Laminate thickness has been designed to provide the best combination of properties in terms of electrical insulation and weatherability.

Similarly, Wacker's recent introduction of 'Tectosil', a silicone-based, thermo-formable elastic polymer sheet claims low costs and ease of manufacture. The sheet's thermoplastic properties allow quick and inexpensive processing without curing or chemical reactions. The lamination process therefore benefits from a shorter



Source: iSuppli.

Figure 2. Global PV module production forecast (iSuppli).

production cycle and a high tolerance to local temperature differences within the laminator. Tectosil can be used to make any type of module and is suitable for either vacuum laminators or continuous processes.

Although far from providing an exhaustive review, these examples demonstrate the innovations taking place in the PV materials realm with the aim of enhancing module protection and the ease of fabrication.

Laminator market

According to VLSI Research, there are approximately 50 equipment suppliers that offer either dedicated lamination tools or laminators as part of a suite of systems for module assembly. This figure includes those that offer laminators as part of a turnkey production solution.

The laminator equipment market exceeded US$300 million in 2008, a CAGR of approximately 100% compared to 2007. In alphabetical order, the Top 5 suppliers (by US$ revenue) were 3S Swiss Solar Systems (Switzerland); Bürkle (Germany); Meier Solar (Germany); Nishimbo (Japan) and NPC (Japan).

Other lamination equipment suppliers include Spire Corporation, Komax, ecoprojecti, as well as P.Energy and 3S, discussed in the following section.

Lamination process

The ability to use EVA material in sheet form quickly led to the development of the 'roll-to-roll' lamination process, which rapid took over as the standard method of encapsulant processing.

Encapsulant processing typically involves a sheet of material being placed onto the glass, onto which the pre-sorted and connected solar cells are placed. Another layer of sheet encapsulant is then placed on top of this, followed by a final insulating film layer on the back of the solar panel. The completed laminate is then placed into a laminator machine, which is heated to an optimum temperature to melt the encapsulant material. A vacuum process is then applied to remove any air bubbles trapped during the heating process, resulting in a sealed solar cell array that is bonded to the glass surface.

The result is a mechanism whereby the electrical connections are suspended in an EVA matrix. While the glass provides the required durability, rigidity and surface transparency, the backside's protective backsheet provides physical protection, electrical insulation and a barrier to moisture ingress.

Laminator developments and requirements

With the exception of exotic encapsulants that are available on the market, there seem to be few material and laminator equipment suppliers that face any specific processing challenges other than achieving optimum process settings. Confidence in mainstream materials built up over many years of market involvement is most likely the reason for this optimism.

However, equipment suppliers must develop tools that are compatible with or capable of adapting to different lamination materials or to the extreme

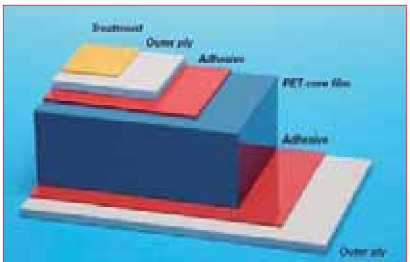


Figure 3. Krempel's 'AKASOL' polymer backsheet film design.

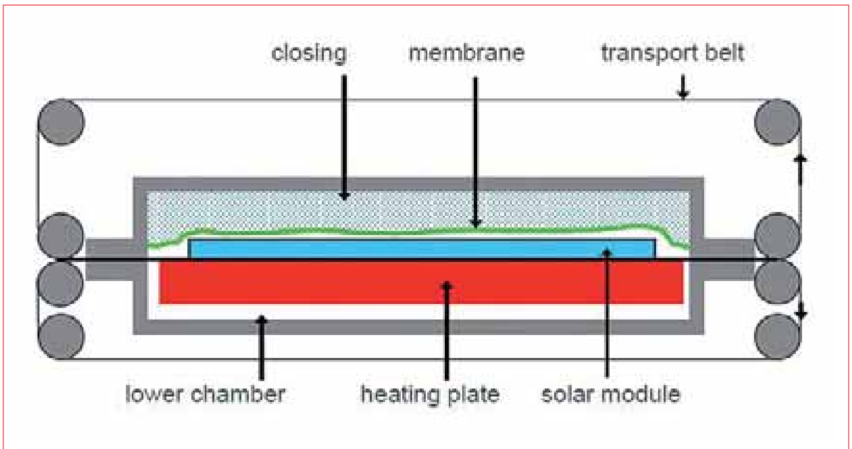


Figure 4. Schematic of roll-to-roll laminator (source: Kuraray Group).

heat procedures used in the lamination process. Electrical heating plates or oil-based tube heaters can be used for this application, while recent developments have seen hybrids of these two systems become available that are intended to further optimize the process. As a result, there has been a gradual trend towards improved process optimization and cycle-time reduction that has been at the heart of equipment-related developments.

Optimized process control dictates three key aspects of the tools' function: heating, curing and cooling. This process has been tightened to within a few degrees, and can be flexible in accommodating the varying specifications of the materials being used.

As with the trend to towards a greater degree of collaboration between material suppliers and module manufacturers, lamination equipment suppliers are having to better meet the needs of the customers.

Italy-based P.Energy has made a successful business of catering for the emerging Italian module manufacturing market. This comes on the back of favourable feed-in tariffs and the Italian government's attempts to promote domestic manufacturing to meet demand for solar installations.

Since December 2008, P.Energy has supplied four automated production lines to module manufacturers in Italy, and one to Portugal. The 10MW automated line shipped in December last year was for Torri Solare Srl, located in Brescia, Italy. In January 2009, GOOSUN of Porto, Portugal received another 10MW automated line, the first automated line in the country, said a spokesperson.

More recently, P.Energy delivered a 20MW automated production line to V-Energy srl in Biella, Italy in April 2008, while the company has customers such as Solar Semiconductor as far afield as India.

On contacting Gabriele Pettenuzzo, President of P.Energy, the equipment supplier executive was quick to reiterate the need to meet evolving customer demand. A key attribute currently requested from his customers was temperature uniformity in the heat plate, citing a need for a temperature range within ± 2°C.

To enable this level of temperature uniformity, Pettenuzzo noted that: "In our laminator we have from eight to 20 PID temperature control points – the number depends on the work area of the laminator in question. Besides, we design special heaters for different heating performance from the head to the tail of the electric heater, and with the power increase in this way we can warrant ± 2°C across the plate."

Pettenuzzo sees this as a key differentiator with his company's laminators. He also noted that special care and different curing cycle-times were often needed with thinner or different backsheet materials.

Conventional heating elements create a wide range of temperature differences and hot spots that result in inconsistent sealing. High-volume applications require greater levels of temperature homogeneity with maximum temperature difference on the heating plate of 2°C absolute.

3S Swiss Solar Systems is another major equipment supplier that has focused considerable attention on the need to precisely control temperature homogeneity with maximum temperature difference on the heating plate of 2°C absolute. The patented 'Hybrid Heating Plate' is claimed to combine the advantages of both electrical and oil heating techniques that generates higher temperature homogeneity, boosting yields and throughput.

The heating system has 40 electrical rod elements of 2kW each. Heat carrier oil transmits the heat from the rod elements to the heating plate at high speed allowing for very short heating times. After lamination, the cooling press permits controlled cooling of the module. 3S claims that the technology shortens the time between lamination and post processing, as well as reducing interior stress in the module.

Alessio Maiocchi, Product Manager at 3S for its laminator line, commented that as the lamination process determines the lifetime of the module, it is imperative that a complete understanding of the process is assured.

"The lamination process is more than cooking a cake in an oven", commented Maiocchi. "A deep understanding of what happens during lamination is necessary to optimize cost and quality for long-life solar modules in order to reach grid parity."

Maiocchi described the company's MLS (membrane lifetime extension strategy) as testament to work done to observe the lamination process and obtain a deep understanding of the dynamics at play. "How

Figure 5. P.Energy's L900A is a fully automatic photovoltaic module laminator.

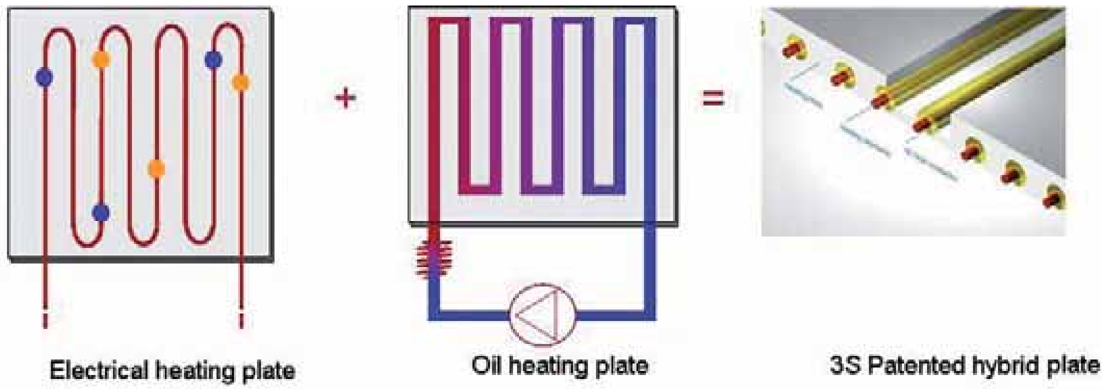


Figure 6. 3S Swiss Solar Systems' 'Hybrid Heating Plate' design.

we handle the material membrane inside the laminator during processing is critical to a long-term operation of the module. A key aspect is not to put mechanical stress on the membrane as this ultimately reduces the module lifetime", he said.

The company use an inbuilt camera and specially developed vision system to observe the lamination process. According to Maiocchi, the membrane lifetime can be drastically extended while achieving a TCO reduction of 25% over a five-year period.

"For recipe optimization we work with design of experiments. Our recipes are based on experiments, thus on statistical values", noted Maiocchi. "The benefit for our customers from this is the optimization of their lamination process and the quality of the modules. This results in lower process costs and thus a real competitive advantage".

Time and again in speaking with Maiocchi, the issue of direct customer collaboration and the company's in-depth understanding of not only the lamination process but the full module assembly process came through as key aspects that were required to provide the performance that customers require today.

Conclusion

Although much of the emphasis in the topics covered within this article have focused on the material quality issues and attention to detail on process control, high-volume manufacturing requires a concerted effort to constantly improve productivity of the lamination process and in turn the productivity of the total module manufacturing line.

Such is the competitive landscape that greater attention to these factors is becoming a key differentiator for both equipment suppliers and module manufacturers. In the next edition of *Photovoltaics International*, the second part of this article will look closely at developments undertaken to improve cycle-times of the lamination process and overall productivity improvements.

Power Generation

Never mind the recession, never mind the pressure to reduce carbon emissions


Source: YouTube

HARDtalk interview with Eni's Paolo Scaroni.

Italian oil and gas giant Eni has announced that the only viable energy source for the future is solar, admitting hydrocarbon defeat and having complete disregard for any other type of renewable.

Speaking in an interview on the BBC's HARDtalk program Eni's CEO, Paolo Scaroni said the company looked ahead to a future where fossil fuel is not driving transportation, yet Eni is still pushing to increase oil reserves and oil production.

Further grilling on this aspect revealed that the company is investing €120 million in the research and development (R&D) of solar power over a period of four years (2008-2011). Scaroni said that, "the alternative energy which we can produce today [is] not the solution" and that the "solar technology we have today is a kind of obsolete technology dated back 70 to 80 years...[it] is not the technology we are looking for".

HARDtalk hit back at Eni's solar proposals saying that the €120 million is not a sizeable enough investment to prove true commitment to renewable energy sources, comparing the company to rival BP, which has invested US$1 billion in renewable energy sources in 2009 alone. Interviewer Stephen Sackur, pointed out that Eni's investment in renewable energy looks pretty poor when the fact that the company's €1.76 billion profit for the first quarter of 2009 is considered.

The HARDtalk interview highlights that Eni has put all of its renewable eggs into one basket and seems to be sitting back in the hope that a more profit-mounting technology will emerge. Until then, the oil company seems set on continuing to strongly invest in the oil market.

European Region News Focus

PV inverter efficiency record set by Fraunhofer ISE

A new world record of 99.03% for the efficiency of inverters used in photovoltaic systems has been set by the Fraunhofer Institute for Solar Energy Systems ISE. Key to the new record was using junction field-effect transistors (JFETs) made of silicon carbide (SiC) manufactured by SemiSouth Laboratories as well as improving the circuit technology used in the device.

The world record was measured for a complete PV inverter, according to Fraunhofer, including its internal power supply, a digital signal processor (DSP) for controls, an LCL grid filter and a relay for grid connection.

Fraunhofer ISE expects the components to be transferred to production inverters in the future as other benefits were seen with lower thermal losses, smaller cooling devices being used, and a more compact construction. Field tests are planned to demonstrate viability in practice. SiC transistors perform better than conventional IGBTs of silicon as well as offer significant performance advantage in higher reverse voltage applications.

According to Fraunhofer, a 30kW inverter system, with an efficiency value of 1% higher than normal systems, results in an additional yield over 10 years of 3000kWh or €1300.

Opel, Betasol complete first phase of HCPV solar power plant in Spain

High-concentration photovoltaics developer Opel International and its Spanish partner, Betasol, have finished the first phase of a planned four-phase, 440kW utility-grade solar power plant in Tarragona, Spain. This initial 110KW phase is one of the first HCPV installations supplying commercial electricity to the power grid and is already generating revenue for Betasol, the partners said.

The installation features dual-axis tracker-mounted Opel Mk-I HCPV panels, which can focus more than 500 suns onto high-efficiency multijunction GaAs solar cells. The companies expect the remainder of the system to be completed during the third quarter.

"This installation has attracted great interest of potential customers in both Europe and Africa," said Robert Pico, CEO of Opel.


Q-Cells plant.

Q-Cells International to construct 50MWp solar park in Bavaria

Q-Cells SE and MEMC Electronic Materials have revealed the formation of a joint venture to construct extremely large solar parks, in which each partner will have a 50% share. The first shared project will be a facility in Strasskirchen, Bavaria.

Q-Cells International has been commissioned to construct the first facility, which will have a total capacity of around 50MWp, making it the largest ground-mounted PV system in Germany to be operated using crystalline solar cell technology.

The project will use approximately 225,000 modules, installed on a surface area of around 135 hectares. The amount of electricity produced by this plant corresponds to the power consumption of 15,000 households, thereby eliminating around 35,000 tons of CO_2 each year.

Ken Hannah, MEMC's SVP/CFO, has said that under the terms of the agreement, MEMC will invest up to US$100 million of capital in the joint venture during the third and fourth quarters of this year. Q-Cells is expected to invest around US$100m so that the two partners can cover the bridging finance during the construction phase.

When completed, this facility is to be sold to a third party. The facility is expected to be complete and connected to the public electricity network at the end of 2009.

Large-scale BIPV system commissioned in France

With attractive feed-in tariffs for BIPV systems in France, a 205 kilowatt, module system has been commissioned at a chicken farm in Bretagne, France.

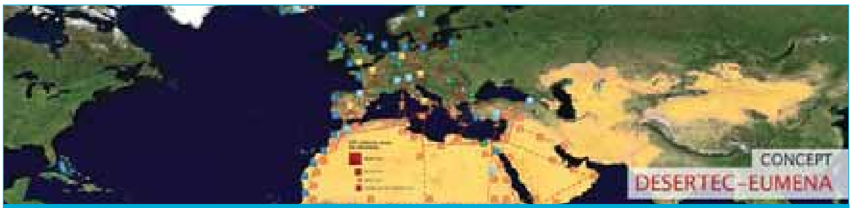
French system supplier Solar Diffusion undertook the project.

The tariff currently paid for power fed into the grid is €0.60 for every kilowatt-hour. The system uses Sputnik S-series control converters.


Solar Diffusion plant in Bretagne.

Abengoa Solar joins the multi-national DESERTEC project

Abengoa Solar has joined the list of founders for the Desertec Initiative, a project that includes among its members the Club of Rome, the Union of the Mediterranean, TREC, and other



Abengoa map of DESERTEC project.

institutions. Industry founders also include the industrial conglomerate Siemens AG, power companies RWE and E.ON, re-insurer Munich Re AG, Deutsche Bank AG, the electrical engineering firm ABB, Cevital, HSH Nordbank, M+W Zander, Schott Solar, and Solar Millennium/MSM.

Abengoa solar already has an established presence in Northern Africa with solar plants in Algeria and Morocco. Santiago Seage, Abengoa's CEO, remarked that "Northern Africa and the Middle East are undoubtedly areas with a tremendous solar energy potential, for both the region's own use as well as exporting as soon as we have the necessary infrastructure and regulatory measures in place."

The plan of this project is to harvest the solar energy from the deserts of Northern Africa and other regions in the 'sun belt' to be distributed in locally and throughout Europe. Solar thermal power plants would make up the majority of the energy-harvesting techniques. Such plants are already running in the U.S., Spain and elsewhere.

Desertec would like to see 15% of European energy come from this region and have the Middle East and Northern Africa energy independent and efficient by 2050. Because the infrastructure and technology needed to support this wide-ranging initiative, Desertec's first benchmark is to garner support for what will be a multi-decade project.

Green Energy Technology announces US$16m thin-film plant plans

Green Energy Technology will be investing US$16m in a solar farm to be built in Spain as part of its efforts to gain a better footing in the European market. The project will integrate Green Energy's thin-film photovoltaic modules into Europe and build its experience in the PV power generation segment.

Green Energy did not reveal the name of its Spanish partner in the solar farm, nor provide the location or further details of the project. The company reported pre-tax losses of US$2.8m for the first six months of the year and it said that it will finance the investment through bank loans and the issue of global depository receipts.

aleo solar expands into northern Germany

aleo solar AG has announced that it is expanding a greenfield photovoltaic power plant in Südergellersen in the district of Lüneburg, Germany. The turnkey expansion project will boost the output of the existing solar farm from 530 to 1040kW.

The aleo 5,850 S_16 solar modules will save about 570 tons of CO_2 each year. Norbert Schlesiger, of aleo solar AG said, "The high output of our solar modules means that greenfield solar farms can be profitable even in northern Germany."

Schlesiger's mention of profitability in north Germany points towards the fact that this area has not yet been a key area of growth. Projects such as this will produce a more important market for Germany, leaving room for future expansion.

The construction of this plant will begin in the third quarter of 2009, with solar modules expected t be connected to the grid by the end of the year.

Asia Region News Focus

Suntech signs up for multi-GW projects in China

Suntech Power has signed several definitive agreements for the development of 1.8GW of solar power plants. The plan is to develop 300MW, 500MW, 500MW and 500MW of solar projects in several locations throughout China in several stages.

The agreements have been finalised with each of Shaanxi provincial government (300MW); Shizuishan city government, Ningxia province (500MW); Qinghai provincial government (500MW), and Panzhihua city government, Sichuan province (500MW).

While these projects are subject to passing certain conditions, including obtaining related permits from the National Development and Reform

Commission, drafting project designs and ensuring sufficient funding has been garnered, it is expected that the first of the projects will be commissioned before long.

Suntech and Sydney Theatre Company using Pluto power to 'Green the Wharf'

Suntech Power, a large crystalline silicon PV module manufacturer, is collaborating with Sydney Theatre Company (STC) to install a solar power system using Pluto technology at a capacity of 500kW. Upon completion in 2010, it will be one of the largest rooftop installations in Australia and will reduce STC's power grid draw by 70%.

It is estimated that over 25 years the project will generate 10,350MWh of solar power.

U.S. Region News Focus

SolarCity makes leasing program available to customers of L.A. Department of Water and Power

SolarCity's SolarLease program has been made available to customers of the largest municipal utility in the U.S., the Los Angeles Department of Water and Power (LADWP). The solar leasing option is a 20-year lease with fixed monthly payments for the life of the lease, so savings increase over time if electricity rates rise.

A SolarCity solar lease of a 4kW PV system, appropriate for a typical three-bedroom home in Los Angeles, would start at US$55 per month, with no money down, on approved credit, the company said. The consumer can also benefit from LADWP's own solar rebates, which are said to be among the most generous offered by U.S. utility companies.

The first month's payment for a SolarLease is due when the system is turned on. The lease option includes financing, design, installation, a performance guarantee, the company's Web-based SolarGuard monitoring service, and repair service.

SolarCity module testing.

Four companies place bids for 150-200MW plant in Phoenix, Arizona

Four companies, BrightSource Energy, Johnson Controls, Tessera Solar, and a team of US Energy Partners plus Munich Energy Partners America have proposals to build the first utility-scale solar project in Phoenix, Arizona. The city has called for proposals to build a 150-200MW solar power station situated on a closed landfill.

The project can be developed on about 1,200 acres as part of Mayor Phil Gordon's effort to make Phoenix 'greener.' Each bidder specialises in a different solar technology; the result should be decided in 3Q09.

GreenWing Energy signs agreement with SolFocus for utility scale deployments of CPV

GreenWing Energy Management and SolFocus have announced an agreement for SolFocus to supply high concentration photovoltaic (CPV) systems for GreenWing's large-scale solar power projects in the western United States.

SolFocus CPV systems modules.

This agreement allows for the expansion of GreenWing's business into the solar energy sector; the company intends to install the SolFocus CPV systems in both new utility-scale projects of 20-300MW and larger distributed generation applications of up to 1-20MW.

The SolFocus 1100S system uses approximately 1/1000th of the active, expensive solar cell material compared to traditional PV panels. These cells, for use in CPV systems, have a reported double efficiency level compared to traditional silicon PV cells. In solar-rich regions, the SolFocus CPV technology allows for efficiency rates that help solar power costs approach equivalence with fossil fuel generation.

The SolFocus CPV design is being peddled as far better for the environment in comparison to other solar power generation technologies as it has very low water usage, emissions free electricity, no noise from sites, no permanent shadowing or wildlife corridor interruptions, and no disruptive solar glare.

Financial details of the agreement, location of the projects, and timing of the developments were not disclosed.

SkyFuel installs SkyTrough collectors at Sunray's 43MW plant

SkyFuel has signed an agreement with Sunray Energy, which is a fully owned subsidiary of Cogentrix Energy, for the installation of SkyTrough collectors.

SkyFuel SkyTrough.

The SkyTrough collectors will be installed at Sunray's 43MW parabolic trough generating plant in California; this plant was formerly known as Solar Energy Generation Systems I and II (SEGS I & II).

This agreement allows for the first commercial installation of SkyTrough, which will allow the system to be demonstrated as an upcoming instrumental aspect of full-scale solar generation.

SkyTrough is an advanced parabolic trough concentrator, which uses glass-free ReflecTech Mirror Film reflectors, offering a dramatic departure from the prior state-of-the-art for parabolic trough concentrating collectors. This is due to the fact that ReflecTech Film does not shatter and will not cause expensive and time-consuming damage to receiver tubes.

Although business terms are yet to be disclosed, construction of the SkyTrough installation at Sunray's plant will begin in the current quarter with completion and commercial electricity production scheduled for the end of 2009.

BP Solar to install, operate 2.42MW PV rooftop system on FedEx hub in New Jersey

FedEx Ground, the small-package shipping unit of FedEx, plans to have installed what it calls the largest rooftop solar-electric system in the United States at its distribution hub in Woodbridge, NJ. The project is the third between a FedEx operating company and BP Solar and the fifth solar power project for FedEx. The 2.42MW photovoltaic power system will employ about 12,400 BP panels across approximately 3.3 acres of rooftop space.

BP will begin installing the system in August and expects to finish the job by October. When completed, BP will operate the system and FedEx will buy the power generated, which will be as much as 2.6 million kW/hr of electricity annually and up to 30% of the hub's yearly energy needs.

Last year, FedEx Freight installed two solar power plants in Southern California, a 282KW array in Whittier and a 269KW system in Fontana. In 2005, FedEx Express activated a 904KW system at its Oakland, CA, hub – the first of its kind in the FedEx family. The Oakland system meets up to 80% of that facility's peak energy demand, the company says.

FedEx is building its Central and Eastern European gateway at the Cologne/Bonn, Germany, airport, which is slated for completion in 2010 and will include a 1.4MW PV power system.

Once all the PV power systems are activated, FedEx will have more than 5.25MW of solar installed at the five sites.

eSolar commissions 5MW solar thermal power tower in Southern California

eSolar has commissioned a 5MW concentrating solar thermal power plant in the Antelope Valley in eastern Los Angeles County. The 24,000-mirror Sierra SunTower, which the company says is the only power tower of its kind currently operating in the U.S., produces electricity for Southern California Edison and can power more than 4000 homes in the area.

Constructed in less than a year, the CST power plant marks the first of several developments in the Antelope Valley region using eSolar technology. This project created 300 jobs over the course of its construction.

eSolar develops its California projects on parcels of previously disturbed private lands. The company says that by using this approach, it avoids many of the permitting and environmental pitfalls of development on pristine desert lands.

Located in northern Lancaster, Sierra SunTower is built on private land designated for heavy industrial use. The decision to site projects solely on private land is unique within the utility-scale solar industry, and the distinction has garnered support from local environmental advocates.

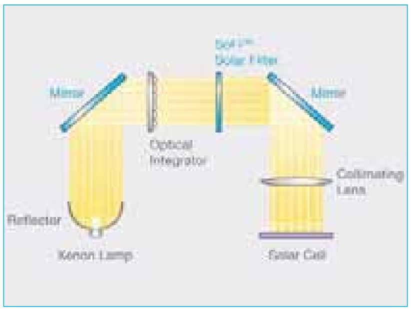
In February, eSolar announced an agreement with NRG Energy to develop three plants in California and New Mexico that will generate up to 465MW of electricity using the Sierra SunTower technology. Additionally, in March, eSolar licensed its technology to India-based ACME Group for approximately 1GW of eSolar solar thermal capacity.

5MW commercial power plant in Southern California

News

Product Briefings

Optics Balzers



Optics Balzers 'SoFi' solar filters offer correct spectral characteristics

Product Briefing Outline: Optics Balzers has developed interference filters satisfying customer-specific requirements. The 'SoFi Solar Filters' offer the correct spectral characteristics, long-term stability and accurate reproducibility even when manufactured in large volumes.

Problem: An increasing number of interference filters are being applied for quality checking and further development of solar cells. The solar cells are tested by means of sun simulators. With the aid of the new interference filters developed by Optics Balzers, the illumination spectrum of a lamp is converted so that it becomes equivalent to the solar spectrum. The nature of this spectrum is defined in a standard (IEC 60904-9) and divided into different quality classes.

Solution: According to this standard, the SoFi Solar Filters achieve not only the highest quality grade (Class A), but also produce spectra with much narrower specifications. For special sun simulator applications not covered by the standard, Optics Balzers is in a position to design and manufacture innovative filters meeting entirely different customer-specific spectral characteristic requirements. In order to split sunlight into different spectral regions, the interference filters can also be used as optically stable beam splitters which are resistant to environmental influences. Such beam splitters are applied, for example, in concentrator cells (concentrating photovoltaics), which split sun radiation and direct it to different solar cell types with optimal efficiency.

Applications: Sun simulators, concentrator cells.

Platform: The optical filter coatings manufactured by sophisticated sputter coating ensure a consistently high quality even when volume-produced and are characterized by their spectral and environmental stability.

Availability: Currently available.

Satcon

Satcon offers 1MW 'Prism' fully integrated power conversion solution

Product Briefing Outline: Satcon's 'Prism' is a fully integrated 1MW medium voltage solution optimized for utility-scale solar PV installations.

Problem: Utility-scale projects are becoming more prevalent and customers are asking for a highly efficient, completely integrated package for large-scale installations.

Solution: Prism is a fully customizable 1MW platform, complete with factory integrated step-up transformers, switchgear and electronics. The solution will be delivered complete in an all-climate outdoor enclosure and ready to connect to the PV array and utility grid, enabling rapid installation through a modular prepackaged design. Prism is claimed to dramatically increase the ease and speed of a typical utility scale PV installation, while also providing the unparalleled power production efficiencies that can only be realized through this full factory integrated and tested power conversion platform. The complete solution will come with Satcon's standard five-year warranty included, and optional warranty terms up to 20 years available. Integrated transformers and switchgear are fully customizable, and Satcon system consultants are available to assist with project requirements and configurations.

Applications: Large-scale PV utility plants.

Platform: Satcon's Prism 1MW integrated medium voltage solution is based on factory-integrated pairs of Satcon's highly efficient PowerGate Plus 500kW solar PV inverters.

Availability: Currently available.

Groupo Clavijo

Solar tracker with azimuthal brake system from Groupo Clavijo tackles high winds

Product Briefing Outline: Groupo Clavijo has developed an advanced double-axis solar tracker specifically for the US market using a patented hydraulic brake system in the azimuth movement. Miller Welding will manufacture and commercialize this system in the United States under a partnership agreement with Clavijo.

Problem: Solar tracker systems are required to work in varied environments including high wind to provide the overall system performance of the solar modules. Brakes are required to withstand high winds but can cause damage to the mobile elements of the tracker, reducing life span and increasing energy costs.

Solution: The brake works as a clip on the orientation crown and the pinion of the gear motor and eliminates dynamic loads that the force of the wind multiplies, which is a critical aspect in other trackers on the market. The gear motor includes an electrical brake that helps the hydraulic brake in strong winds and absorbs the effect of the wind on the mobile elements of the tracker. Both brakes are placed on opposite sides of the crown, and this spreads out the load and makes the tracker very stable.

Applications: Winds stronger than 160km/h.

Platform: The post is the support element and also the place where the electrical elements, the motor and the hydraulic centre are installed and fixed and locked inside. This part covers and protects all the control elements, thus increasing the safety of the tracker and reducing any possibilities of theft. Bronze bushings in all the articulations and integrated safety systems, such as a hydraulic brake, limit switches for the azimuth movement, and physical limits for the cenital-vertical movement. The reinforced crown is specially designed for Clavijo's tracker and is the support for the azimuth turn. Each of the trackers has an independent programme that controls and manages the possible incidents with alarms, which could be managed directly on the tracker thanks to a manual panel, integrated into internal monitoring, or put on the internet.

Availability: Currently available.

Product Briefings

System Photonics

System Photonics BIPV modules designed for ventilated façades

Product Briefing Outline: System Photonics has introduced a commercial-scale BIPV 'ROOF' collection system that is designed for ventilated façades. The product line uses ceramic materials combined with next-generation crystalline silicon photovoltaic cells to allow for flexibility in design without compromising functionality. These BIPV modules also take advantage of Dupont PV5300 Series encapsulant sheets made of clear, tough ionomer.

Problem: Achieving the balance between aesthetics and functionality or durability can pose problems in BIPV applications.

Solution: System Photonics designed its ROOF Collection tiles with open, frameless edges for architectural elegance and simplicity. Compared with other encapsulants, the stiffer DuPont PV5300 ionomer sheet makes modules more impact-resistant and durable in weather-exposed open edges. Tiles come in various colours and their passive elements are made in the same size and with the same ceramic material as the crystalline silicon module.

Applications: BIPV façades.

Platform: The system uses a thin 3mm ceramic backsheet and an interlayer five times harder and 100 times more resistant than those normally used (EVA, PVB).

Availability: Currently available.

Sputnik Engineering AG

Sputnik's SolarMax 330C-SV designed for MW installations

Product Briefing Outline: The Swiss manufacturer of solar inverters, Sputnik Engineering AG, is launching a new central inverter called SolarMax 330C-SV (SV stands for special voltage) with a rated capacity of 330kW that works in the MPP (maximum power point range) between 450 and 800V. As many as three SolarMax 330C-SVs can be combined in one megawatt station which can then be directly fed into a medium-voltage grid. The standard warranty can be extended to recognize and fix plant failures for 20 years.

Problem: Reduced costs and improved efficiency of all products are required for an integrated PV power system to reach grid parity and below. Inverters are being targeted to reduce BOS and efficiency improvements. Focus on transformers is required to meet industry goals.

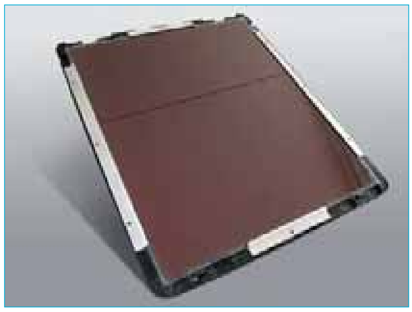
Solution: In the new central inverter, SolarMax 330C-SV Sputnik has eliminated the transformer, reducing the device's size and weight by more than half and its costs by 15%. The slimmed-down the SolarMax 330C-SV weighs in at 1200kg. Another advantage of the transformerless technology is its 98% efficiency levels. This technology has proven itself in all of the Swiss manufacturer's string inverters and in the new SolarMax S series of central inverters.

Applications: Large-scale utility PV power plants.

Platform: Like all other SolarMax inverters, the new device is TÜV type-tested. In addition, SolarMax 330C-SV meets the requirements contained in the BDEW (Federal Association of German Energy and Water Industries) medium voltage technical guideline ('Generating Plants Connected to the Medium-Voltage Network'), which has been in force in Germany since January 2009.

Availability: October 2009 onwards.

Renusol GmbH



Renusol GmbH develops new thin-film module mounting systems

Product Briefing Outline: Renusol GmbH has introduced three new mounting systems – ConSole DS, VarioSole DS and InterSole XL – for thin-film solar modules using a new injection-compression technology. They are designed for thin-film modules and solar plants for industrial roofs. Europe-wide patents have already been filed for all new systems.

Problem: The growth in thin-film modules/laminate production requires new mounting techniques that incorporate low-cost solutions while providing fast and safe fitting. Conventional c-Si module mounting systems are not designed specifically for thin-film applications.

Solution: ConSole DS has been designed for modern flat-roof mounting systems for thin-film modules/laminates measuring 1.1m x 1.3m and has been developed in close partnership with ersol Thin Film GmbH. InterSole XL lends itself particularly for use on agricultural and commercial buildings as such buildings are often roofed in profiled corrugated sheets or trapezoidal profiles and purling spacings of up to 1.5m. VarioSole DS makes frameless glass/glass laminates (1.1m x 1.3m) easier to fit on pitched roofs. First, integral anti-slip protection and spacers ensure that the laminates can be laid safely on the substructure during installation. Second, the laminates are anchored in linear fashion and secured with clamping bars. These clamping bars can also be matched to the structural requirements of the laminates made from various combinations of glass if required. Third, the height-adjustable, highly loadable roof hooks mean the number of mounting points can be matched to the roof's substructure.

Applications: Thin-film modules/laminates for industrial rooftops.

Platform: Various industrial roof applications.

Availability: Currently available.

Service & service architecture – yield monitoring, optimization and reporting for commercial-scale solar utility installations

Steve Voss, **Dr. Tassos Golnas**, **Steve Hester** & **Mark Culpepper**, Sun Edison LLC, Beltsville, Maryland, USA

ABSTRACT

Over the past five years the primary metric for the PV industry has evolved from watts to kilowatt-hours. This transition has emphasized the importance of PV asset monitoring, operation and maintenance. The need to maximize system economics, by increasing uptime and decreasing service costs, requires a complex set of high quality data to drive decision making and continuous improvement efforts and is driving a rapid maturation of the PV industry, as discussed in this paper.

Introduction

Incentive structures based on kWh production, such as feed-in-tariffs, performance-based incentives and renewable energy credits, have become the norm in the PV industry. Additionally, many companies are now applying the structures and principles of project finance to PV projects. The purpose of project finance is to create a business structure which brings together multiple entities, aligns their interests, and allocates the project's inputs and outputs (i.e. risks and rewards) in such a way that the overall benefits derived from the project are maximized.

In the simplest possible scenario, this has meant a transition from a simple cash transaction between integrator and host to a more complex transaction involving a third-party financing partner. Historically, under the cash sale model, photovoltaic systems were built by integrators who purchased equipment through distributors and maintained minimal responsibility for the long-term operation of the systems. This created a disconnected supply chain with little or no accountability for the ultimate operation and productivity of the system beyond the initial transaction. Even today, it is difficult for many OEM suppliers to account for the ultimate destination and performance of their products. This disconnect has been made possible in part by the inherent reliability of photovoltaic systems which operate without moving parts. However, no system is failsafe and as a result many assets underperformed or were inadequately monitored to ensure proper operation. This mode of operation is unsustainable since it ignores the ultimate purpose of a photovoltaic system: the reliable delivery of power (capacity) and energy.

The introduction of power purchase agreements (PPAs) to the solar industry goes a long way towards rectifying this disconnect, enabling the host to avoid the high capital investment and only pay for kilowatt-hours delivered or peak energy savings. However, to focus on the PPA exclusively is to oversimplify the symbiotic relationships created through project finance. When properly applied to the photovoltaics industry, project finance will align the interests of all parties involved in the finance, construction and operation of a power plant, including host, integrator, project investor, utility, subsidizing agency and OEM provider alike. This is accomplished by creating a project entity whose economic engine is driven by the value creation of the asset throughout its operational life. This entity is the Solar Energy Services Provider (SESP).

Initially, the SESP is responsible for managing the complex contractual relationships required. Project finance is built on a series of contracts which define the roles, responsibilities and obligations of the various parties involved. With regards to power production, project finance typically involves four primary contracts: 1) a construction and equipment contract; 2) a long-term fuel contract; 3) a long-term power purchase agreement; and 4) an operating and maintenance contract [1]. For solar projects the fuel contract is obviously eliminated; however, it is frequently replaced by a contract for the environmental attributes of the system, which under some incentive structures can represent a significant portion of project revenues.

This deal structure has most frequently been applied to extremely large projects which can justify relatively high transactional costs. PV projects – particularly on the commercial scale – are small in comparison. The successful SESP must therefore focus on efficiency, strong relationships, repeatability and risk mitigation.

From an operational perspective, this requires a complete auditable trail

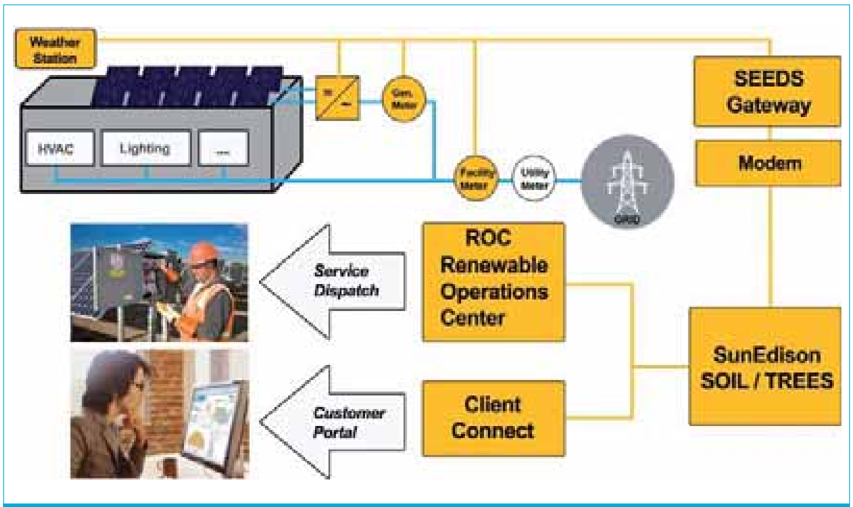


Figure 1. ECO infrastructure example for a net-metered rooftop system.

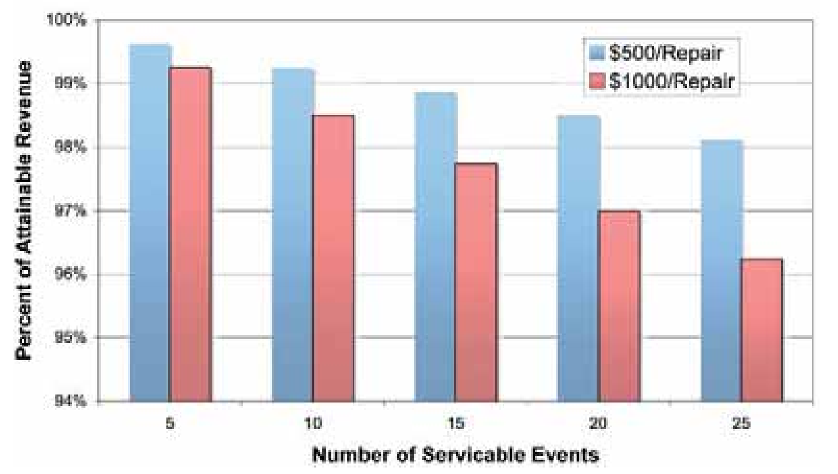


Figure 2. Example of possible impact of O&M expenditure on a 1MW portfolio of PV assets with a fixed uptime of 98.5%. The make-up of the outages – in terms of frequency and average cost to repair – has a significant impact on realized cash from operations.

of system components, generation data and system performance metrics which provide accountability and transparency to project performance and value delivered to the various stakeholders. In other words, in order for this business model to be sustainable, all parties must be able to validate that all covenants, contracts and commitments are being honoured.

The ECO architecture

ECO (Energy Costs Optimization) is the services architecture developed by SunEdison for monitoring and operating a portfolio of solar PV power plants. ECO increases solar savings for host customers and reduces investment risks for financiers by providing information necessary for effective decision making. ECO includes the following components:

- **SEEDS** (SunEdison Energy & Environmental Data System) – the equipment and software platform for remote monitoring and control of solar PV power plants.
- **SOIL** (Site Objects & Information Ledger) – the asset management system, data repository, and analytics engine for site and monitoring information, storing data in 1-min or 15-min intervals, and providing a comprehensive listing of site components.
- **TREES** (Tariff and Rate Engine for Energy Systems) – the billing and monetization engine that enables the company to automate energy billing and to calculate customers' energy costs and savings.
- **ROC** (Renewable Operations Center) – the facility where company staff monitor power plants, detect and diagnose issues, process service tickets and dispatch service crews.
- **Client Connect** – the online monitoring portal that the company's customers use to access solar energy production, environmental attributes, energy costs, and SunEdison bills.

All the components of the ECO architecture are necessary to efficiently operate and service a portfolio of photovoltaic power plants. By combining information on operation and economics, disseminating the information and enabling efficient response to the information, this toolset serves two fundamental needs. The first is the transparency and accountability required to operate effectively under the project finance model, while the second is the provision of actionable information required to maximize the economic value of the assets monitored.

From the standpoint of the PV power plant, energy yield (or kilowatt hours produced) is the key metric driving economic value. The ability to rapidly detect, respond to and restore underperforming systems is essential to maximizing that energy yield. However, over time, it is also important to minimize the cost of achieving high uptimes, especially when dealing with a portfolio of distributed assets where the fixed costs of a 'truck roll' or service deployment are relatively high. The calculus used to evaluate system uptime must include: the economic value of the energy (opportunity cost), the cost to repair the system and the frequency and duration of outages.

Consider a 1MW portfolio of PV assets deployed in Southern California. Assuming a performance-based incentive of US$0.34/kWh, a PPA rate of US$0.11/kWh, maximum production of 1500kWh/kW and an uptime of 98.5%, this portfolio would produce cash flows of US$675,000 per year. Taking the definition of uptime as set out in Equation 1 in the following section, a 1% decrease in uptime translates directly to a 1% reduction in cash from operations. However, the cost to achieve that uptime is determined by the number of outage events and the average cost to repair. Fig. 2 illustrates the impact on total cash flows from the portfolio when the number of outages ranges from five to 25 events and the average cost to repair ranges from US$500-1000 per event. If the events are too frequent and/or too costly to repair, then the advantages of high uptime are soon lost.

At the risk of stating the obvious, the Solar Energy Services Provider must strive to maximize uptime by minimizing the duration and frequency of outage events, while simultaneously minimizing the average cost to repair systems. This can only be accomplished by a thorough understanding of the failure modes and mechanisms. ECO has enabled SunEdison to undertake a rigorous, data-driven approach to identifying, eliminating and reducing the cost impact of system outages and maximizing the financial return of our portfolio of systems.

In the future, as power (as opposed to energy) becomes an increasingly important part of the value equation, availability or firmness will become increasingly important as well. This in turn will reinforce the necessity of maintaining the full suite of tools provided by the ECO architecture.

The effort to eliminate and/or reduce the cost impact of various outage causes is an iterative process that requires defining, measuring, analyzing and controlling key parameters. It is a long-term endeavour aimed at continuous improvement and is of value to all the stakeholders involved in the project finance model. The remainder of this article will be an exploration of some of the operational data derived from ECO and which is being used to drive SunEdison's continuous improvement efforts.

Review of the SunEdison solar fleet

As of June 2009, SunEdison manages more than 70MWp of PV systems in North America and Europe, the vast majority of which are deployed in Distributed Generation sites. Data regarding the reliability of PV systems worldwide are relatively scarce, as research institutions generally manage a small number of small sites. On the other hand, commercial operators are usually very protective of their performance data in the same way as semiconductor device manufacturers tend to be protective of their yield data. We have decided to publish detailed information at this time based on the belief that transparency is of greater value than any potential intellectual advantage.

Number of systems	198
Average size (kWp)	259
Minimum size (kWp)	23
Maximum size (kWp)	1727
Average age (months)	11.9
Minimum age (months)	0.3
Maximum age (months)	44.6

Table 1. SunEdison's systems' statistics.

The systems included in this survey account for 77% of SunEdison's managed fleet in terms of installed MWp and 78% in terms of number of systems under management as of June 2009 (see Table 1). Cumulative operation time of the systems at the end of the survey period was 196 system years. The subset of SunEdison systems surveyed was selected exclusively on the basis of the project's financing scheme, and covers a wide variety of geographic and environmental conditions as shown in Fig. 3.

The following energy production and outage survey covers the period between 1/1/2008 and 4/30/2009, unless stated otherwise.

For the purposes of this paper we define *uptime* as the ratio of the energy produced (as measured by revenue-grade meters installed at the customer facilities) to the energy that *could have potentially been* generated if there was no reduced performance due to component downtime and corrective maintenance:

Uptime = Energy Produced (kWh) / Production Potential (kWh) (1)

Reduced performance events, often loosely described as *outages*, occur when the generated energy is considerably less than the energy expected due to irradiance and temperature conditions. Analysis of extensive historical performance logs allows SunEdison to assign a system-specific expected production value that is modulated by existing conditions.

The *production potential* of a system is estimated based on the available insolation and the characteristics of the system according to the following formula:

Production Potential = Irradiance (sun-hours) * OPR (%) * System Size (kWp) (2)

where *OPR* or *Operational*

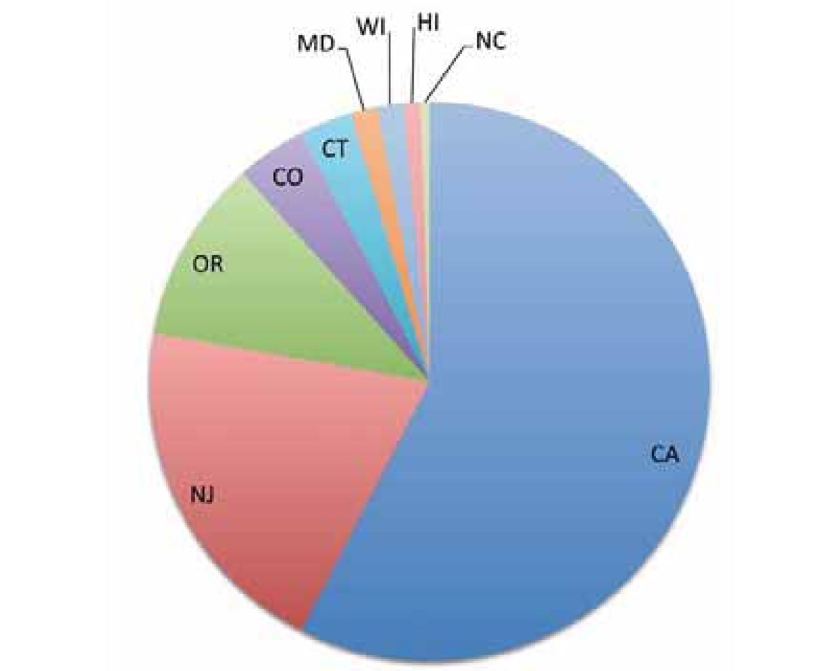


Figure 3. Geographical distribution of surveyed systems. The size of the slices represents the number of systems in each U.S. state.

Performance Ratio is a system-specific, algorithm-based estimate of output based on environmental conditions and historical energy harvest with an accuracy of approximately ±3% for a given one-hour time interval.

Outages are automatically flagged by SunEdison's back office Site Objects and Information Ledger (SOIL) when the production is less than 60% of the expected value. In addition to these automatically generated reports, expert staff at the Renewables Operation Center use advanced algorithms to identify reduced performance events of a less pronounced character. Once an outage is reported, the staff generates a service ticket, determines the severity of the event and dispatches qualified service personnel as necessary.

When the issue is resolved and energy generation is reinstated to its expected levels, we calculate the production potential as defined by Equation 2. This unrealized generation represents the impact of the outage expressed in kWh. For the 198 systems in the period under consideration, the aggregated energy generation statistics are as shown in Table 2.

As mentioned earlier, maintaining a distributed portfolio of assets represents significant challenges beyond those encountered for larger standalone systems. Larger systems are capable of supporting dedicated maintenance staff and on-site spare parts inventories, while distributed assets require a significantly higher degree of coordination and sophistication. Given that two of North America's largest PV plants – Nellis Air Force Base (14MW) and Alamosa (8.2MW) – achieved uptimes of 98.8% [2] and 99.0% [3] respectively in 2008, we believe the accomplishment of a 98.6% uptime rate across a portfolio of 198 DG systems represents quite an achievement.

It is worth noting that 88 (approximately 45%) of the systems under examination did not experience a single outage throughout the 16 months of this survey.

Analysis of the data

First and foremost, it is important to recognize that not all outages are created equally. Fig. 4 shows the cumulative lost production versus the cumulative number of outage events. The first point of note in this chart is the fact that the first 10% of outages account for more than 60% of the total lost production, and are considered to be high-impact events. Secondly, it is important to note that the bottom 50% of outages account for less than 10% of total lost production – these are considered nuisance events. Both categories are of significant concern, but for different economic reasons: the high-impact events because of the lost production, and the nuisance events due to the impact on portfolio O&M costs as described in Fig. 2 earlier.

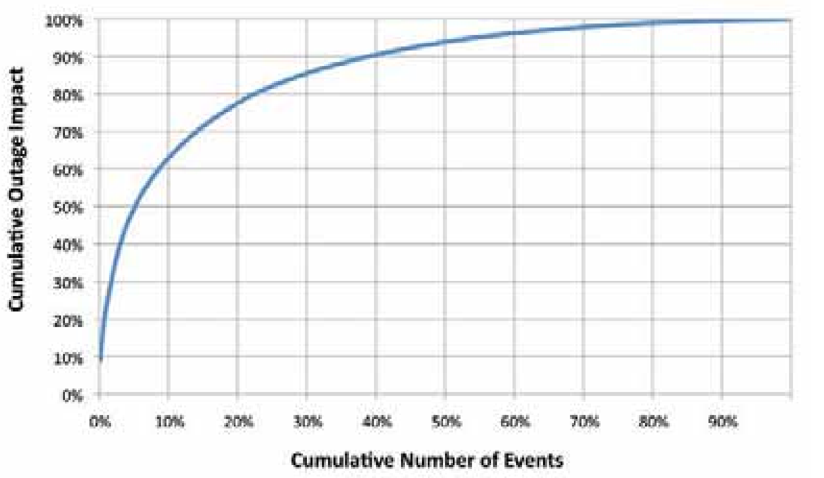


Figure 4. Cumulative impact of outages plotted against the individual events, which are sorted in descending severity. During the period considered, 10% of the outages were responsible for more than 60% of the lost production potential.

A. Expected (Modelled) Generation (kWh)	62,767,945
B. Actual Generation (kWh)	68,863,289
C. Unrealized Production Potential (kWh)	1,196,799
D. Performance or B/A	109.7%
E. Uptime or B/(B+C)	98.6%

Table 2. Aggregated energy generation statistics (SunEdison).

Pareto charts of subsystem failures

The relative energy impact of the outages, categorized according to the subsystem or condition that originated the outage, is presented in Fig. 5. However, as noted above, the frequency of outages is also important. Fig. 6 therefore shows both the impact and frequency of outage events, categorized according to conditions or subsystem of origin.

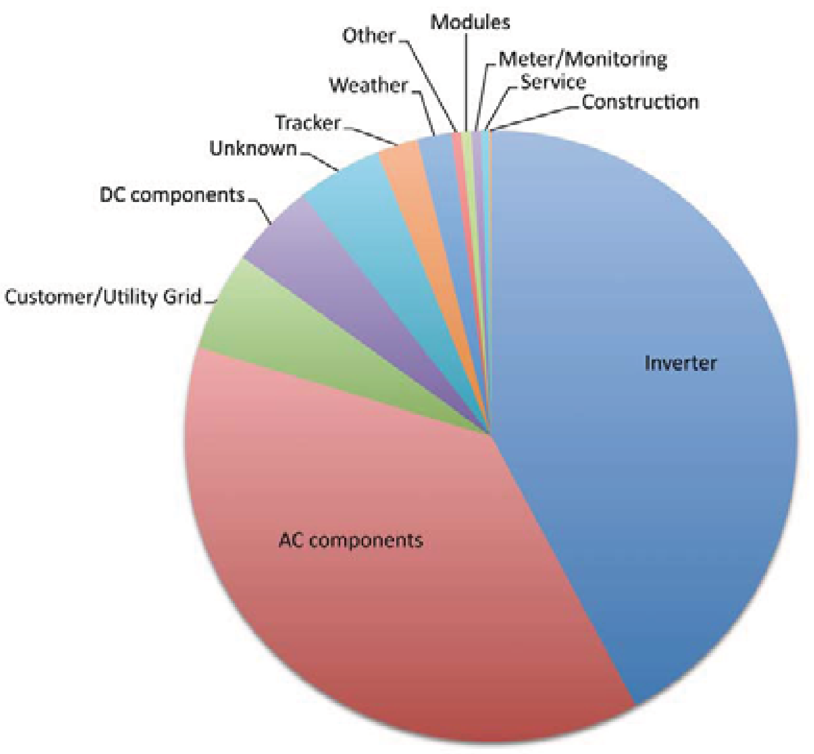


Figure 5. Relative impact of outages in terms of unrealized production potential (shown in descending order). The outages impacted 110 systems (in a fleet of 198) over the 16-month period from January 2008 to April 2009.

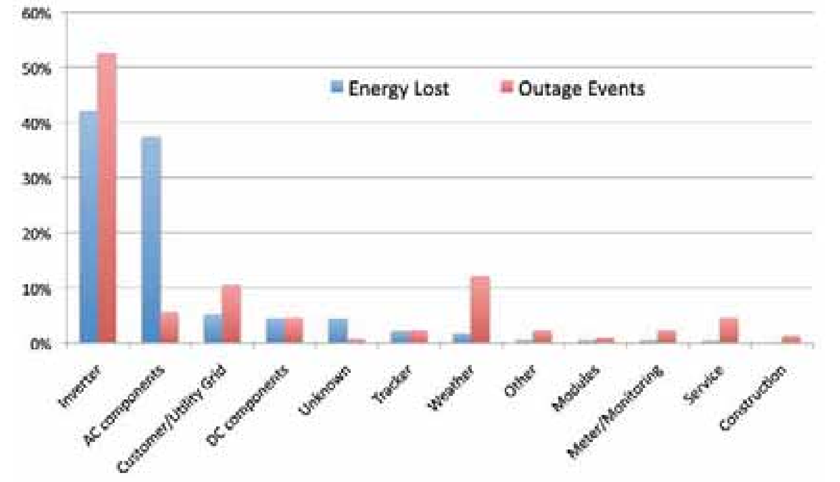


Figure 6. Pareto of relative outage impact with indication of corresponding event frequency. The impact of the inverter outages is proportional to the outage frequency, but the impact of AC component and weather-related outages are inversely proportional to their frequency.

From these it becomes clear that the subsystem most susceptible to outages is the inverter while it is also responsible for a very large percentage of the lost production potential. Another obvious conclusion is that failures of AC components, though infrequent, were observed to have a disproportionately large impact in terms of energy loss. Conversely, weather conditions (mainly snow) may frequently cause reduced performance, but their energy impact is minimal. Based on these observations, we have focused our continuous improvement efforts on the inverter and the AC components, which are discussed in detail later.

Inverter outages

As the most active component in the system, the inverter is also naturally the most vulnerable component. It is therefore worthwhile to take a closer look at the causes behind the outages to which it is related. As mentioned in the data analysis section, each ticket contains a diagnosis of the primary cause of the outage. The common primary causes of inverter failures have been identified and reduced to 19 categories based on the experience of SunEdison service operations personnel.

From the chart in Fig. 7, it is evident that control board failures were the most severe and most frequent cause of inverter-related unrealized production potential. The failing cards were specific to a particular inverter model and the components were replaced under warranty. In terms of the impact on uptime, board failures amounted to only 0.14% of the total production potential of the surveyed systems; however, their financial impact was more pronounced as the identification and troubleshooting of the failures required dispatching of service personnel at a rate proportional to the frequency of the events. At the end of the day, we have been quite pleased with the ability of our OEM partner to identify and address this issue through their own rigorous continuous improvement and quality assurance programs and we expect this particular outage category to be dramatically reduced in the next reporting period.

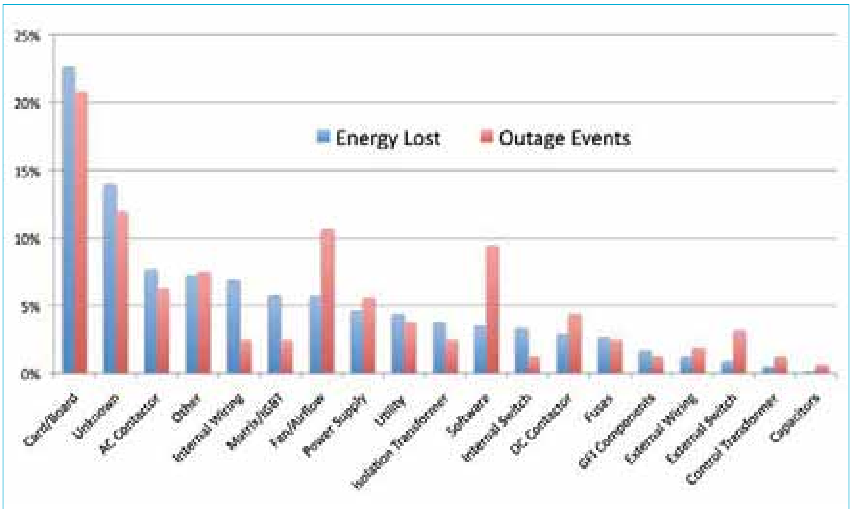


Figure 7. Energy impact Pareto of primary causes for inverter outages with indication of corresponding relative frequency. The percentages refer to the inverter-specific subtotals for energy lost and outage events.

The next inverter outage category is unfortunately 'unknown'. This represents an unacceptable level of uncertainty and we are currently working to better integrate inverter fault codes in SEEDS and SOIL to address this issue.

Fans and software were also behind numerous failures; however, their impact on uptime was relatively lower. Both of these causes fall under the nuisance category. Recent development efforts enable the company to address a subset of outages by remote inverter controls initiated through the ROC. Software errors can be cleared in this manner; fan faults currently require a visit by field service. The ability to clear certain fault categories remotely drives stronger service financials by reducing both the duration and the cost to repair those faults by eliminating the need for dispatching service personnel.

Conversely, defective internal wiring – albeit infrequent – caused the loss of a disproportionate amount of energy due to the complexity of the repair. Here again, we will rely on the ongoing efforts of our OEM partners to reduce the instances of this outage category.

With regards to inverter outages our efforts rely heavily on the capabilities of our OEM partners. The most important thing that SunEdison can do in this area is to ensure that we establish and maintain a high degree of visibility into outage causes, thus enabling us to provide valuable feedback, validate the efficacy of changes made by the OEM and finally to ensure that we can leverage remote reset capabilities to the greatest extent possible. These efforts will likely result in an overall reduction in the frequency, duration and average cost of repair for inverter-related faults.

AC component outages

As illustrated in Fig. 6, a relatively small number of AC component outages cause a disproportionately large amount of production potential to remain unrealized. In fact, five of the top 10 outages for the period analyzed were attributed to issues between the inverter output and the point of common coupling. While these events were rare, they resulted in long duration outages due to the degree of inspection and re-work required to ensure that the issues had been thoroughly addressed and the systems could be safely restarted. The severity of such instances led the Engineering, Construction and Service departments to prescribe solutions that have addressed the cause of these events, including: performing facility coordination studies, best practices to avoid ground faults, quality inspections for equipment receiving, and use of more robust materials suited to harsh conditions. As a result, we expect to see a further reduction in outages related to faults on the AC side of the system.

Call to action – what remains to be done?

Consistency and verifiability of data is the basis of all continuous improvement in this regard. Through the process of fulfilling our responsibilities as a Solar Energy Services Provider, SunEdison has built the tools that enable the collection of the required trustworthy data. The data has been critical to achieving the high uptimes and energy production described earlier across a diverse and distributed portfolio of assets. Furthermore, the information is critical to creating the internal feedback loops between Field Operations, Design & Engineering and Procurement teams within the company, and will be strengthened to ensure improved operations.

For example, the current analysis details issues encountered after systems have been commissioned for commercial operation. Extending this level of portfolio-wide analysis to include issues encountered prior to system acceptance will be important for a truly thorough and robust continuous improvement program. Additionally, improving the time and geographic resolution for various outage causes (e.g. for inverter fan failures) will be important to improving preventative maintenance programs.

As partners, Solar Energy Services Providers and OEM suppliers need to continue to strengthen the feedback loop between system failures and product development and management, which necessitates an open two-way dialogue.

In the future, operational data will also be critical to the shaping of code, standards and certification requirements. The data requirements necessary to inform and guide this type of decision-making are undoubtedly different from the data required for product development and maintenance purposes. In time, it is likely that PV-related codes and standards can be made more liberal and robust. These outcomes are not mutually exclusive assuming that the industry is capable of demonstrating what is legitimately required to ensure safe and reliable long-term operation. For this reason, it is critical that Solar Energy Service Providers and other system operators be open about failure modes and causes – particularly those related to design and construction.

Additionally, as inverters and photovoltaic systems become increasingly aware and responsive to the grid, real-world data on scenarios and responses will be critical to the process of defining what is appropriate and what is not. Companies must be committed to working with utility partners based on the strength of their data-collection capabilities. SunEdison has made a substantial financial commitment to establishing the Solar Technology Acceleration Center (Solar TAC) in Aurora, Colorado. Xcel Energy, Abengoa Solar and SunEdison constitute the organization's founding members with other important utility and industry partners also preparing to join. In the near future, Solar TAC will establish itself as an important venue for the testing and validation of new technologies and integration approaches which will help to shape the way solar systems perform and interact with the grid.

Conclusion

As a fleet, the SunEdison portfolio of projects continues to exceed expectations both in terms of energy produced and in production lost due to outages. With uptimes in excess of 98% firmly established, the company is working to continuously improve the efficiency with which these uptimes are maintained by reducing the frequency of nuisance outages, reducing the likelihood of major outages and reducing the lost production resulting from unavoidable equipment failures through faster and more focused responses.

ECO contains all the essential components required to effectively manage our portfolio: from monitoring and communications, through back-office functionality to outward-facing tools that enable the monetization of asset performance. And at the end of the day, this ability to reliably monetize asset performance is what matters most.

Using the ECO architecture, it is possible to institute economic dispatch protocols whereby ROC operators are able to prioritize response and repair efforts based on the economic impact of outages. SunEdison has been able to institute data-driven continuous improvement programs to maximize system reliability while minimizing O&M costs, and have also provided our partners with transparent data on the monetary value of our systems.

As the industry continues to evolve, the ability to translate operational inputs into economic outputs will only become more important. Efficiencies will improve, functional capabilities will be expanded, and business and finance models will evolve – but transparency, accountability and demonstrable economic value will remain as fundamental requirements.

By demanding a higher level of financial transparency and operational accountability, the project finance business model has helped push the solar industry into the steep acceleration stage of a learning curve which is essential to the future of solar as a viable – and material – long-term energy solution. The result of this learning curve will be an industry capable of going beyond grid parity to a point where distributed generation PV assets will provide quantifiable operational and economic benefits to consumers, investors and grid operators throughout the value chain.

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About the Authors

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Mark Culpepper is responsible for shaping SunEdison's service-oriented architecture for data acquisition and power plant control, creating the connection between solar energy data and customers' immediate financial and energy savings. With over 18 years in the telecommunications and IT security industries, his mission is to simplify solar energy services, providing government, commercial and utility customers the real-time data and analytics needed to optimize solar production and asset performance.

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Multifunctional PV battery systems for industrial applications

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ABSTRACT

Power quality and reliability are two very important factors in electrical power supply, particularly for specific branches of industry. Multifunctional PV battery systems can improve power quality, substitute uninterruptible power supply systems, and can offer additional services such as energy management and peak shaving. This article presents the results of an analysis of possible services under current German conditions and the measurement results of laboratory tests and a pilot demonstration.

Introduction

Given the worldwide efforts being made to give priority to renewable energy, there is a wide range of potential applications for multifunctional PV inverters to create grid areas with a high power quality, e.g. for industry, and integrate these systems effectively in the electrical power system operation and energy supply.

The objective of the 'Multifunctional Photovoltaic Inverter' (Multi-PV) research and development project was to develop a multifunctional PV inverter that connects not only the PV modules but also a battery unit [1]. In addition to feeding in the active power from PV to the public grid, this type of inverter is also intended to be used to improve the local power quality and, in combination with battery storage, ensure an uninterrupted power supply for critical loads in industrial networks. Another goal is to use the battery storage for energy management purposes, such as peak shaving, and to provide services for network operation, such as balancing power.

Figure 1. Industrial site of Hübner GmbH in Kassel (courtesy of ISET).

ISET e.V. and SMA Solar Technology AG (SMA) in Kassel, Germany investigated the general conditions for the operation of multifunctional PV inverters (from technological and economic perspectives) and developed the corresponding inverter technology. The 100kVA prototype is under operation at the industrial site of the project partner Hübner GmbH (see Fig. 1) demonstrating the developed functionalities.

Fig. 2 gives a schematic overview of the Multi-PV concept. In addition to the PV generator, a battery is connected via the DC/DC converter to the DC link of the PV inverter. Industrial loads with additional services, such as improved power quality, are decoupled from other loads and the public grid by an inductor as well as a fast circuit-breaker. The inductor is necessary to locally improve the power quality and provide uninterruptible power

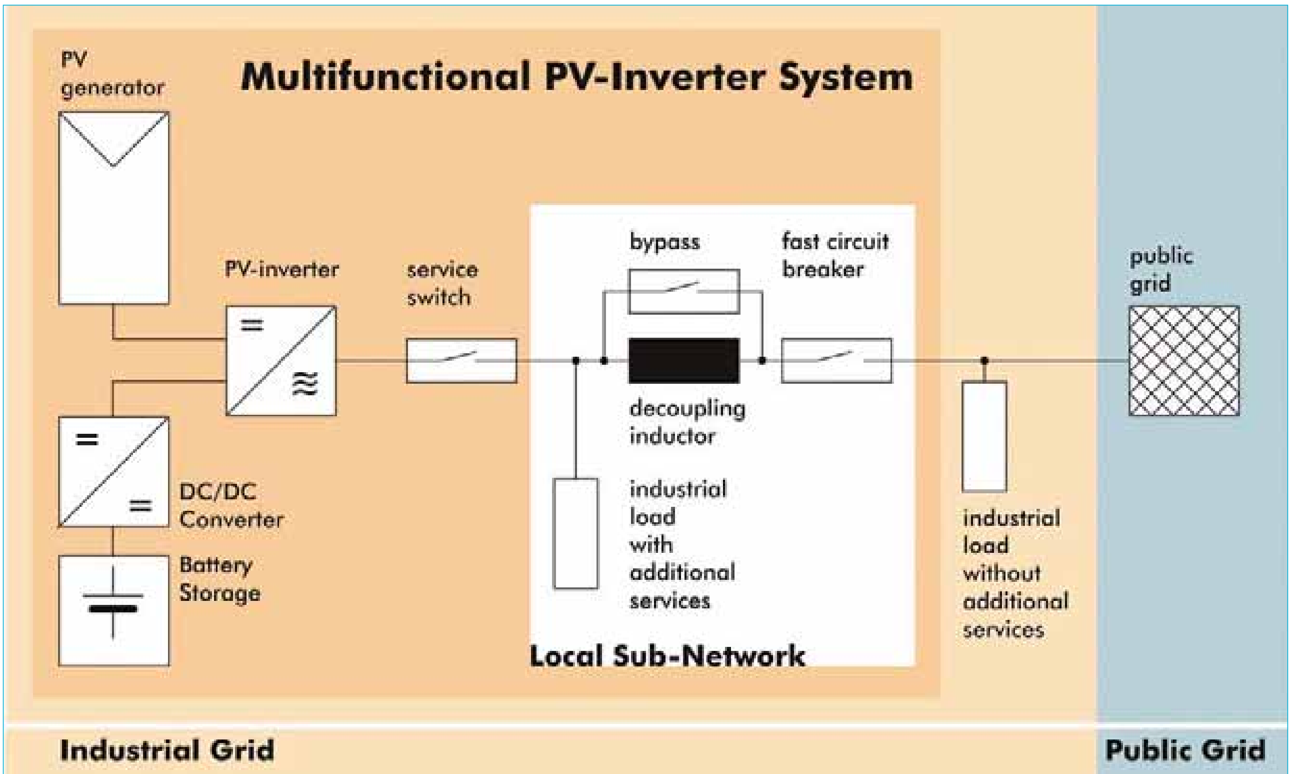

Figure 2. Schematic of a Multi-PV system at an industrial site [2].

supply to critical industrial loads. These new components (battery, decoupling inductance, and fast circuit-breaker) enhance the capabilities of a standard PV inverter to a multifunctional device with many possibilities to provide additional services.

This paper presents the results of an investigation of the economic potential of multifunctional inverters under German conditions, such as feed-in tariff, European Energy Exchange (EEX), markets for ancillary services and power supply tariffs. In addition, it provides experiences from the laboratory tests and prototype operation at the industrial partner.

Power Generation

Economic potential

The services given in Table 1 can be considered in an economic analysis with their respective sources of benefits. Different investigations determined the optimal power dispatch to achieve maximum economic profit with the Multi-PV system [2-6]. Three exemplary companies (C1, C2 and C3) with their respective load profiles are analyzed. The optimal dispatch results and sensitivity analyses show that the achieved profit mainly depends on the characteristics of the load profile itself. As one example, the optimized power dispatch schedule is given in Fig. 4 for C1 in the year 2007 taking into account peak-shaving, trading on the day-ahead market, and participating on tertiary balancing services markets.

"The optimal dispatch results and sensitivity analyses show that the achieved profit mainly depends on the characteristics of the load profile itself."

The possible services are analyzed in more detail in [4] limiting them to the economic interesting services. It can be seen that the greatest profits result from restricting the system to peak shaving and the UPS functionality.

Fig. 3 shows the additional profit from peak shaving including UPS functionality by the Multi-PV system for company C1 depending on the battery capacity and the capacity price for power supply. The colour of the map indicates the additional annual benefit (compared to a conventional PV system + UPS unit) and the black dotted line marks the maximum additional benefit at a given capacity price. In this example, the investment costs for the battery are assumed to be 95 €/kWh battery capacity and 110 €/kW for the DC/DC-converter and the disconnection unit. Due to there being only 22-24 battery cycles per year, the lifetime for all components was calculated as 20 years.

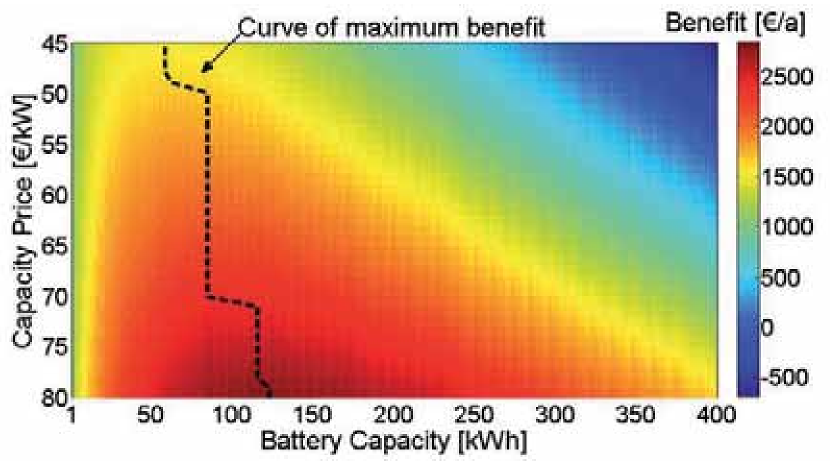

Figure 3. Additional profit for company C1 depending on the batteries' capacity and the capacity price for power supply [4].

Table 2 gives an overview of the range of the maximum profit provided by the Multi-PV system for each of the three investigated companies with the capacity price in the range of 45-80 €/kW per annum. The additional profit provided by the Multi-PV system with peak shaving and UPS functionality mainly depends on the characteristics of the companies' load profile. The less common, the shorter and the higher the load peaks are, the less energy is required from the battery. So, the battery size can be smaller.

Sensitivity analyses show that the additional investment costs (due to battery and DC-DC-converter) only have a minor influence on the profit because of the generally small component costs.

A comparison of the integrated Multi-PV concept (only one inverter for PV modules and battery) with the modular concept (two separate inverters for PV modules and battery) shows that the integrated concept is more profitable (saving one DC/DC-converter) despite having the constraint of only one inverter.

Experiences from laboratory and prototype operation

During the project run time, a laboratory sample (Fig. 5) and a prototype unit were developed and tested by ISET and SMA. While SMA is responsible for the hardware layout of the laboratory sample, the control

Services	Benefits by
Improvement of local power quality	Substitution of conventional devices or increased power quality
Compensation of reactive power	Substitution of conventional devices or reduction of reactive power purchase costs [3]
Uninterruptible power supply (UPS)	Substitution of conventional devices or increased reliability
Peak shaving	Reduction of capacity costs
Energy management	Reduction of energy costs
Participation on balancing services markets	Market prices for primary control, secondary control and tertiary reserve
Power trading	Market prices on day-ahead or intraday-market of the EEX
Ancillary services	Payments for providing active and reactive power control to the network operator

Table 1. Possible services by Multi-PV and their respective sources of benefit [4].

	C 1	C 2	C 3
Range of optimal battery size [kWh]	59-123	45	46-51
Additional Annual Revenues [€/a]	3,360-5,383	6,504-10,004	3,145-4,101
Additional Annual Costs [€/a]	1,805-2,544	1,631	1,699-1,755
Additional Annual Profit [€/a]	1,555-2,839	4,873-8,373	1,446-2,346

Table 2. Maximum possible profit provided by Multi-PV under the aforementioned framework conditions [4].

of the inverter is realized with a rapid-control-prototyping system [7] by ISET. Experience from testing the laboratory sample is applied to the development process of the prototype unit. In regard to a serial product, the prototype unit is completely engineered by SMA.

Taking into account the principle of decoupled sub-networks [9] used for local voltage control and UPS functionality, it is not possible to combine all of the functionalities described in Table 1 together. Table 3 presents an overview of possible combinations of the different functionalities.

Laboratory measurement results

Laboratory tests concerning local power quality improvements are carried out with the laboratory sample in ISET's DeMoTec. For these experiments a Spitzenberger & Spies network simulator with a nominal apparent power of 90kVA was used to influence the grid systematically and in a reproducible fashion. The following results of the laboratory tests show the influence of the decoupling inductor on

- steady-state voltage variations,
- transient voltage variations, and
- voltage quality.

Steady-state voltage variations

Steady-state voltage variations of the grid voltage are compensated only for loads in the sub-network through an advanced control algorithm and the application of the decoupling inductor. The voltage in the sub-network is controlled to a pre-defined set-point by injection of reactive power.

Function	With Decoupling Inductor	Without Decoupling Inductor
Feed-in of PV energy	yes	yes
Local PQ Improvement	yes	no
UPS Functionality	yes	yes/no*
Provision of Control Energy	yes	yes
Peak Shaving	yes	yes
Reactive Power Supply/ Compensation at PCC**	no	yes
Harmonics Compensation at PCC	no	yes

Table 3. Possible functionality depending on the system configuration, modified from [7] (* = dependent on the UPS classification according to EN 62040-3; ** = Point of Common Coupling).

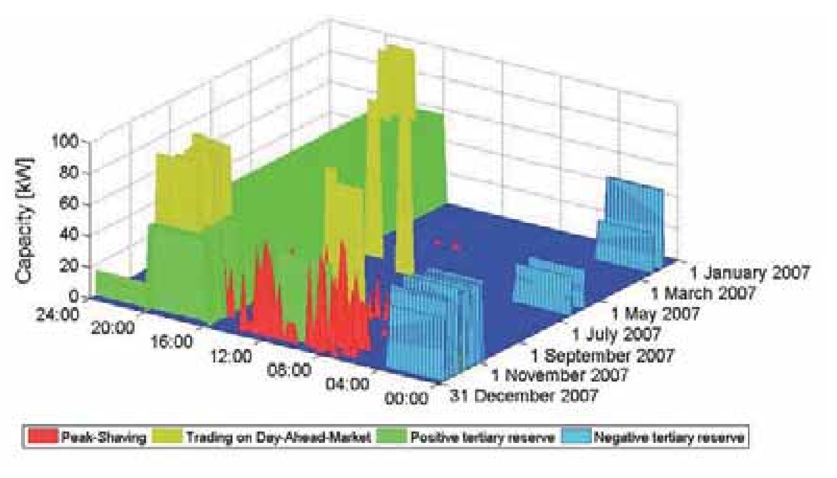

Figure 4. Optimized power dispatch schedule for the exemplary company C1 [4].

Courtesy: ISET.

Figure 5. Laboratory sample of the Multi-PV at ISET e.V.'s DeMoTec.

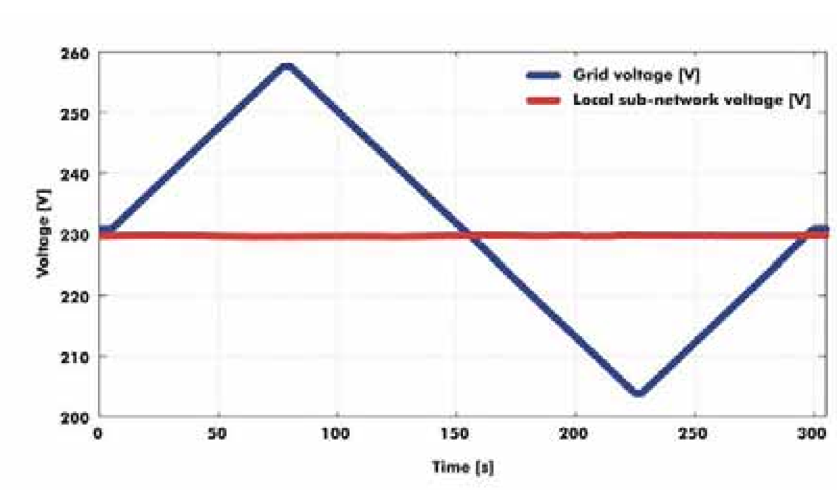

Figure 6. Measured sub-network voltage during an applied grid voltage ramp of $230V_{RMS}$ ± 10% [2].

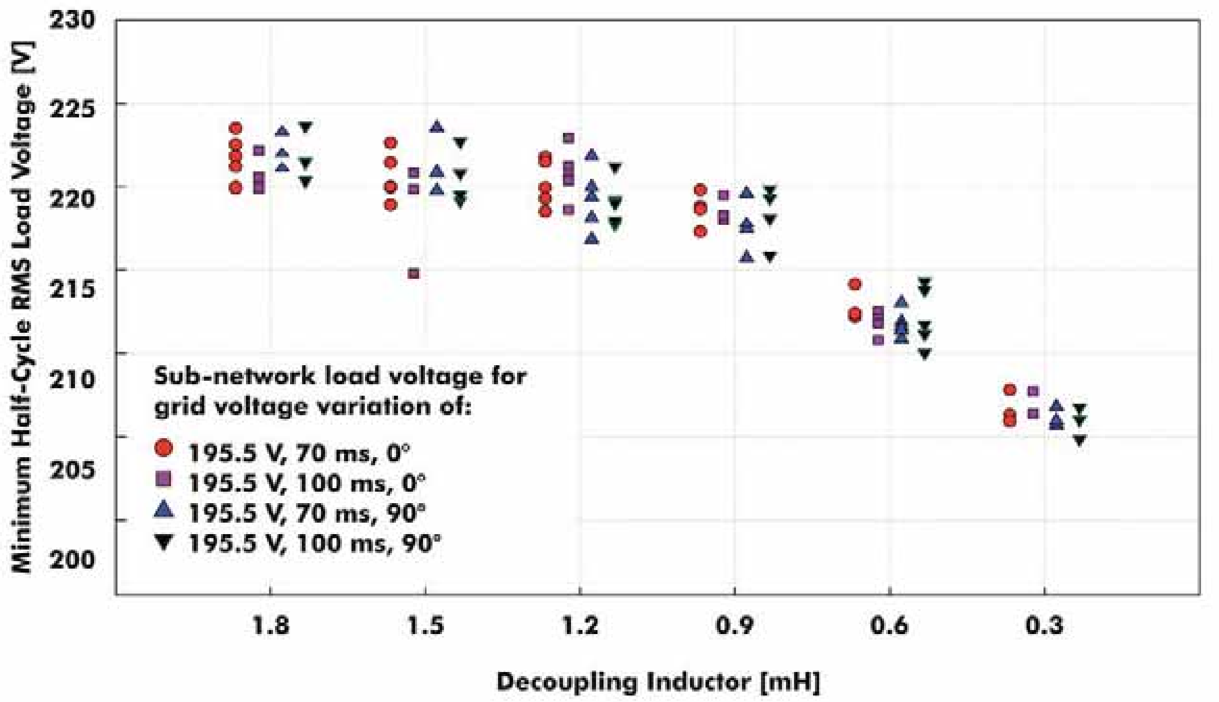

Figure 7. Reaction of load phase 3 to different three-phase voltage dips with 85% remaining nominal voltage for several decoupling inductors [2].

Measurement results of the laboratory sample for a grid voltage variation of $230V_{RMS}$ ± 10% are shown in Fig. 6. The sub-network voltage is controlled to the set-point of 230V.

Transient voltage variations

Voltage dips in the grid are damped for sensitive loads in the local sub-network through injection of an additional reactive current by the inverter. Depending on several parameters, e.g. the size of the decoupling inductor, the damping factor capability can vary. Measurement results for several types of voltage dips are exemplarily shown in Fig. 7.

Allowing a voltage deviation of ± 10% at most, a decoupling inductor of 0.6mH is sufficient for the considered voltage dips. If deeper dips in the network voltage occur and the operating mode has to be switched to a UPS service, the chosen value of the decoupling inductor must be tested to comply with the classification according to EN 62040-3 [10].

"Voltage dips in the grid are damped for sensitive loads in the local sub-network through injection of an additional reactive current by the inverter."

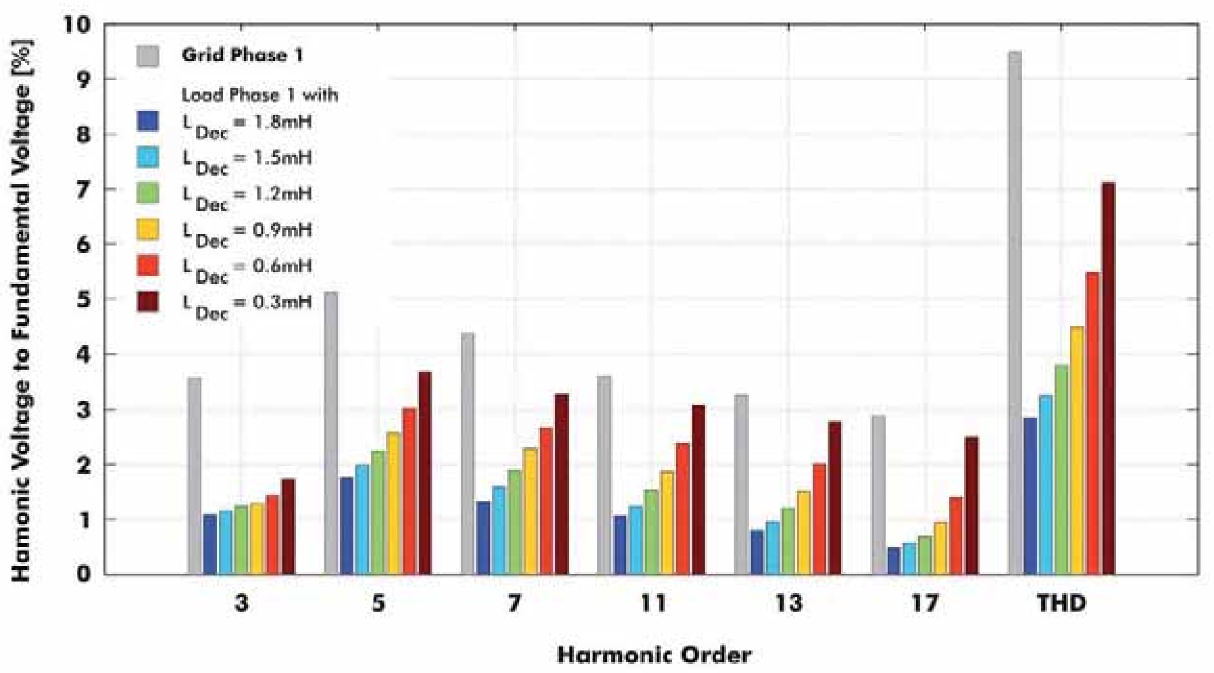

Figure 8. Harmonic reduction for various decoupling inductors where P_{MPV} = 50kW and $P_{sub\text{-}net}$ = 100kW [2].

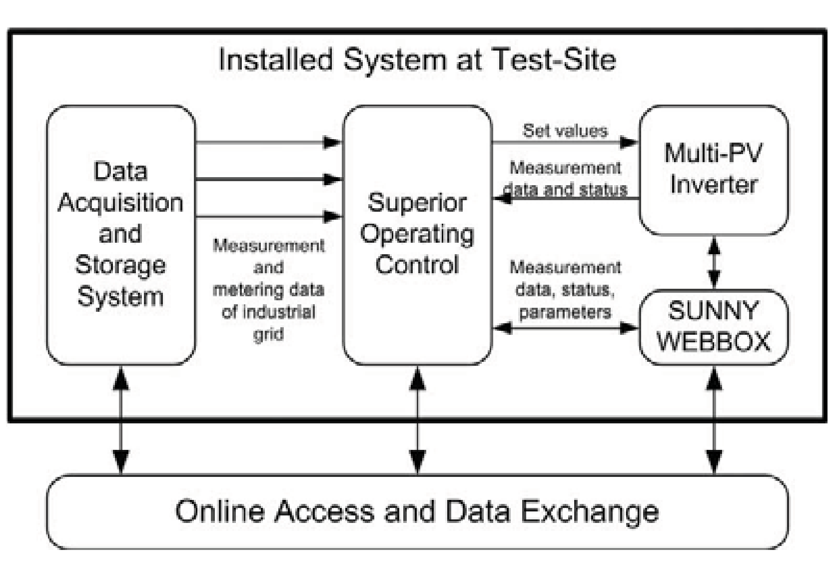

Figure 9. Assembly of the Multi-PV prototype system with data acquisition system, superior operating control and Multi-PV inverter [8].

Voltage quality improvement

Powerful motors, fast-changing loads or welding machines can affect voltage quality especially in industrial environments. An improvement of voltage quality for loads in the sub-network is achieved. The behaviour of the Multi-PV is tested for typical odd harmonics (3rd, 5th, 7th, 11th, 13th and 17th) with different amplitudes. Measurement results are given in Fig. 8.

The grid is disturbed by a total harmonic distortion (THD) of 9.5 %. Depending on the size of the decoupling inductor, the THD value in the sub-network is improved to 7.11 % at minimum and 2.83 % at maximum. This means that rather than a voltage quality of class 3 of DIN EN 61000-2-4, the quality is improved to class 2 (for decoupling inductors from 0.3mH to 1.5mH) and to class 1 for a decoupling inductor of 1.8mH.

Prototype operation in industrial environments

Since December 2008, the developed prototype system runs at the test site of Hübner GmbH in Kassel. The following sections present the general configuration and first test results of the application of reactive power compensation.

General configuration

The schematic in Fig. 9 shows the interaction of the used components in the prototype system. The Multi-PV inverter has several basic operating modes, e.g. MPP-Tracking, reactive power injection and UPS functionality. The system is managed by the Superior Operating Control and is based on the measurement and metering data of the Data Acquisition System. It defines the operating times of the system, oversees the battery management and calculates appropriate set-point values for additional functionalities as reactive power compensation and peak shaving and provides them to the Multi-PV inverter.

Reactive power compensation

The operator of an industrial grid has to keep a certain power factor at the Point of Common Coupling (PCC) against the utility to avoid paying for reactive energy. If the reactive power compensation demand and the solar radiation profile are known, the power compensation can be partly taken over or substituted completely by the Multi-PV inverter system.

> "If the reactive power compensation demand and the solar radiation profile are known, the power compensation can be partly taken over or substituted completely by the Multi-PV inverter system."

A Matlab/Simulink model of the assembly shown in Fig. 9 is developed to test the used control algorithm for reactive power compensation with measurement data of the test site.

Figure 10 shows simulation results of the 15-minute average power factor over a whole day (28th April 2009) with and without reactive power compensation. It can clearly be seen that the average power factor at the PCC without reactive power compensation is smaller than the desired set-point of 0.95. Using the reactive power compensation operating mode, the average power factor is limited reliably.

The algorithm is implemented to the superior operating control of the prototyping system. Measurement results of the 15-minute average power factor from 14th July 2009 are shown in Fig. 11.

The measurement results confirm the simulation results; the average power factor is limited reliably to the given set-point of 0.95. This proves the feasibility of reactive power compensation with a PV inverter in an industrial environment. Limits resulting from the parallel operation of PV-injection and reactive power compensation – for example, a limitation of the apparent power reserve – are considered by the developed control algorithm.

Conclusions

The results of this investigation show that the developed Multi-PV system can provide additional economic profits for companies. Case studies have been performed for three different industrial sites, and results show that individual conditions strongly influence the potential profitability. Most interesting

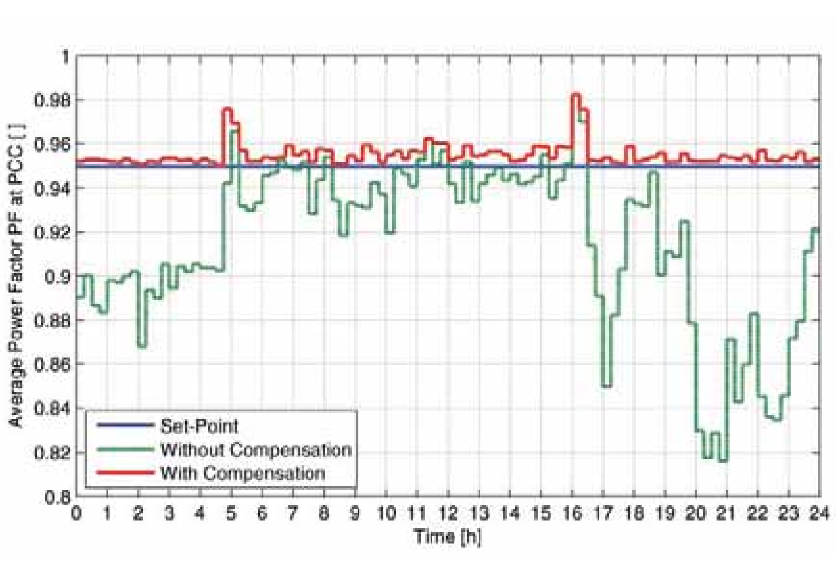

Figure 10. Simulation results of the power factor at the PCC with and without reactive power compensation using measurement data from 28th April 2009.

Power Generation

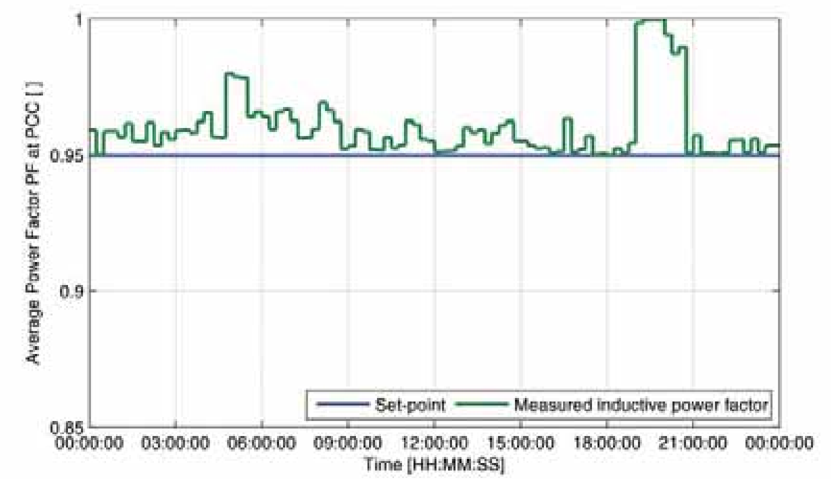

Figure 11. Measurement results of the average power factor of the test site from 14th July 2009.

among these conditions are peak shaving and uninterruptible power supply, while functions such as participation in power exchange markets and balancing services markets may be of interest in the future when the legal framework allows more flexible participation than it does currently. Finally, the improvement of the local power quality and reactive power compensation can also be beneficial.

Technical feasibility of additional functionalities is proved by measurements in the laboratory and at Hübner's test site. Power Quality is improved in the case of steady-state and transient voltage variations as well as for voltage quality. Reactive power compensation is demonstrated under real terms in an industrial environment.

In summary, it can be said that the Multi-PV system is an innovative approach. It integrates a photovoltaic system within the emergency power supply strategy of companies and in many cases, the reliability and duration of the uninterruptible and emergency power supply can be increased significantly if the local photovoltaic power generation and the larger battery size are taken into account. The integration of photovoltaic-based local power generation and the emergency power supply allows the use of only one inverter instead of two separate ones. Using one multifunctional inverter in an integrated system can considerably reduce investment costs and increase the overall profitability of the investment.

Acknowledgement

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Demonstrating CPV performance using power rating

Francisca Rubio & **Pedro Banda**, ISFOC, Puertollano, Spain

ABSTRACT

Armed with the aim of generating a knowledge base on CPV technology, ISFOC has installed 1.4MW of CPV and is executing up to a total of 3MW of power plants incorporating seven different technologies, all scheduled for completion in 2009. These pilot plants are being established to assist the industry in the setting up of pilot production lines and to obtain very valuable information such as reliability, suitability and production [1]. Rating measurement approaches have been proposed by ISFOC, but there remains a need for an international standard that is accepted by the CPV community. This paper presents ISFOC's proposed standards set and outlines the methodology adopted by the company in this respect.

Introduction

In order to generate key knowledge on CPV technology, ISFOC set out to establish a rating measurement for power plant acceptance, following its own methodology. Based on the equations of the Shockley model, only one measurement is needed to establish the nominal power of the CPV system. This procedure measures heat-sink temperature to calculate the cell temperature through the thermal resistance, as well as direct normal irradiation (DNI) using a pyrheliometer and the I-V curve [2]. ISFOC has proposed this approach to demonstrate the performance of CPV modules and plants, and with its experience in the sector, ISFOC is in the privileged position of contributing to the definition of new standards for the power and energy rating for CPV systems

Power rating: IEC Committee

The Working Group 7 of the IEC TC82 Committee is working actively to develop the new standards needed for the improvement of the CPV technology and market.

A standard that is sorely needed is that of power rating, as it is the only way of comparing the performance of modules from different manufacturers. This subgroup of Group 7 of the TC82 of the IEC is headed by Sarah Kurtz (NREL), who has presented to the IEC Committee a 'New Work Item proposal' with the title "Concentrator Photovoltaic (CPV) Module and Assembly Performance Testing and Energy Rating: Part 1: Performance Measurements and Power Rating - Irradiance and Temperature".

The purpose of this test standard is to define a testing and rating procedure, which provides the CPV module power (watts) for a set of defined conditions. Secondly, the standard would provide a method of determining a set of characterization parameter values for the module.

This standard is based on the IEC 61853-1 (power rating methodology for flat-plate PV modules) [3], which provides the PV module power (watts) at maximum power operation for a set of defined conditions. In the case of CPV modules, the set of conditions is varied.

As the power depends of the radiation and temperature level, Table 1 shows the layout for logging power measurements at different levels of radiation and temperature. Of course, this set of parameters and the procedures to carry out the measurements need to be adapted to the CPV conditions in question.

> "The challenges faced by these new solar simulators will be temperature and radiation level control, as well as the spectrum to test the CPV modules at different conditions."

The IEC 61853-1 standard outlines two possible procedures for carrying out this test: using a solar simulator for the indoor measurements or using natural sunlight.

Indoor measurement challenges

One of the best ways of carrying out the measurements under the set of conditions described in Table 1 is by performing these measurements indoor under controlled conditions. As CPV requires collimated light, these measurements must be taken with a solar simulator. Some solar simulators under development have demonstrated very good results [4] and it is hoped that they will be used to characterize CPV modules under the conditions of this new standard.

The challenges faced by these new solar simulators will be temperature and radiation level control, as well as the spectrum to test the CPV modules at different conditions.

As ISFOC does not yet have a solar simulator, this procedure has to date been checked in outdoor conditions.

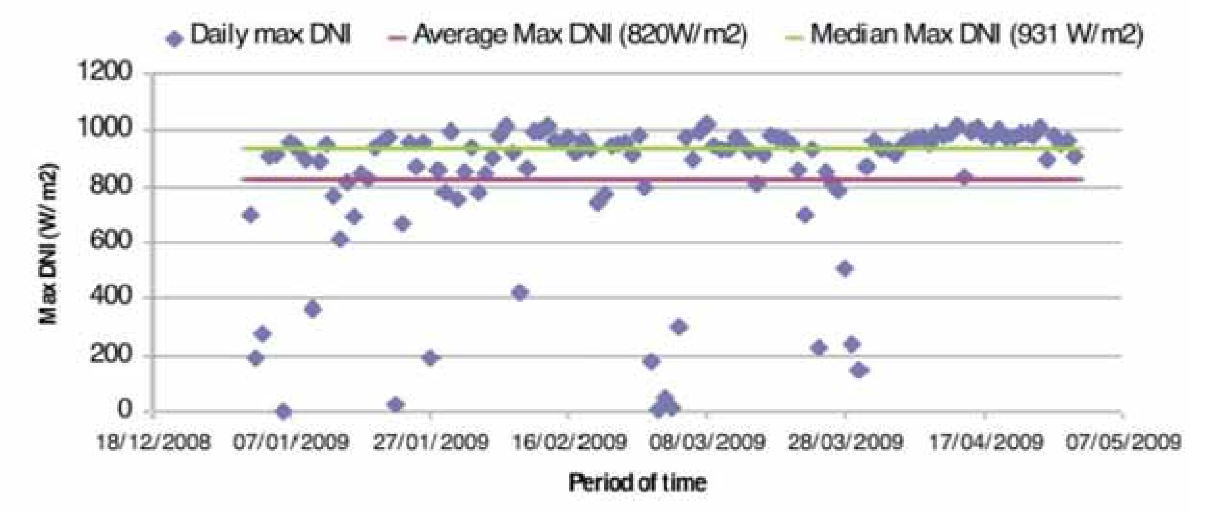
Outdoor measurements

In the case of natural sunlight, the PV standard describes a procedure of shading the modules for changing temperature conditions or the filtering of radiation to modify its value. However, this methodology needs developed very concisely and carefully, given the difficulty of performing the procedure due to the size of some CPV modules. It is also a concern that the filter of radiation could have spectrum variations, a concern that could be more important in this type of module than for flat PV.

In checking the standard, ISFOC used this method in a whole concentrator system where it is impossible to use shades or filter to change the conditions.

Irrad.	Air Mass	Module temperature			
		15°C	25°C	50°C	75°C
1100	AM1.5				
1000	AM1.5				
800	AM1.5				
600	AM1.5				
400	AM1.5				
200	AM1.5				

Table 1. Set of parameters for IEC 61853-1.



Power Generation

Figure 1. Daily values of max DNI showing average and median line in Puertollano between the months of January and April 2009.

To remedy this, measurements were taken on different days and at different ambient temperatures and radiation levels in an attempt to satisfy the conditions requirements.

Measurement methodology

All measurements taken for this paper were carried out at ISFOC facilities in Puertollano (Spain) using two concentrators: A and B. These HCPV systems feature concentrator modules on a two-axis tracker. Both concentrators have a nominal power of 6100W at 850W/m^2 and 60°C of equivalent operating cell temperature.

The standard ISFOC measurement equipment [5] was used in this procedure.

The I-V curve of the system is measured with a capacitive charge using multirange I/V tracing equipment developed by the Institute of Solar Energy from the Universidad Politécnica de Madrid. This equipment incorporates a discharged capacitor that is charged during the measurement until the system reaches the open circuit condition. This tracer is capable of carrying out a number of successive measurements in a short period of time over a prolonged period for a range of different concentrator systems.

Direct radiation is measured by two pyrheliometers (Middleton DN5) installed in two independent trackers. Back plate temperature – or 'module temperature', to adhere to flat PV nomenclature – is measured with several thermal sensors on the back part of the module behind the cell. The cell temperature can then be calculated by adding the thermal drop caused by the thermal resistance of the elements between the back plate and the cell, information available from the manufacturer. Wind conditions are measured using a 3m-high anemometer, while the ambient temperature is measured with a thermal sensor Young model 41003, with multiplate radiation shield.

All measurements were taken between the months of January and May 2009 in Puertollano, Spain. Two further measurements taken in August 2008 and October 2008 were also studied for comparison purposes. Care was taken to ensure that all measurements were taken over a short period of time in order to ensure uniformity of local conditions for each set of measurements. While every effort will be made to use these measurements to calculate the nominal power under the standard conditions, the ISFOC standard conditions were also taken into account for comparison purposes, and are as follows: DNI = 850W/m^2; Equivalent cell temperature = 60°C; wind speed lower than 3.3m/s.

Standard method results

The first task is the translation of the PV table of conditions to a set of parameters for CPV. Radiation should be taken as direct normal radiation rather than global radiation, given that it is being applied to CPV. Following an analysis of data of the direct normal radiation in Puertollano between the months of January and April, the results were assimilated and are presented in Figs. 1 and 2.

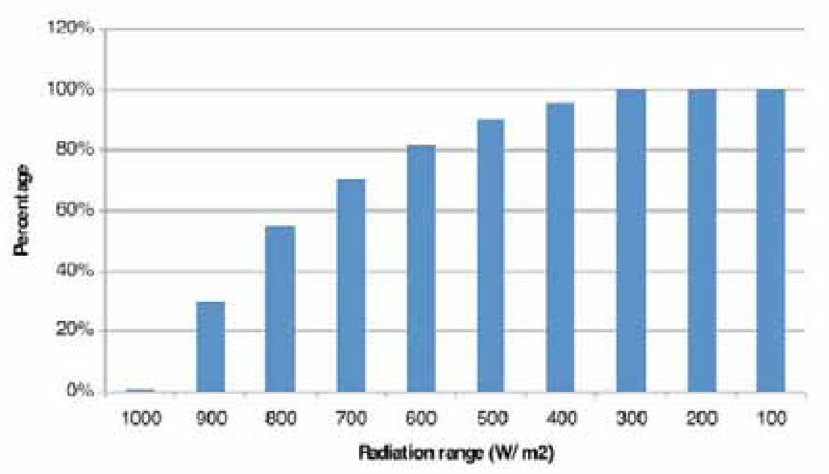


Figure 2. Frequency (%) of DNI values for which the radiation is larger than the abscise value in Puertollano between January and April 2009.

Irrad.	Air Mass	Module temperature			
		15°C	25°C	50°C	75°C
1100	AM1.5				
1000	AM1.5				
800	AM1.5				
600	AM1.5				
400	AM1.5				
200	AM1.5				

Table 2. Shaded set of parameters that could be filled for outdoor conditions in CPV.

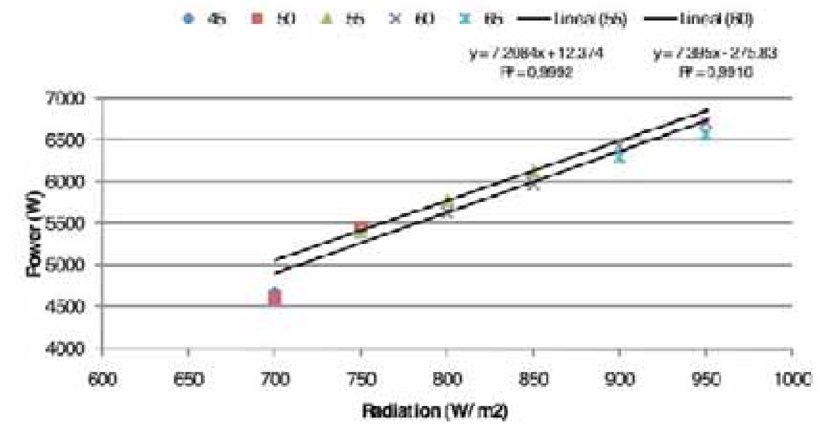


Figure 3. Power array output versus radiation at different levels of temperature.

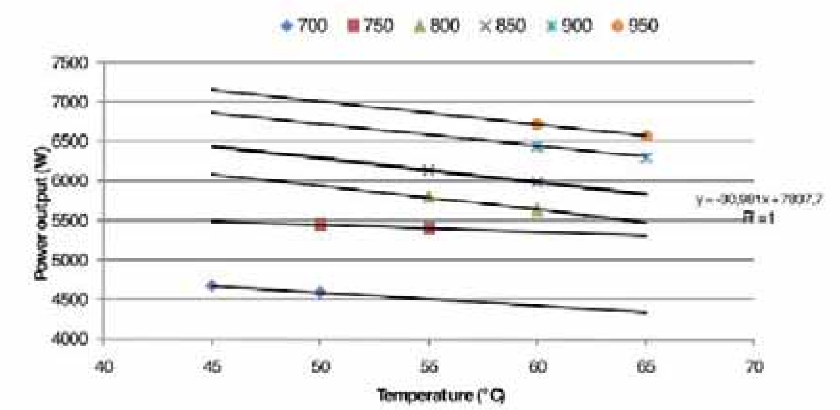


Figure 4. Array power output versus temperature at different levels of radiation.

Data was collected using ISFOC's meteorological station, which collects measurements every day at one-minute intervals.

Fig. 1 shows that 50% of the days in Puertollano during the months of January and April have more than 930W/m^2 as maximum DNI, while the data in Fig. 2 suggests that this figure was higher than 700W/m^2 70% of the time. The values rarely dip below 400W/m^2. For this reason, only data above 700W/m^2 is considered as it is typical in CPV standards, because is very unusual to obtain stable data below this value.

Data collected over 15 days from two concentrators was used in this study. Module temperatures were always between 45°C and 75°C, depending of the radiation and ambient temperature.

Had it been necessary to fill Table 1 with real data at Air Mass 1.5, there would not have been sufficient values to fill the table. Therefore data with different air mass values was included, as any 'geometric' value of AM1.5 does not assure the standard or the same spectrum value.

With these measured values, it can be assumed that Table 1 in its entirety could only be partially filled using data taken from outdoor conditions, as shown in Table 2.

To allow for a wider set of conditions, Table 3 features radiation values from 700W/m^2 to 950W/m^2 in increments

		Module temperature				
		45°C	50°C	55°C	60°C	65°C
DNI (W/m²)	700					
	750					
	800					
	850					
	900					
	950					

Table 3. Data log allowing for CPV conditions range.

		Module temperature				
		45°C	50°C	55°C	60°C	65°C
DNI (W/m²)	700	4682.32	4595.53			
	750		5457.54	5412.90		
	800			5790.69	5640.25	
	850			6133.74	5978.84	
	900				6441.65	6301.33
	950				6718.48	6570.15

Table 4. Array power output in Watts for a set of values of radiation (W/m²) and temperature (°C).

Concentrator A						
Date	B(W/m²)	Tplate(°C)	Tcell(°C)	Pmeas(W)	Pcal(W)	Diff
18/02/2009	928.29	61.24	79.31	6515.98	6123.58	0.39%
05/05/2009	927	62.48	81.02	6514.20	6138.28	0.63%
25/03/2009	774.88	58.88	74.16	5887.84	6022.90	-1.26%
08/10/2008	824.34	54.24	70.73	5784.91	6051.33	-0.80%

Table 5. Calculated power using ISFOC's method for different conditions for concentrator A.

Concentrator B						
Date	B(W/m²)	Tplate(°C)	Tcell(°C)	Pmeas(W)	Pcal(W)	Diff
26/02/2009	894.54	57.34	74.03	5821.61	6037.21	-1.03%
03/04/2009	908.52	53.40	71.53	6530.96	6216.42	1.91%
21/08/2009	917.69	67.55	85.91	6409.11	6151.11	-0.84%

Table 6. Calculated power using ISFOC's method for different conditions for concentrator B.

of 50W/m², while module temperatures between 45 and 70°C are logged in 5°C increments. After four months of measurements, only a small portion of the data needed for the table was available because low values of temperatures with high radiation or high temperatures for low radiation did not occur.

Representing power versus radiation level, the linear regression of the power for each set of module temperatures is shown in Fig. 3.

With the available data, only regression lines were obtained for 55°C and 60°C back plate module temperature. The output power is then calculated at 850W/m² and back plate at 60°C, obtaining P0 = 6005.67W. Power represented versus temperature yields the data in Fig. 4.

The regression lines show a great dispersion in slopes, which correspond to unusual values of the power to temperature relationship for multijunction cells. The reason for such dispersion is because there are only two data sets for each regression line, resulting in inaccurate results. For reasons of comparison, taking the 850W/m² line and 44°C for the module back plate, which is equivalent to 60°C at the cell (like the ISFOC standard condition), then the output power is P_0=6474.536W. This result means that the calculated value is 6% higher than the nominal one.

ISFOC methodology: technical specifications

Again, for comparison reasons, the ISFOC methodology was also applied to this set-up, and was adapted to the outdoor measurements in order to analyze the data obtained during these measurements.

The ISFOC procedure for concentrator rating has been described in several papers [2,5] and is used by the company for acceptance of CPV power plants [6]. It is based on a set of measurements taken over a short period of time, which are then translated to the standard conditions with equations based on the Shockley model. The standard conditions for concentrator characterisation are defined at 850W/m² and 60°C of cell temperature.

The measurement conditions are established as follows:

- The sky around the sun should not be cloudy during the measurement.
- The direct radiation should be higher than 700W/m².
- The wind speed should be lower than 3.33m/s.

In order to determine the DC Power of the concentrator, the following variables are monitored during the measurements:

- The I-V curve of the system is measured with a capacitive charge, as described before.
- Direct radiation is measured by two pyrheliometers.
- Back plate temperature is measured with several thermal sensors on the back part of the module behind the cell.
- For this method it is necessary to know the internal thermal resistance between the cell and the back plate. Applying Equation 1 will yield the operating cell temperature from the actual measured back plate temperature.

$$T_{cell} = T_{b-s} + B \times R_{cell-back} \quad (1)$$

- Wind conditions – speed and direction – are also measured in order to determine their effect on the final rating in the future.
- The current and voltage values are then translated to as-defined standard test conditions following Equations 2 and 3, deduced from the Shockley equation model.

$$I_2 = I_1 \frac{B_{oper}}{B_{mea}} \quad (2)$$

Where

I_2 Standard test conditions current
I_1 Measured current
B_{mea} Measured direct beam radiation
B_{oper} Standard test conditions direct beam radiation

Where

N Number of cells in series connection
IL_{meaj} Short-circuit current of each junction
E_{gj} Band gap of each junction
V_{oc} System open circuit voltage
T_{oper} Standard test conditions cell temperature
T_{cell} Measured cell temperature

This method allows the calculation of DC power of the concentrator using only a set of few representative measurements in controlled conditions. Data obtained on the same days has been used to perform the calculation in line with the ISFOC procedure, together with some other previous measurements.

(3) $$V_2 = V_1 + N \times \frac{0.0257 \times (T_{oper} - T_{cell})}{297} \times \ln\left(\frac{(I_{Lmeas1} - I_i)\times(I_{Lmeas2} - I_i)\times(I_{Lmeas3} - I_i)}{I_{Lmeas1} \times I_{Lmeas2} \times I_{Lmeas3}}\right) + \left(N \times (E_{g1} + E_{g2} + E_{g3}) - V_{OCmed}\right) \times \left(1 - \frac{T_{oper}}{T_{cel}}\right)$$

		Module temperature				
		45°C	50°C	55°C	60°C	65°C
DNI (W/m²)	700	5061.53	5029.17			
	750		5381.46	5346.80		
	800			5695.86	5658.88	
	850			6043.99	6004.70	
	900				6349.60	6308.00
	950				6693.57	6649.66

Table 7. Power measured at 927W/m² translated to the ISFOC set of conditions.

		Module temperature				
		45°C	50°C	55°C	60°C	65°C
DNI (W/m²)	700	8.10%	9.44%			
	750		-1.39%	-1.22%		
	800			-1.64%	0.33%	
	850			-1.46%	0.43%	
	900				-1.43%	0.11%
	950				-0.37%	1.21%

Table 8. Range of error between translated and measured values.

Concentrator B						
	Day	Time	Air mass	Rad+Temp	Radiation (W/m²)	Temp mod (°C)
1	03-abr	11:30	1.36	HRLT	905.303	54.607
2	21-ago	14:30	1.18	HRLT	919.4	68.42
3	23-feb	11:26	1.86	LRLT	800.555	58.321
4	23-feb	15:00	1.733	LRHT	800.699	62.34

Table 9. Set of measurements chosen for the bilinear interpolation method.

Only one set of parameters from these days with stable radiation and temperature was taken into account, resulting in the data shown in Tables 5 and 6.

It is clear from these data sets that the results are very close to the nominal power, with maximum error of 1.91%. The validity of this method has been tested with different concentrators, different ambient conditions and on different days of the year. This methodology will be proposed to the IEC Committee as a technical specification for plants' acceptance.

These equations can also be used to fill theoretically the table with the CPV set of conditions shown in Table 3. Translating one of the curves measured at 927W/m² and 62.8°C to the CPV conditions, the data in Table 7 is obtained.

Calculating the error of this translation versus the real measurements is calculated results in the data shown in Table 8.

From this data set, it can be seen that the errors between the theoretical translated values and the measured ones, except for the values of very low direct radiation, are lower than 1.5%. These results demonstrate the quality performance of ISFOC's equations in calculating power at different conditions, and could even be used in the future to fill the entire table of conditions.

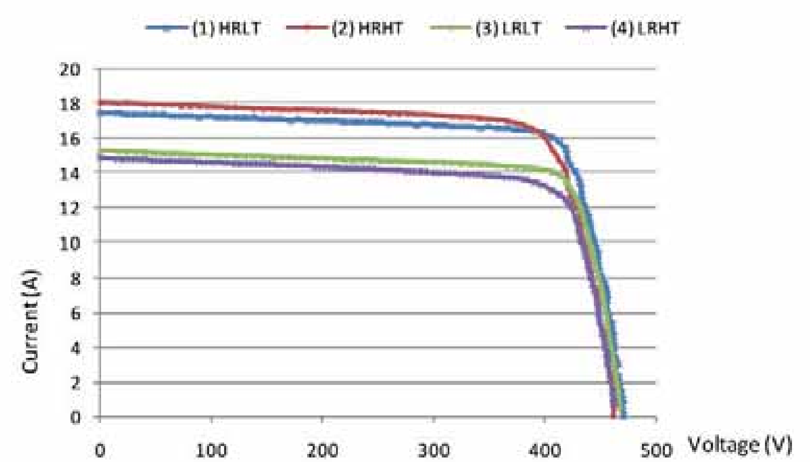


Figure 5. I-V curves of the four sets of chosen measurements.

Other methods

ISFOC has analyzed other rating procedures for comparison purposes.

Bilinear interpolation

As it is very difficult to obtain data at various different conditions in order to perform the study of interpolation or regression, the methodology of bilinear interpolation as described by Bill Marion for flat modules [7] was applied in this case. This procedure requires only four I-V curves in different conditions:

- High radiation and low temperature HRLT
- High radiation and high temperature HRHT
- Low radiation and low temperature LRLT
- Low radiation and high temperature LRHT.

Using ISFOC's accumulated data, it was found to be difficult to achieve such conditions and consequently the four required curves, especially with a fixed Air Mass = 1.5. This difficulty is because the real CPV working conditions are, in fact, very narrow. Therefore, different air mass conditions were employed – in every case below AM 2 – to fill the four cases, using the data shown in Table 9. The four I-V curves of concentrator B are represented in Fig. 5.

This procedure requires the translation of curve 1 and 2 to curve 5, and curves 3 and 4 to curve 6, using Equations 4-11. Once curves 5 and 6 have been established, the final translated curve 7 is obtained using Equations 12 and 13, shown in Fig. 6.

The final power value calculated with this method is P_0=6000.8847W at 850W/m² and 60°C of module (back plate) temperature. Attempting these calculations at 44°C module temperature (to be close to the 60°C cell temperature of the ISFOC standard conditions), the translation does not work properly because all the curves are translated to a lower temperature and a higher V_{oc}, yielding inaccurate results.

The power calculated with this methodology for the ISFOC standard conditions is P_0=5616.638W – almost 8% less than the nominal power value.

$$I_{SC} = \frac{E}{E_1} \cdot I_{SC(1)} \cdot \left[1 + \alpha \cdot (T - T_1)\right] \quad (4)$$

$$V_{OC} = V_{OC(1)} \cdot \left[1 + \beta \cdot (T - T_1)\right] \cdot \left[1 + (m \cdot T + b) \cdot \ln \frac{E}{E_1}\right] \quad (5)$$

$$\alpha = \left(\frac{I_{SC(2)} \cdot E_1}{I_{SC(1)} \cdot E_2} - 1 \right) \Big/ (T_2 - T_1) \quad (6)$$

$$F(\beta, m, b) = \left[1 + \beta \cdot (T - T_1)\right] \cdot \left[1 + (m \cdot T + b) \cdot \ln\left(\frac{E}{E_1}\right)\right] - \frac{V_{OC}}{V_{OC(1)}} = 0 \quad (7)$$

$$I_5 = I_1 = I'_2 \quad (8)$$

$$V_5 = V_1 + \frac{(V'_2 - V_1)(V_{OC(5)} - V_{OC(1)})}{(V_{OC(2')} - V_{OC(1)})} \quad (9)$$

$$I_6 = I_3 = I'_4 \quad (10)$$

$$V_6 = V_3 + \frac{(V'_4 - V_3)(V_{OC(6)} - V_{OC(3)})}{(V_{OC(4')} - V_{OC(3)})} \quad (11)$$

$$V_7 = V_5 = V_6 \quad (12)$$

$$I_7 = I_6 + \frac{(I_5 - I_6)(I_{SC(7)} - I_{SC(6)})}{(I_{SC(5')} - I_{SC(6)})} \quad (13)$$

Regression methodology

Regression methodology is based on the American Standard Test Method for "Rating Electrical Performance of Concentrator Terrestrial Photovoltaic Modules and Systems under Natural Sunlight" ASTM E 2527-06 [8]. This method, which has been used in the U.S. for several years, involves the determination of the performance of a CPV system by measuring the maximum power over a wide range of irradiance, air temperature and wind values.

A multiple linear regression is used to rate the maximum power at standard concentrator reporting conditions, defined as T_0 = 20ºC; v_0 = 4m/s; E_0 = 850W/m^2, where E is the direct solar irradiance; T_a is the air temperature; v is the wind speed and P is the maximum power.

The calculation of the results is carried out by computing the regression coefficients a_1, a_2, a_3 and a_4 by performing a multiple linear regression of P as a function of E, v and T_a using Equation 14.

$$P = E \cdot (a_1 + a_2 \cdot E + a_3 \cdot T_a + a_4 \cdot v) \quad (14)$$

In order to calculate the nominal power of the system, the value of P_0 is determined by substituting the values of T_0, v_0, E_0, and the calculated values of a_1, a_2, a_3 and a_4 in Equation 15.

$$P_0 = E_0 \cdot (a_1 + a_2 \cdot E_0 + a_3 \cdot T_0 + a_4 \cdot v_0) \quad (15)$$

The same data as was used for the interpolation methods has been used to carry out the regression, which means that there are seven days of data available for each concentrator. Prior to carrying out the calculations, the data was filtered for radiation higher than 700W/m^2 with a variation lower than 0.4% every minute.

	Regression coefficients
a1	7.260300387
a2	-0.000547589
a3	0.007266881
a4	0.029880332

Table 10. Regression coefficients using data collected over five days.

The wind should not have variations higher than 5m/s every five minutes, which is not likely to pose any problems in Puertollano.

The results of the linear regression are clearly dependent on the amount of data used as

including only one day's data does not yield representative results. The calculated power for one day's data is P_0= 5518,8042W at the nominal conditions (T_0 = 20°C, v_0 = 4m/s, E_0 = 850W/m^2); three days' data results in calculated power of P_0 = 5988.8745W; while five days' data yields a power value of P_0 = 6000.7523W at standard conditions. The regression coefficients are shown in Table 10.

Using this method with the ISFOC standard conditions, an ambient temperature of 10°C ambient temperature needs to be forced in order to make the cell temperature as close to 60°C as possible. With this temperature and 3.3m/s wind speed, a power value of P_0 = 5921.20W is obtained, 3% smaller than the nominal value.

Methods comparison, summary and conclusions

Table 11 illustrates the final data of the array power output at standard conditions of DNI = 850W/m^2, cell temperature = 60°C and wind lower than 3.3 m/s for an entire concentrator system.

On comparison of all the aforementioned rating procedures, it must be noted that these results are not definitive as they are derived from only four months of measurements in one location using only two concentrators. Futures studies will confirm the validity of these first results.

Secondly, it must also be stressed that that some of the methods mentioned here were developed for modules and indoor measurements and, contrarily, these procedures were applied to entire systems and outdoor measurements under real conditions.

	Power in STC conditions (W)	Diff
Nominal Power	6100.000	0.00%
PV method	6474.536	6.14%
Bilinear interpolation	5616.638	-7.92%
Regression method	5921.205	-2.93%
ISFOC worst case	6216.420	1.91%

Table 11. Array power output of the different procedures in ISFOC standard conditions (DNI = 850 W/m^2, cell temperature = 60°C and wind lower than 3.3 m/s) vs. nominal power.

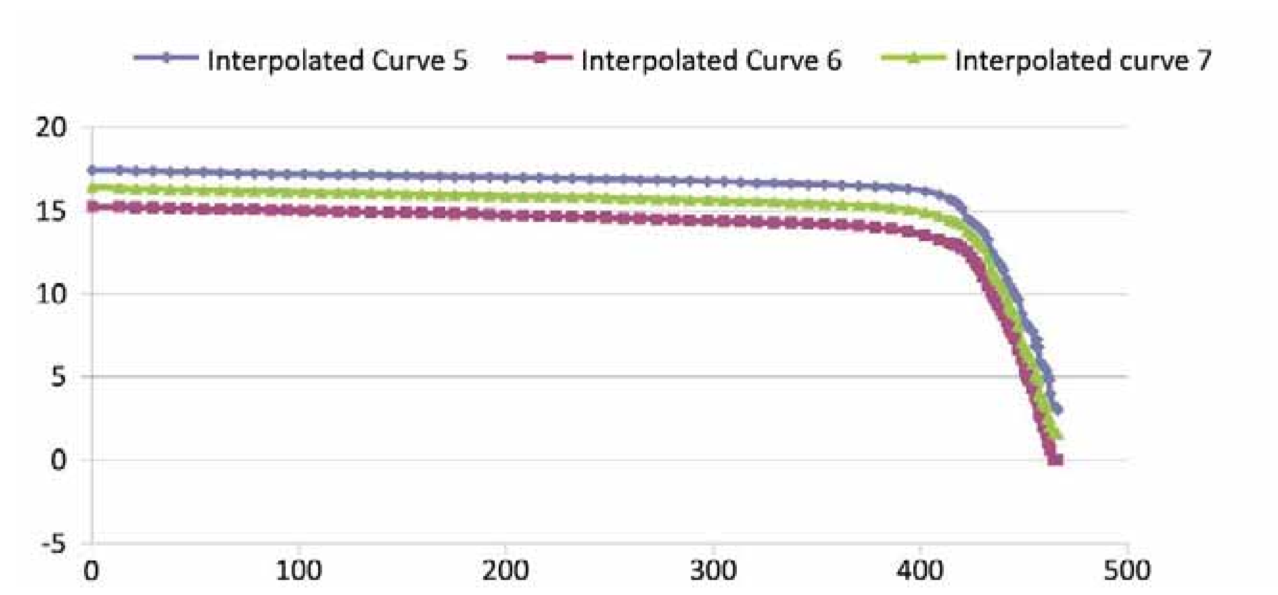


Figure 6. Translated and interpolated curves 5, 6 and 7, achieved using the bilinear interpolation method.

Power Generation

Following this study of the different methodologies, it can be concluded that:

- The first method based on the PV standard needs several days to perform the measurements requires for the data table, and even so, not all of the required measurements have been obtained in this case. The procedure to obtain the data under the condition of shading and light filtering is not feasible for a whole concentrator. New procedures for indoor and outdoor conditions need to be developed for this new standard proposal.
- The method of bilinear interpolation also needs many different measurements, taken at different times of the year, as well as intensive calculations.
- The regression methodology needs at least three to five days to ensure good results. The final coefficients do not necessarily have a physical interpretation as shown previously.

The ISFOC method has proven that with only a few measurements in the given measurement conditions and with only one simple calculation, the results are repetitive and stable, even at different times of the year. The narrow operating conditions of CPV systems allow a good stability for corrections.

Conclusions

The procedure chosen by the IEC Committee as the international standard for power rating is that based on the flat PV power rating defined with a different set of conditions. Therefore all efforts need to be focused on the development of measurement procedures under this set of conditions.

As this paper has demonstrated, the CPV set of parameters needs to be reduced to the narrow operating conditions of the CPV systems. Measuring the entire set of conditions under real conditions is very difficult in many locations. Therefore, a new procedure for outdoor conditions measurement need to be set but, more importantly, there is now an opportunity to develop new solar simulators and standards to carry out this procedure under indoor conditions.

ISFOC's procedure will be used as an international technical specifications reference for acceptation plants. Furthermore, the equations could even be used as a way to obtain the theoretical values for the entire set of measurement conditions.

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About the Authors

Francisca Rubio graduated as an electronic engineer from Granada University in Spain. She worked for 10 years in the fields of electronics and LEDs and was responsible for the Electronic Area in the R&D Department of Valeo Lighting in Martos, where she developed LED-based headlamps for the automotive industry. She joined ISFOC in September 2006 as head of the R&D Department.

Pedro Banda has a Ph.D. in electronic engineering from RMIT in Australia and graduated as a telecommunications engineer from UPM in Spain. His background is in the semiconductor industry, where he held various technology, development and management positions at Lucent Technologies, BP Solar (Spain) and IMEC (Belgium). He currently holds the role of ISFOC Director General.

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Market Watch

News

China offers big subsidy to solar power developers

In a move that is set to boost the solar sector, China has launched an unexpected plan, named the "Golden Sun" project, to offer large subsidies to independent solar power projects from around the country.

The Chinese Ministry of Finance said the government would subsidize 50% of investment for solar power projects as well as relevant power transmission and distribution systems that connect to grid networks. The subsidy amount will be 70% for independent photovoltaic power generating systems in remote regions that are off-grid.

The government plans to install more than 500MW of solar power pilot projects in two to three years. But the total generating capacity in such pilot projects in each province in principle should not exceed 20MW.

Grid companies are required to buy all surplus electricity output from solar power projects that generate primarily for the developers' own needs, at similar rates to benchmark on-grid tariffs set for coal-fired power generators.

Earlier this year, the Ministry said it would provide ¥20/Wp of subsidy for projects attached to buildings that have capacity of more than 50kWp, which could cut the power generating cost by around half to about ¥1/kWh.

Each project must have a generating capacity of at least 300kWp to qualify for the subsidy, in addition to other requirements, while construction will have to be completed in one year and operations will have to last for at least 20 years.

Those likely to benefit from these subsidies include, Suntech Power, Yingli Green Energy, Trina Solar and JA Solar.

China is expected to raise its 2020 solar power generation target more than fivefold to at least 10GW. With incentives, analysts expect over 2GW in new solar capacity will be installed as early as 2011, up from just over 100MW in 2008.

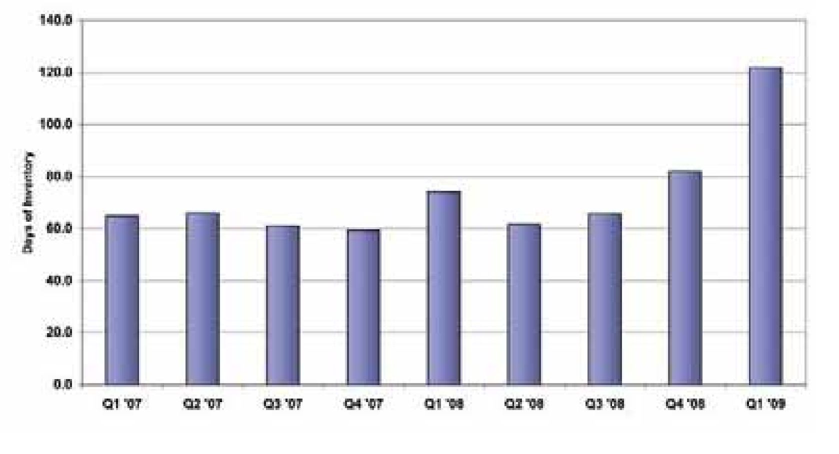
U.S. News Focus

Fresco Solar offers US$2.95 per installed watt pricing for megawatt-scale PV power systems in US

Fresco Solar says it will build solar photovoltaic ground arrays of 1MW or more anywhere in the United States for US$2.95 per watt or US$2.95 million per megawatt system. The Morgan Hill, CA-based engineering, procurement, and construction company bases its new pricing model on the DC STC size of the PV system.

The package includes delivery, installation, and testing of the racking, panels, and inverters as well as associated foundations and wiring. The price does not include sales and use taxes, local permits and fees, and any land development costs.

Solarbuzz's latest retail module price survey found 420 modules priced (without sales tax) below US$4.75 per watt, with the lowest prices from U.S. retailers for a multicrystalline silicon module at US$2.48 per watt and for a monocrystalline module at US$2.80 per watt. As for thin-film panels, the consultancy found units priced as low as US$1.76 per watt from an Asian-based retailer. Module costs usually account for 50% or more of the total installed cost of a PV power system.



Source: Photovoltaics International

iSuppli Corp: Average days of inventory in the PV industry (July 2009).

iSuppli warns over solar industry supply chain inventory build

Market research firm iSuppli has warned that solar module inventory held in the supply chain increased significantly in the first quarter of 2009, due to continued capacity additions and weaker than expected demand. Average inventories throughout the solar supply chain actually increased by 64.3% in Q109, according to iSuppli. Combined supply chain inventories (average days) that include polysilicon and wafers as well as cells and modules actually increased to more than 121 days in Q109, up from 74.2 days in Q108.

"The worldwide solar industry for the first quarter added the equivalent of one-and-a-half months of excess inventory in just one year," said Dr. Henning Wicht, principal analyst, photovoltaics research, for iSuppli. "With new polysilicon capacity coming online this year, the PV industry will suffer further price erosion, at all nodes of the value chain."

Indeed, research undertaken by PV-Tech in March 2009 highlighted that there had been a 50% or more increase in polysilicon capacity projections from the major producers through 2012, compared to just nine months earlier.

Veeco Instruments announces DayStar Technology assets purchase

Veeco Instruments has completed a transaction to purchase certain assets of DayStar Technologies. This decision highlights Veeco's penetration of the rapidly growing CIGS solar market. This news came less than a week after the company's COO, Ratson Morad resigned from the company.

Veeco has purchased selected equipment, taken over leased facilities and hired DayStar's R&D group in Clifton Park, New York.

U.S. House passes historic energy and environmental bill; Obama, solar industry execs laud action

In a political victory for President Barack Obama, House Speaker Nancy Pelosi, and their allies in Congress, one of the strongest pieces of energy and environmental legislation in American history narrowly won passage in the U.S. House of Representatives. After a flurry of last-minute intense lobbying and political deal-making, HR 2454 – the American Clean Energy and Security Act (ACES) – passed by a close 219-212 tally, which included 44 Democrats voting against the measure and 8 Republicans voting in favour of it.

The bill now goes to the Senate, where it is expected to go through some potentially major revisions and may have a tough time being approved.

President Obama applauded the House's passage of the bill in his weekly address, saying the legislation "will open the door to a clean energy economy and a better future for America."

"The energy bill that passed the House will finally create a set of incentives that will spark a clean energy transformation in our economy," said the U.S. chief executive. "It will spur the development of low carbon sources of energy – everything from wind, solar, and geothermal power to safer nuclear energy and cleaner coal. It will spur new energy savings, like the efficient windows and other materials that reduce heating costs in the winter and cooling costs in the summer. And most importantly, it will make possible the creation of millions of new jobs."

"The list goes on and on, but the point is this: this legislation will finally make clean energy the profitable kind of energy," claimed President Obama later in his address. "That will lead to the creation of new businesses and entire new industries. And that will lead to American jobs that pay well and cannot be outsourced."

Solar and other clean energy leaders also praised the U.S. House's passage of ACES.

"Leveraging the collective experience at the state and international levels over the last decade, the climate bill is an impressive feat of legislative engineering that sets feasible near-term targets for GHG (greenhouse gas) reductions while embracing the importance of aggressive long-run goals," commented Dan Adler, President of the California Clean Energy Fund, a nonprofit organization.

"While the cap and trade component of this bill is critical, the importance of the national standard for renewable energy generation should not be overlooked. It will take years to fully regulate carbon dioxide. In the meantime, this bill provides financing mechanisms that will increase the use of renewable energy immediately, curbing climate change emissions and spurring significant investment in the green economy now."

The comprehensive climate protection and clean energy bill, if passed in some form by the U.S. Senate and amended by both the House and Senate, would likely land on President Obama's desk for signing later this year.

European News Focus

Solar Millennium completes sales of 25% stakes in Andasol 1 and 2

Solar Millennium AG sold 25% stakes from the Andasol 1 and 2 solar plants to ACS/Cobra Group, a Spanish company with a history of buying from Solar Millennium. The sale of the stakes improves Solar Millennium AG's liquidity situation even further and added an earnings effect of €12 million. As a result, Solar Millennium has changed its funding strategy for the Andasol power plants. No other details from the contract were disclosed.

Spain reins in thermsolar and PV plant expansion

The Spanish government has decided to cap the amount of thermosolar and photovoltaic plants allowed in the country to reduce the price load on ratepayers and taxpayers. A Royal Decree will go to Spain's energy regulators to enforce this measure.

The Spanish government promotes clean fuels by letting generators charge as much as 10 times more for renewable energy. This price hike, in combination with guaranteed returns for 25 years, attracted €20 billion of investment to solar power.

Initially, the ministry had too many requests to review and register and as a result the photovoltaic industry's activities halted for almost five months. Determined not to make the same mistake again, the energy committee is working "as quickly as possible" on the registration process for thermosolar plants – about 100 applications totalling 4,300MW of capacity as of 19 June 2009. The government's current thermosolar energy goal of 500MW has already been met threefold and once it reaches its 2010 benchmark another new law will be drafted.

Solyndra's backlog passes US$2 billion as new sales agreement signed

Cylindrical CIGS-based thin-film PV specialist Solyndra has passed the US$2 billion in sales backlog with the signing of a new long-term sales agreement with German systems integrator Umwelt-Sonne-Energie, worth US$238 million through 2013. Unlike other thin-film producers, Solyndra is specifically targeting only rooftop installations, due to its unique solar system technology that is claimed to generate more electricity on an annual basis, compared to other technologies from typical low-slope commercial rooftops.

Solyndra's thin-film module.

In October 2008, Solyndra's backlog stood at US$1.2 billion, and the company has since secured over US$800 million in long-term contracts. Europe is a key market for Solyndra and in particular Germany. Umwelt-Sonne-Energie mainly operates in Germany as well as the Czech Republic, Belgium, Austria and Croatia.

MEMC makes major investment in downstream solar projects with Q-Cells

MEMC Electronic Materials and Q-Cells International, a subsidiary of Q-Cells SE that specialises in building and operating PV power plants, have established a joint venture that will see MEMC partner with an investment of US$100 million in solar power plants. The first project is a massive 50MWp solar park in Strasskirchen, Bavaria, using crystalline solar cell-based modules. MEMC will have a 50% stake in the project. Upon completion, the partners said they would sell the park to a third party.

MEMC is able to invest such sums required due to its US$1.2 billion in cash and short-term investments and trades with almost no debt. China-based LDK is highly leveraged and does not have the capital to invest in the same way as MEMC.

Solar Millennium AG sells 25% stakes from the Andasol 1 and 2 solar plants.

News

German PV market overview

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ABSTRACT

The global PV market is undergoing fundamental change. According to a new survey by EuPD Research, Germany is once again the most important PV sales market worldwide this year. Current market conditions are tightening, but within Germany there is still plenty of undiscovered potential. The transformation of the PV market from a supply-driven sellers' market to a demand-driven buyers' market is, however, an accelerated process rather than a slow development.

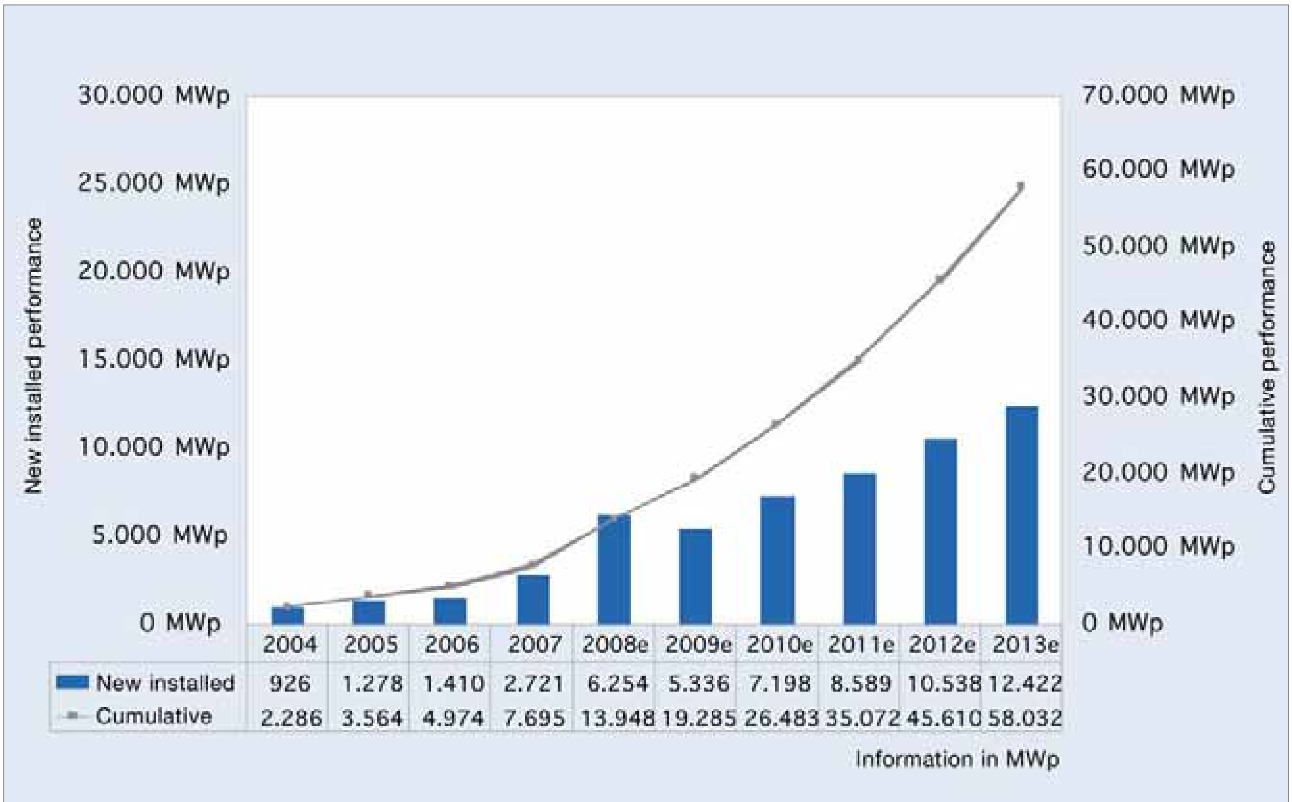
Germany takes the lead once again

After years of constant growth, the global PV market in 2009 is undergoing fundamental change, as shown in the graph in Figure 1. Multiple incidents – the severe financial crisis, the resulting tightening of the market environment and declining sales all along the value chain – are overlapping and to some extent strengthening the other's effects. On the one hand, the financial situation is weakening the largely investment-driven solar industry, while at the same time the political changes that occurred in the past few months are taking their toll on producers of solar components. The recently amended Real Decreto in Spain, for example, caused a total collapse of the once strong and promising Spanish PV market, a market that nowadays is considered to be no more than a one-hit wonder. The growth of other European markets including France, Italy and Greece has fallen far short of expectations, and the credit crisis is causing further uncertainty within the market. At this stage, even the multi-billion dollar bailouts and governmental investment packages have not had a significant positive influence on the tense market situation.

Natural process of consolidation

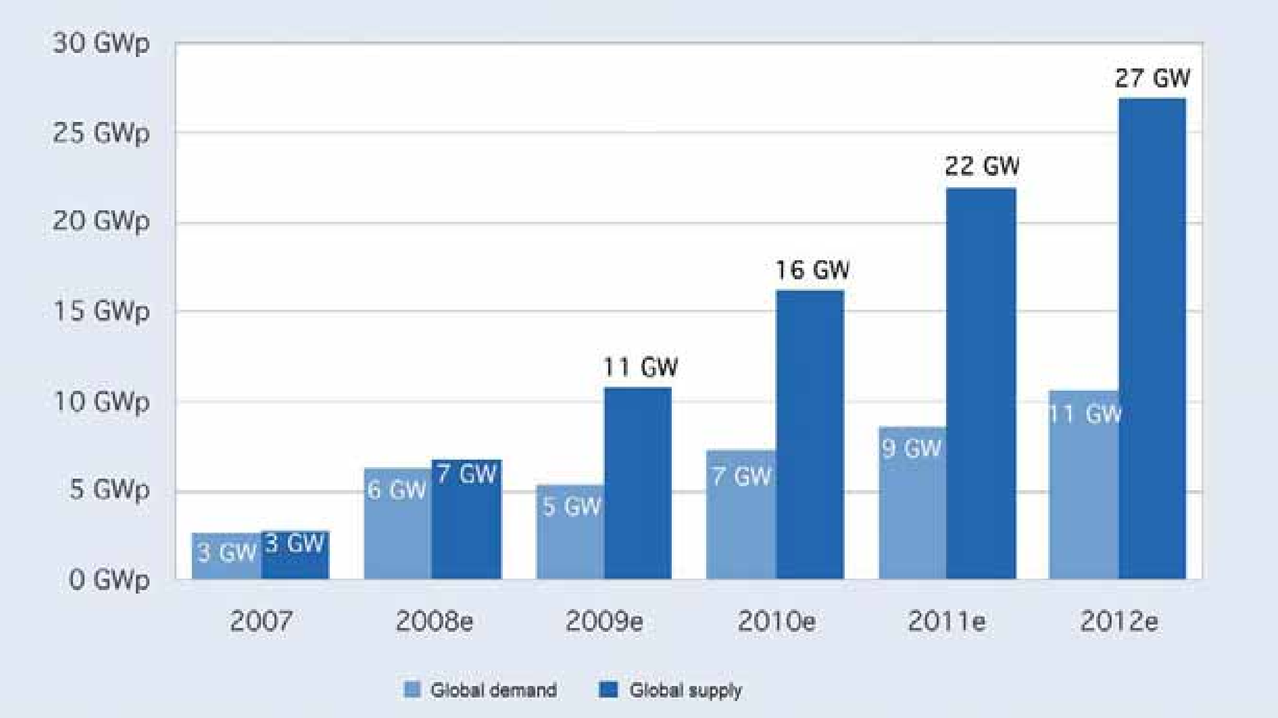
In the short term, adapting to these totally new market conditions will be an enormous challenge for producers, suppliers and distributors. For some of them it might even pose an existential threat. A long-term perspective shows that the PV branch is only undergoing a natural process of consolidation. But there is no need to panic. Within the last 10 years, photovoltaics has developed tremendously from a niche technology to a serious alternative in regards to power generation. From an economic perspective, the PV branch has developed from a small high-tech segment to a considerable business factor, especially in Germany.

> "The financial situation is weakening the largely investment-driven solar industry, while at the same time the political changes that occurred in recent months are taking their toll on producers of solar components."



Source: EuPD Research 2009

Figure 1. Development of global PV demand.



Source: EuPD Research 2009

Figure 2. Global supply vs. demand (including estimate to 2012).

It is clear that the market has experienced high annual growth rates resulting in stable sales areas but has been strongly dependent on national incentive schemes. According to the new EuPD Research survey on one of the core sales markets in the world, the German PV market, Germany will once again be the leading market worldwide in 2009. The study, entitled "The German PV Market: Understand the Demand – Explore the Potential" estimates a respectable cumulative 2GW of newly installed capacity in 2009. Due to robust framework conditions in Germany and strong non-partisan governmental support, the German PV market remains solid in comparison to its international competitors.

Although context factors in Germany are very positive, the regional demand will not be enough to compensate for the global supply surplus. However, guaranteed feed-in tariffs (FiTs) by the Erneuerbare-Energien-Gesetz (EEG) as well as secured access to capital for plant builders by the state-owned bank Kreditanstalt für Wiederaufbau should ensure constant market growth.

Knowing the market is crucial

In general, all companies that are planning activities in the German market environment should consider the regional distinctions. While the aforementioned legal framework is consistently positive, the distribution processes in this country are unique. The authors' findings suggest that in the German market, the installer is the ultimate gatekeeper, which leads to the conclusion that companies and wholesalers should establish a strong regional network with installers or experts on site. Although the process of diffusion in the German market is very well developed, familiarity with installer networks as well as the knowledge of undiscovered potentials is crucial.

> "In the German market, the installer is the ultimate gatekeeper, which leads to the conclusion that companies and wholesalers should establish a strong regional network with installers or experts on site."

According to the study, the theoretical potential for rooftop systems in Germany is between 100 and 170GW, depending on the underlying model assumptions, approximately half of which consists of one- and two-family homes (i.e., private customers). Considering open-space systems, it is political will, rather than availability of space, which will define the direction of the market development. While some states like Bavaria and Brandenburg have held a very liberal position on the use of PV in the past and are even planning to extend the number of solar parks, others states like Baden-Württemberg and Hesse pursue a rather restrictive approval policy.

Regional differences are not only apparent in the various governmental approval practices, they are also caused by different natural conditions like the varying amount of solar radiation. In many cases, there are also regional trends, which can be attributed to diffusion processes, different earning capacities, population densities, etc. Close inspection of these disparities reveals interesting market insights and also shows blank spots on the German PV map.

Market growth: moderate but stable

EuPD Research expects the volume of the German PV market to add up to a record 1.75-2.08GW in 2009, which will likely be surpassed in 2010. Depending on whether the development in the supplier-driven market is sustainable, two scenarios are realistic from 2011 onwards. If the industry is able to sustain continuous market growth, caused by the consequent development of the German market and the initiation of pull effects on the demand side, an increase in annually installed capacity of up to 3.2GW in 2012 is possible. If the strong market growth in 2009 and 2010 should turn out to be a one-time effect – caused by the current strengthening of sales efforts on the German market and the slump in prices – a reduction in the development of the market can be expected. Based on our 'consolidated growth scenario', the authors expect the market volume in 2011 to amount to about 2.3GW, a value that would be below the newly installed capacity in 2010. From 2011 onwards, however, the market should begin growing again on a moderate but stable level.

In the medium term, key indicators like the decline of system prices and the positive business climate cause positive signals for the market development. In addition, most market segments still contain huge market potential, and many regions within Germany have remained largely unaffected by the PV boom of the past few years.

Where is Germany heading?

In 2009, the development of the PV industry will be determined by the amendment of the EEG as well as by further far-reaching circumstances like the financial crisis, the upcoming Bundestag election and the excess supply. Presumably, the financial crisis will have quite different consequences for the demand and supply side. In comparison to other countries, the German demand side is less seriously affected by the crisis because the credit volume of the Kreditanstalt für Wiederaufbau (KfW) has been increased to up to €50 million and guarantees reliable access to capital. In addition, the appeal of safe return investments like PV plants has been increasing because of the continuing slump of the capital markets. This hypothesis is also supported by the results of a EuPD Research survey of German installers and wholesalers, in which about one third of installers expects the financial crisis to further stimulate the demand for PV products.

> "In the first quarter of 2009 the cumulative newly installed capacity was estimated to be 230-290MW, based on statements by market participants along the value chain."

But the effects of the excess supply are different for the various market participants. For the suppliers, it intensifies the competitive pressure and as a consequence further accelerates the consolidation process. Excess supply also encourages the price decline of PV products, which again could have positive effects on the return for the end customer and eventually stimulate demand. The effects should be noticeable at least in the customer groups where the rate of return is the decisive purchase criterion. The next Bundestag election at the end of the third quarter of 2009 is another important event for the market. However, EuPD Research assumes that the effects of the election on the PV market will only be felt in the medium term, if at all.

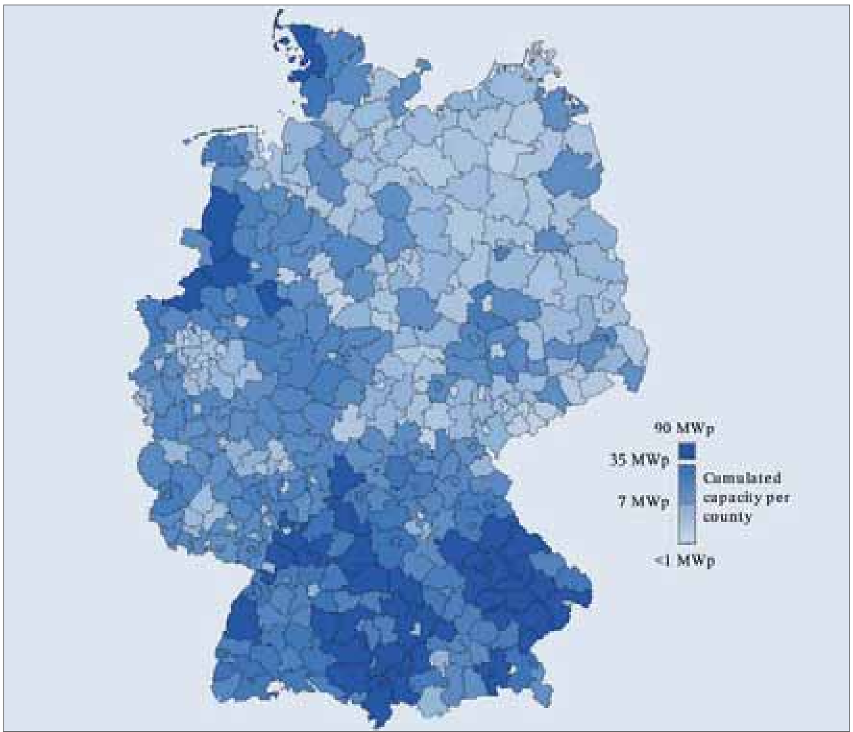


Figure 3. Cumulative capacity 2008 – Germany.

Source: EuPD Research 2009

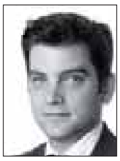
There are several indicators which give reason to hope for a record year in the German PV market, including the decline of module and system prices caused by the global excess supply, relatively moderate (sometimes even potentially positive) effects of the global financial crisis, the record high in business expectations for the next six months, and no immediate risks for German PV. Nevertheless, in the first quarter of 2009 the cumulative newly installed capacity was estimated to be 230-290MW, based on statements by market participants along the value chain. Although this level is not alarmingly low for a first quarter, neither is it the hoped-for sign of considerable market growth in the German market.

Reference

[1] "The German Photovoltaic Market: Understand the Demand – Explore the Potential", EuPD Research, June 2009.

EuPD Research's report "The German PV Market: Understand the Demand – Explore the Potential" was published in June 2009. The comprehensive survey reflects current developments in the world's leading PV market and analyzes customer segments and market potentials at a national and regional level. For further information contact EuPD Research at welcome@eupd-research.com.

About the Authors



Daniel Pohl, MA, graduated from the University of Bonn and the University Paris-Sorbonne with a qualification in North American Studies, literature and political science. He has been working as an editor and media consultant in the field of economics and renewable energies and is now heading the corporate communications department at EuPD Research in Bonn. Throughout his career he published numerous articles on diverse energy topics in national and international special-interest magazines.

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Recent trends in the PV industry: lessons from the patent application filing figures

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Alberto Visentin, European Patent Office, Berlin, Germany

ABSTRACT

This article will look at what trends can be gleaned from patent application publication figures of the past decade in the sector of PV technology. The study looks at the number of patent applications in PV technology published worldwide between 1999 and 2008. The data will show in which regions and countries patent protection is being sought. The figures are taken from patent documentation databases developed by the European Patent Office (EPO) and Japan Patent Office or databases used worldwide and available at the EPO, and they are retrieved mostly using patent classification schemes. The article also provides a brief overview of the role of the EPO and what companies, researchers and individual inventors should keep in mind when applying for a European patent.

Introduction

Patenting activity in the photovoltaic sector has grown rapidly during the past decade, with the number of PV patent applications published by the world's major patent offices more than tripling in the past 10 years (see Fig. 1). This is partly due to the generally growing trend of seeking intellectual property protection all over the world, as more and more individual inventors, companies and research institutions realise the importance and economic impact of patenting their inventions. Growth in the number of PV patent applications has outpaced other sectors, reflecting the growing interest in renewable energy sources in general and recent advances in PV technology in particular.

This paper presents results for some of the most technically and economically relevant PV technologies, such as crystalline and polycrystalline silicon cells, thin film cells, III-V solar cells, dye-sensitized cells, organic solar cells, architectural integration of solar modules and PV concentrators.

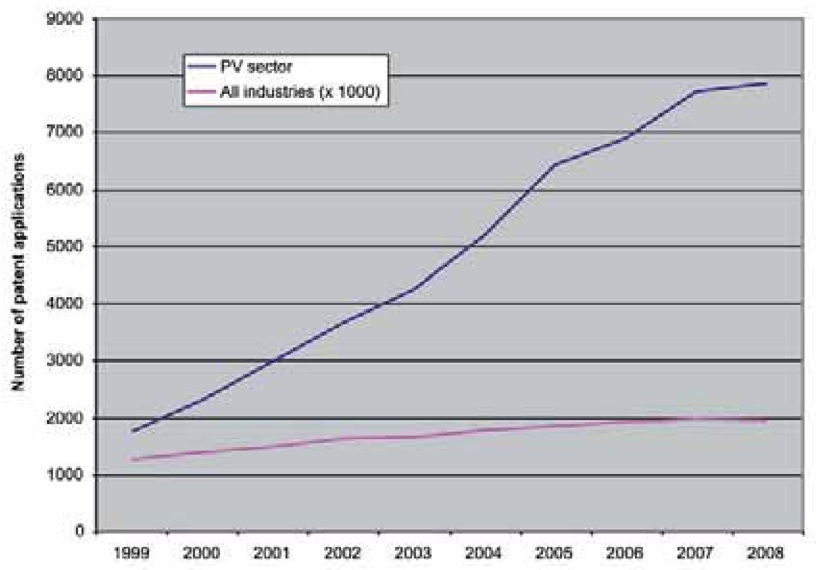

Figure 1. Global PV applications versus all industry applications.

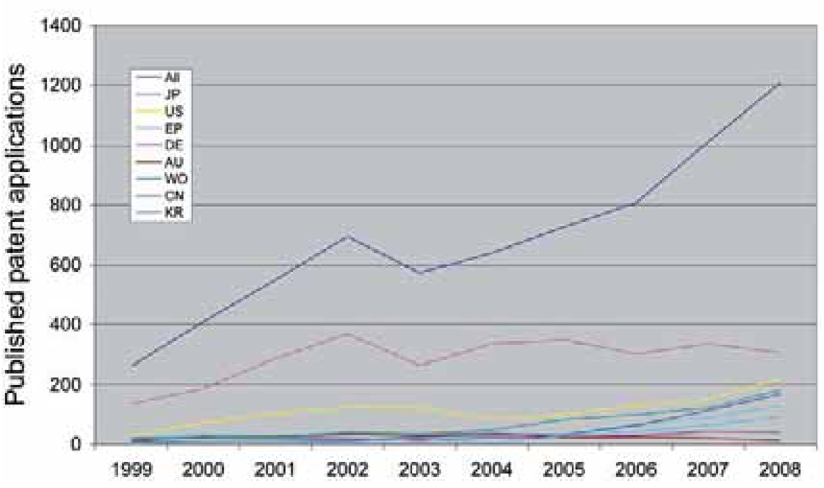

Figure 2. Published patent applications – crystalline and polycrystalline Si devices.

"The number of patent applications is widely regarded as an indicator of the level of innovation in a specific technical field."

Looking at patent filing figures is useful because it can shed light on the success of scientific research and development efforts in a given sector. The number of patent applications is widely regarded as an indicator of the level of innovation in a specific technical field. At the same time it can also give an indication of technology trends that are considered potentially successful.

Legend:

- **All** – patent applications filed at the main patent offices around the world (including, but not exclusively, the below)
- **JP** – patent applications filed with the Japan Patent Office
- **US** – patent applications filed with the US Patent and Trademark Office
- **EP** – regional patent applications filed with the European Patent Office
- **DE** – patent applications filed at the German Patent and Trademark Office
- **AU** – patent applications filed at IP Australia
- **WO** – international patent applications filed at the World Intellectual Property Organization under the Patent Cooperation Treaty, for which the EPO and a select number of major national offices serve as 'international searching authority' and 'international preliminary examining authority'.
- **CN** – patent applications filed at the State Office for Intellectual Property of the People's Republic of China
- **KR** – patent applications filed at the Korean Intellectual Property Office.

The growth in PV patent applications seen in the past 10 years reflects the strong interest of the market and thus a growing demand for patent protection in the field. Analysis of the yearly patenting activity in specific sectors of PV technology and its distribution in different countries allows a detailed study of the trends in targeted markets and the differentiation of growing markets from those that are stable or falling.

Given the multidisciplinary nature of PV technology, which requires experts to have a thorough knowledge of material science and of several specific production technologies for a large spectrum of semiconductor materials both in the laboratory and in industry, it is difficult to provide a comprehensive picture of patent applications relating to all sectors and sub-sectors of PV technology. Therefore, results in this study are given for some of the technically and economically most relevant PV technologies, namely:

Crystalline and polycrystalline silicon cells: this includes all applications related to manufacturing methods for the production of crystalline and polycrystalline silicon solar cells (including multi-step methods) and to the structure of the cells (see Fig. 2).

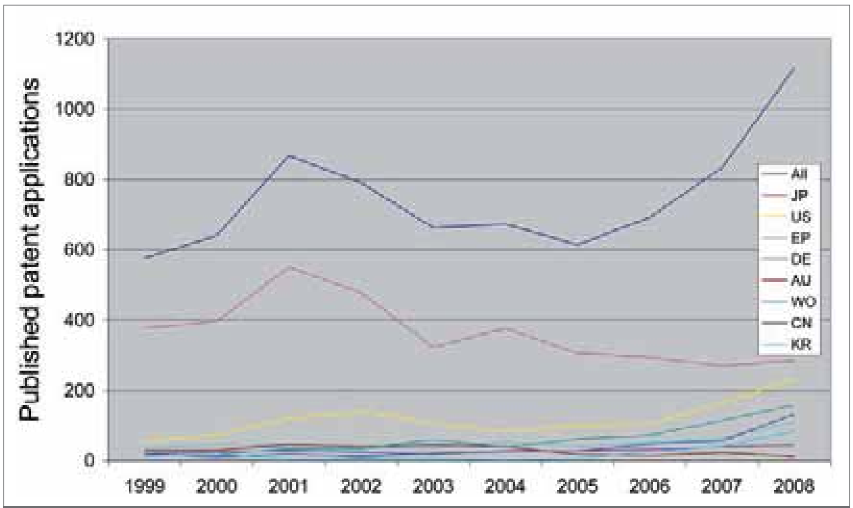

Figure 3. Published patent applications – thin film solar cells.

Thin-film cells: this important sector specifically includes amorphous silicon cells, CIS (and related compounds) cells and II-VI (CdS/CdTe) cells, comprising the methods of materials growth, the structure of the cells and the monolithic integration of series-connected cells to form thin-film modules (see Fig. 3).

III-V solar cells: this comprises III-V material cells, from monojunction GaAs or InP cells to multijunction cells including ternary and quaternary materials. Included also are methods of production of the cells. These cells have recently reached the highest levels of efficiency and are important for use in space and under high light concentration (see Fig. 4).

Dye-sensitized cells: this sector is dedicated to all technical aspects of so-called DSSC (dye-sensitized solar cells) comprising the structure of the cells and modules, their components and their method of fabrication. Although relatively new, this technology has already shown strong growth in numbers of patent applications (see Fig. 5).

Organic solar cells: this sector includes all developments related to solar cells comprising organic materials, and to their methods of fabrication. Also included are patent applications concerning specific organic materials used in organic solar cells (see Fig. 6).

> "Globally acting entrepreneurs tend to seek protection in several countries for the same invention and therefore apply for patent protection in each targeted country."

Architectural integration: this refers to the combination of solar cells and modules in buildings and urban landscapes. An important part of this sector is dedicated to roof systems, roof modules and their specific mounting technology. Important recent market developments in this sector are stimulated by national laws providing a guaranteed tariff for the electricity produced by small PV plants installed by private persons on the roof of their homes (see Fig. 7).

PV concentrators: this sector is dedicated to all aspects of solar light concentration to increase considerably the intensity of light coming on the cells. With the use of concentrators, small solar cells can produce more energy than a much bigger solar cell without concentration. There has been a major increase in patent applications in recent years, surely due to the solar-grade silicon shortage that has opened the way to new PV developments in alternative sectors, consequently leading to a growing demand for patent protection (see Fig. 8).

For each of these technologies, the annual total number of patent applications published around the world for the past 10 years was extracted from patent databases and provides an overview of the development of patent filing activity over time in each individual sector.

The figures also show the main geographical areas in which patent protection was sought, thus giving an indication of the market importance of those countries/regions for the patent applicants. However, this particular

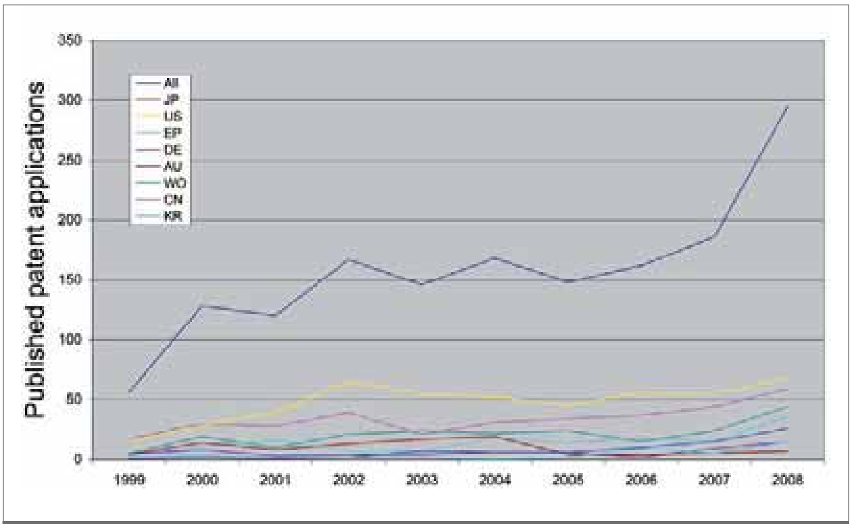

Figure 4. Published patent applications – III-V solar cells.

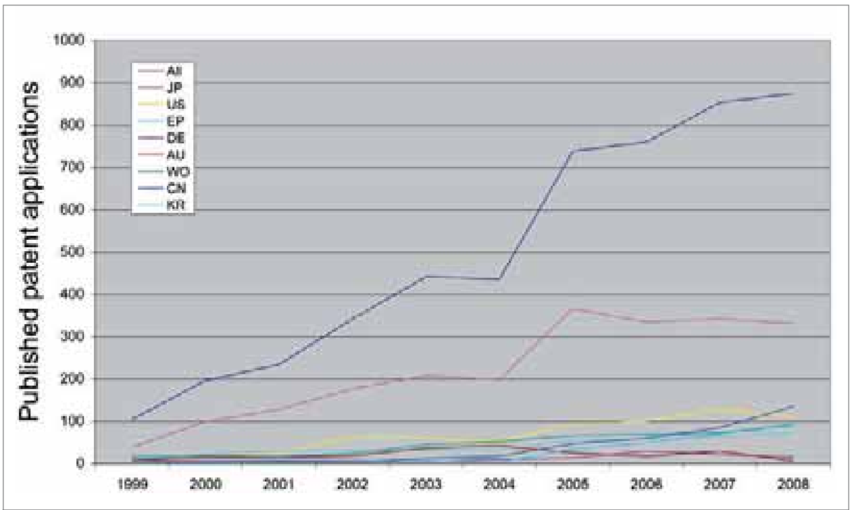

Figure 5. Published patent applications – dye sensitized cells.

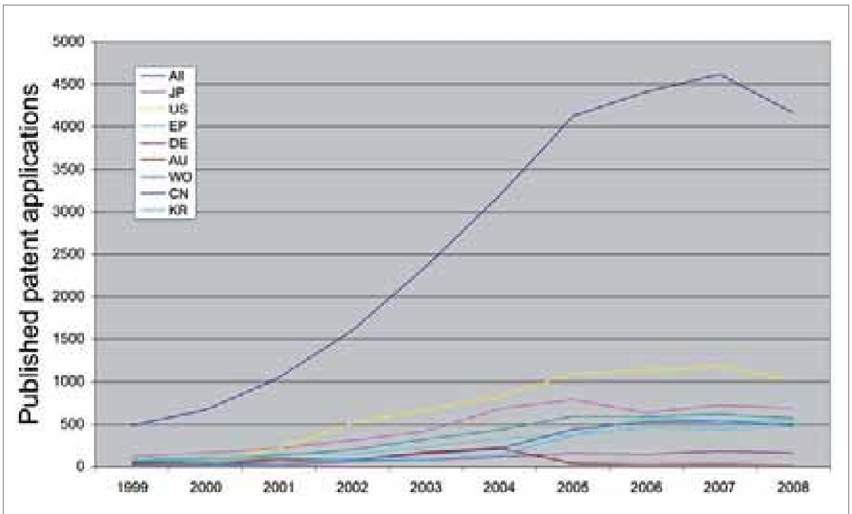

Figure 6. Published patent applications – organic cells.

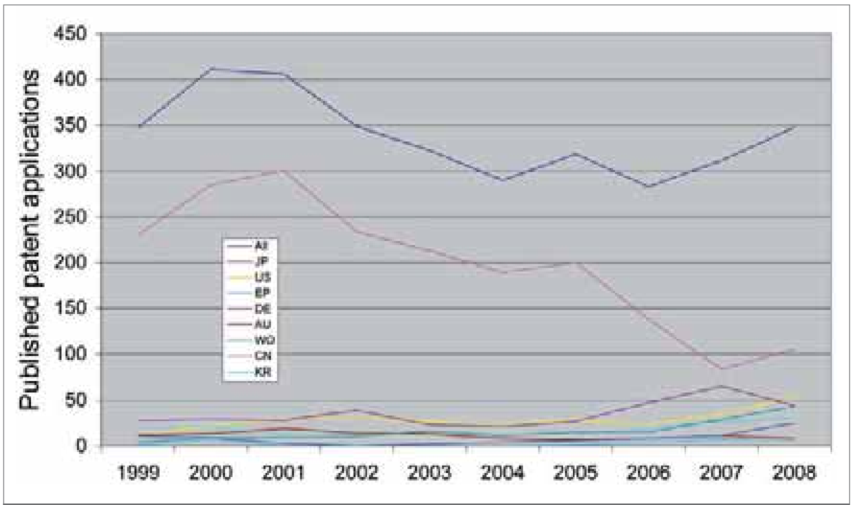

Figure 7. Published patent applications – architectural integration.

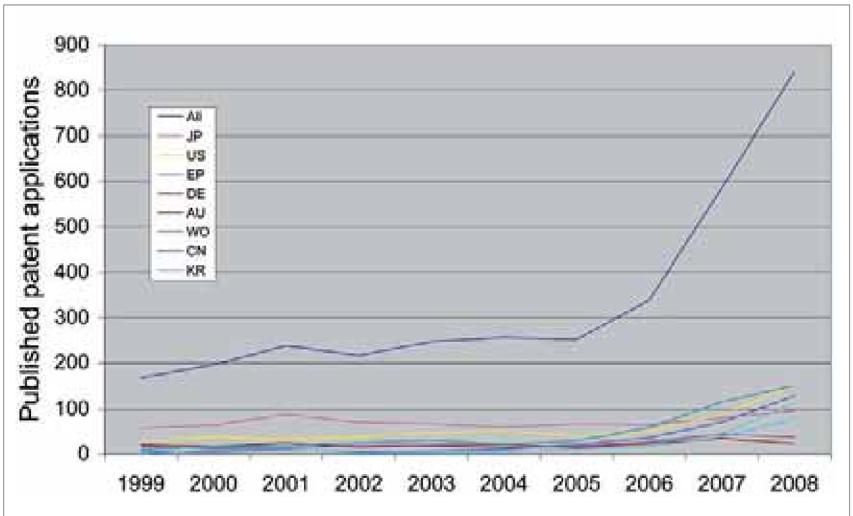

Figure 8. Published patent applications – PV concentrators.

study does not attempt to provide information about the countries of origin of the inventions or the nationality of the inventors or patent applicants.

It is also important to keep in mind that the number of patent applications is not the same as the number of inventions, as globally acting entrepreneurs tend to seek protection in several countries for the same invention and therefore apply for patent protection in each targeted country. A significant number of applications filed would relate to one and the same invention, resulting in a 'family' of patent applications originating from that invention. With the methodology adopted for this study, the overall number of patent applications in a given sector and year are listed, irrespective of the number of applications belonging to the same family.

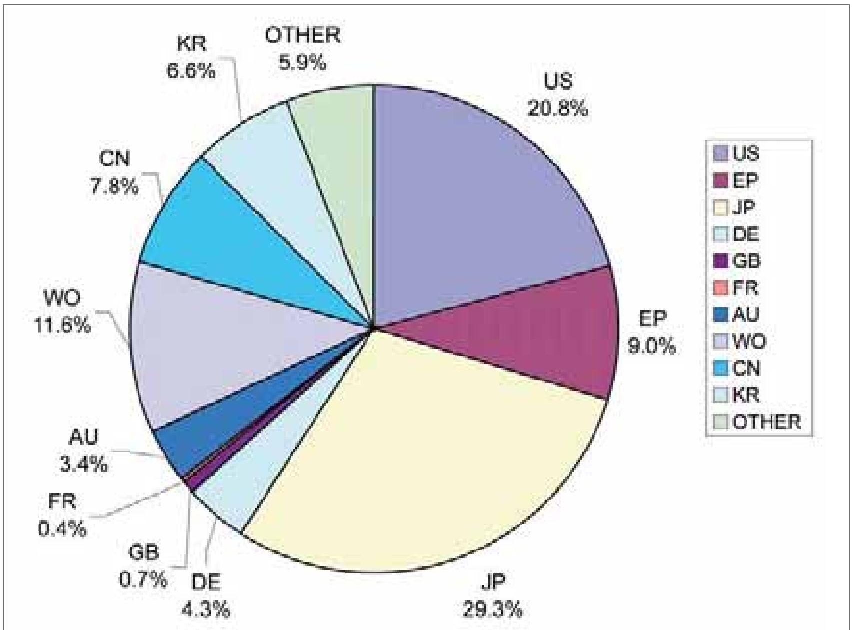

Figure 9. Global patent distribution 1999-2008.

Results and analysis

A look at the number of PV patent applications published worldwide between 1999 and 2008 reveals some interesting trends. Comparing the global filing figures for PV patent applications published in the past decade to the global figures for all patent applications published in all other technical fields (see Fig. 1), it is clear that the PV sector has grown much faster. The number of PV patent applications has more than tripled in the past decade (multiplied by 3.5, compared to 1.5 for all other applications). This demonstrates the increasing importance of patent protection in PV technology.

The distribution according to countries where patent protection is sought (see Fig. 9) is also interesting: most patent applications are filed in the countries/regions where PV technology is largely developed and used. Japan continues to receive the highest number of patent applications in the field, followed by the U.S. Also significant is the number of applications filed using the centralised procedures at the European Patent Office (EPO) and World Intellectual Property Office (international applications filed under the Patent Cooperation Treaty (WIPO (or WO) applications)). Taken together, they almost add up to the number of U.S. applications, showing that both systems, although relatively recent (the EPO has been in existence for just over 30 years), are widely recognised and used.

Also of interest is the strong showing of China and South Korea (CN and KR in Fig. 9). Hardly relevant for PV only a few years ago, both Asian countries, China in particular, are becoming increasingly important markets, with China now one the biggest producers of solar cells in the world. It is worth noting that the Chinese Patent Office (SIPO) was only opened in 1985, and has received during the decade examined in this study about the same number of PV applications as the EPO.

From the technical sectors perspective, while the figures do not show a clear trend in some areas (see the data for architectural integration in Fig. 7), a rapid pace of growth has been seen in other sectors, especially since 2005. A particularly large increase in the number of patent applications is apparent in PV concentrators technology (see Fig. 8), where the numbers grow by 404% between

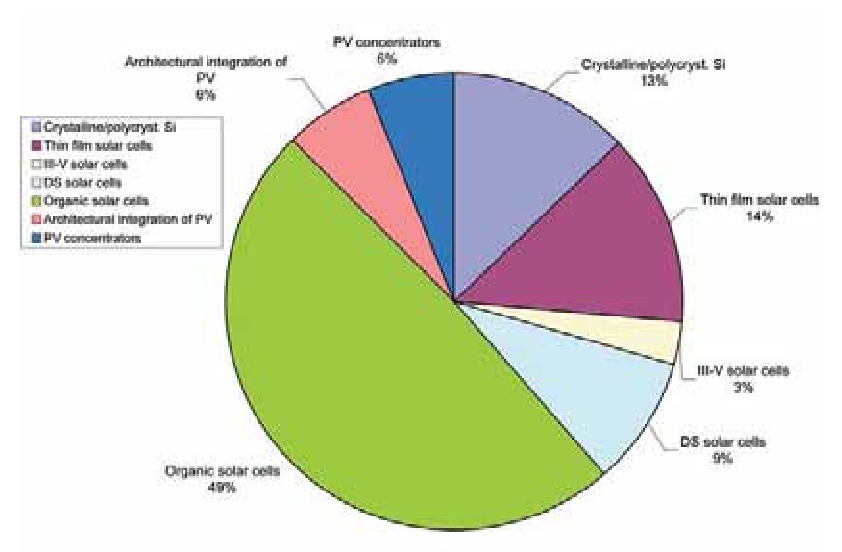

Figure 10. Distribution of main PV technologies 1999-2008.

1999 and 2008; in III-V cells (see Fig. 4), with an increase of 426%; in crystalline/polycrystalline Si cells (see Fig. 2) with an increase of 366%, and in thin-film cells (see Fig. 3), with an increase of 94%.

Even more impressive is the growth of applications in organic solar cell technology (see Fig. 6), with an increase of 754%, and in the field of dye-sensitized cells (see Fig. 5), which grew by 740%. It will be interesting to see if this trend continues at the same pace in the future.

A look at the distribution of technologies in terms of published patent applications in the past decade (see Fig. 10) is also interesting: the largest number of applications relate to organic cell technology (49%), followed by thin-film cells (14%) and crystalline/polycrystalline Si technology (13%). DSSC cells (9%), PV concentrators (6%) and architectural integration (6%) follow. III-V cell technology comes last with a contribution of 3%.

The evolution of this distribution over the years (see Fig. 11) is also telling: there is rapid growth in the number of patents related to new emerging sectors (organic and concentrator technology), while the more mature crystalline/polycrystalline Si technology still makes a strong showing, indicating a continuous effort in the further development of this successful technology.

The new DSSC cells are also undergoing important developments which result in a growing demand for patent protection, and PV concentrator technology with its recent large growth (see Fig. 8) will probably make up a larger proportion of applications in the near future. As for III-V solar cells, they showed a relatively stable number of applications in the decade till 2007 (see Fig. 4) and a clear growth in 2008, which will probably continue. Their position in the percentage distribution has remained quite stable. This technology is highly sophisticated and its use for specific applications (space, high concentration) without real alternatives speaks for its continued development in the future. But this technology will likely maintain the lowest position in the distribution, due to the high cost and complexity of the cells.

Notes on the methodology

The figures are taken from patent documentation databases developed by the European Patent Office (EPO) and the Japan Patent Office or databases used worldwide and available at the EPO. EPO patent examiners currently have access to 121 bibliographic databases (patent and non-patent literature), of which 23 are full text patent databases.

The figures were retrieved mainly using patent classification schemes. The systems used were those of the European Patent Office's scheme (ECLA), WIPO's International Patent Classification (IPC) scheme, the classification used by the Thomson Reuters World Patent Index (WPI), the Japanese classification schemes (FI and F-Term), and specific keywords. Each classification scheme has its own characteristics and the use of several allows one to retrieve documents in the most efficient and complete way.

"There is rapid growth in the number of patents related to new emerging sectors (organic and concentrator technology), while the more mature crystalline/polycrystalline Si technology still makes a strong showing."

For each technical sector, specific ECLA groups, FI and F-Term indices and IPC classification associated with relevant keywords were used to retrieve a data set as complete and precise as possible.

Patent applications are published 18 months after they are first filed, so figures shown for 2008, for example, relate to patents filed in 2006-7. In all the figures and the trends presented in this kind of study, one must therefore take into account that a time delay of 18 months is always present and cannot be avoided.

In this respect it is worth noting that the impact of the financial crisis on patent filing figures is not visible in this study. Any decrease or abrupt change in filing numbers after June 2007 would not yet be captured by these figures (which only include publications till December 2008).

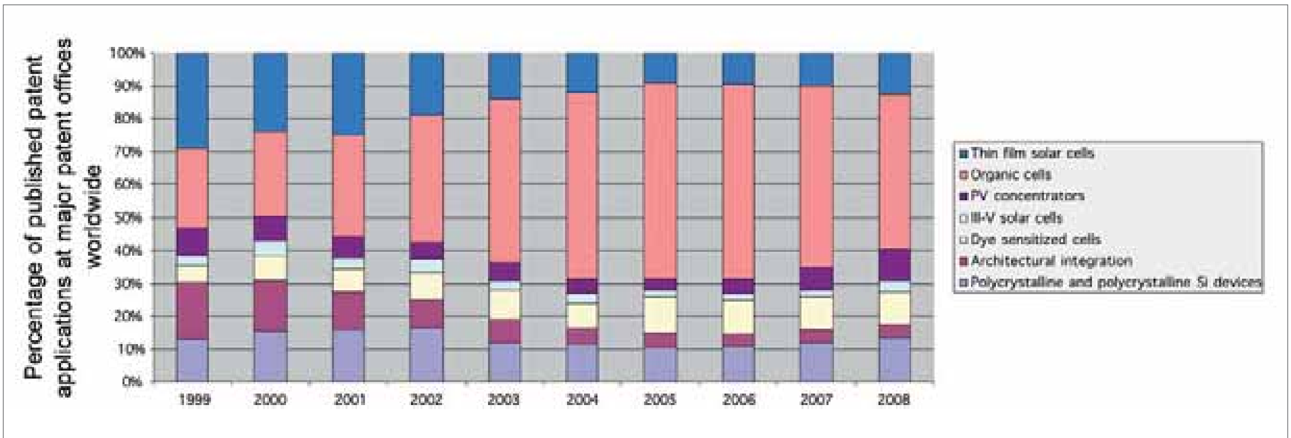

Figure 11. Evolution in the distribution of main PV technologies 1999-2008.

Patenting your invention

By filing a patent at the European Patent Office (EPO), it is possible to obtain patent protection in up to 39 European countries (and reach a market of about 570 million people) on the basis of a single application in one of the EPO's official languages (English, French or German). This makes it the largest transnational patent system in the world. Applicants select the countries in which they would like protection, and, if granted, the European patent has the same legal effects as a national patent in each country. Set up in 1977, the EPO has its headquarters in Munich with offices in The Hague, Berlin, Vienna and Brussels, and employs around 6,700 staff.

Under the European Patent Convention (EPC), patents are only granted for inventions that are new (not known to the public in any form prior to the date of filing or to the priority date), involve an inventive step (not obvious to a skilled person) and are industrially applicable (can be manufactured or used industrially).

There are several things to bear in mind before making a European patent application. Firstly, if an invention is made public in any way before an application is filed (e.g., during business negotiations, academic lecture, etc.), then it can no longer be considered new. Secondly, the fact that an invention is not commercially available does not always mean that it is new. Before filing a patent application, it can be useful to look at catalogues and trade journals to see what is already on the market; and, even more importantly, at the many published patent documents. The EPO's patent databases are the largest in the world: the Office's esp@cenet contains over 64 million patent documents from around the globe and is available via the internet free of charge. Information from patents can also be very useful in identifying business partners and sources of capital.

Patenting can be expensive. The fees for a European application depend very much on the number of designated states and the planned term of the patent. Fees are charged for filing, search, designation, examination, grant and printing, along with renewal fees and translation fees payable later. The overall costs usually also include fees for the services of a patent attorney. As with any investment, the risks and benefits need to be weighed up carefully. However, patenting is advisable in any country where an invention can be expected to yield significant economic benefits. As a general rule, it makes sense to file a European patent application rather than national applications when protection is sought in at least four European countries.

Benefits of a European patent

Patents provide inventors with an exclusive right to prevent third parties from commercially exploiting their inventions for up to 20 years from the date of filing. This enables them to recoup their development costs and gives them time to reap the rewards of their investment. But there are other reasons to file patents. Today, it is often important to have a large patent portfolio to be recognised as a serious business partner and raise capital. Patents have also become an important tool for measuring a company's performance, as well as a trading and bargaining device for cross-licensing and alliances.

In return for the protection bestowed by the patent, the holder has to disclose the details of the invention, which are published in the patent document. This contributes greatly to the dissemination of new technical knowledge. Over 80% of the world's technical knowledge can now be found in patent documents. This inspires further inventions and at the same time prevents the duplication of R&D work.

Quality patents for quality inventions

Every application for a European patent is subject to a thorough search by a patent examiner specialised in the field and a rigorous examination by a team of three patent examiners. This ensures that the application fulfils all the strict requirements of the EPC and only true inventions that deserve protection are patented. In addition, there are several legal mechanisms in place to enable the public to monitor the procedure and to allow decisions taken by the EPO to be challenged, one of which is inspection. European patent applications are published 18 months after the first filing and the file relating to it is open to inspection, meaning that any member of the public can view the communications between the EPO and the parties involved in the procedure free of charge [1].

The EPC also provides a means of centrally opposing European patents within nine months of grant. This legal procedure enables anyone to contest European patents. (Oppositions are filed against about 5% of the European patents granted each year.) In addition, any party to proceedings adversely affected by an EPO decision in grant and opposition proceedings can challenge this decision by an appeal to the EPO's judiciary, the Boards of Appeal.

Faced with a steady rise in the number of applications and a global backlog affecting all of the world's patent offices, the European Patent Office continues to work on making its procedures more efficient, while applying strictly the criteria for patentability and improving the standard of incoming applications.

The EPO also works closely with other patent offices in Europe and worldwide (especially the US, Japan, Korea and China) to make the patent system more effective by reducing duplication of efforts (by exploring work-sharing in everything from documentation and classification to search and substantive examination). As many companies operate globally, a large number of applications filed with the various offices relate to one and the same invention. Work-sharing is key to tackling the global backlog of applications.

Market Watch

Reference

[1] EPO Online Services [available online at http://www.epoline.org/portal/public/registerplus].

About the Author

Alberto Visentin earned a degree in physics from Rome University La Sapienza in 1977. From 1977 to 1979 he worked at the University of Cosenza (Italy) carrying out experiments on concentrating troughs for the exploitation of solar thermal energy. He joined the European Patent Office as a patent examiner in 1980 and has been working in the Berlin office of the EPO since 2003, dealing with the search, classification and examination of patent applications. He has worked in the field of semiconductor technology – in particular optoelectronic and photovoltaic (PV) devices for electricity generation – since 1985 and has presented statistical studies of PV patent applications at the European Photovoltaic Solar Energy Conference in 2004-07.

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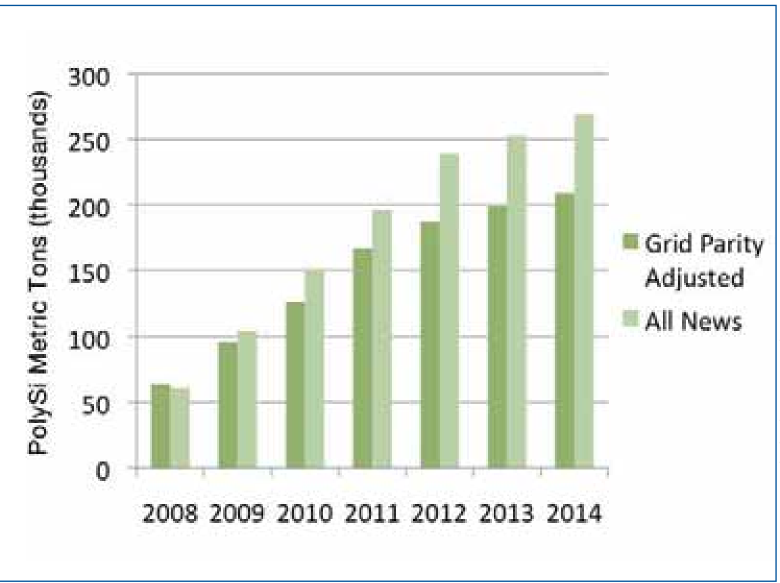
Smoke and mirrors: Will there be enough polysilicon in 2012-2013?

Courtesy of Hemlock Semiconductor

As the solar PV industry rushes headlong into the gigawatt era, the hunger for large quantities of polysilicon will need to be sated to keep the engine humming – even with thin-film PV taking a bigger bite of market share. Although the supply shortage has abated, few observers seem to have a firm grip on just how much poly will be in the pipeline and how much will be needed to meet the cell and module demand in the coming years. A presentation from one of the industry leaders at the recent Intersolar North America show brought some clarity to the poly supply discussion.

Hemlock Semiconductor VP Gary Homan reviewed how his employer has been adding capacity at a fast clip and will continue to do so for the next five years. With US$4 billion in announced expansions, the poly-pack-leading firm projects reaching manufacturing capacities of 36,000 metric tons in 2010 and 63,000 metric tons by 2014 at its plants in Michigan and Tennessee – up from its current capacity of just under 30,000MT.

In terms of what's been announced within the poly sector, that 63,000MT would place Hemlock far ahead of the number-two company in the space, Wacker, which has about 35,000MT projected capacity on the board.



Data source: Hemlock; chart: Tom Cheyney

Acknowledging the easing of the silicon shortage and an overall improvement in the sector, Homan wondered about how the effect of price erosion will drive demand and how future costs may affect the expansion plans of some poly manufacturers. He believes that all of the extra capacity coming online – essentially a 100% pop over the past year, enough to support 10GW of solar production – is contributing to driving silicon costs closer to grid parity levels.

Homan made no secret of his skepticism about some of the announcements made by upstart poly players, especially certain Chinese firms who he discounted as being little more than "smoke and mirrors." He questioned many of the new entrants' "sustainability," wondering about their ability to attract more venture or public financing, and whether they have what it takes to reduce their costs to meet the challenging criteria of the grid parity model (which some established poly companies have already done).

Noting how efficiency in the poly world consists of a combination of quality and consistency, he said that "cost of ownership demands high efficiency per gram of silicon," and that "lower-priced virgin poly will offer the best cost of ownership" based on a lower price coming from a lower cost structure. "Hyperpurity levels equal a higher photon efficiency," Homan explained, and consistent, predicable quality results in higher yields.

He used two data sets for his global polysilicon forecasts, both based on a combination of public information and Hemlock's own number crunching. One set incorporated all the announcements made in the space from both established and new players. The other, adjusted for grid parity costs, provided a more conservative outlook for the sector (see chart).

The all-in version forecasts about a 4.4x increase in the market between 2008 and 2014, from 61,000 to 269,000MT. The more measured projection shows the growth in the 3.3x range, from 64,000 to 209,000MT. The gap between the two data sets' forecasts increases year after year, growing from a difference of 8,000MT for 2009 to a 25,000MT discrepancy in 2010 and reaches 60,000MT in 2014 between the all-in and grid parity-adjusted versions.

If the cell and module demand for poly grows at about 33% per year, what Homan called a moderate pace, his grid parity-adjusted forecast shows the silicon sector able to meet demand up to at least 2014. Just the announced planned capacity of the established poly players alone would be sufficient to meet demand, according to the Hemlock exec.

But if growth takes off at a per-annum rate closer to 50%, another poly shortage could occur by 2012-2013, as Homan's more conservative data showed. The combination of the capacity to be added by both the veteran companies and the newbies would be insufficient to meet the growth potential of an end-market possibly needing enough silicon to build at least 26-28GWp of crystalline-based modules, according to Homan's analyses.

Although he made no direct mention of the impact of silicon-reducing technological improvements such as the development and deployment of more efficient poly reactors and ultrathin, kerf-free wafering techniques, his poly-per-module data trended toward slightly better usage over the five-year span.

The more growth-aggressive of Homan's scenarios suggests that silicon – and the availability or scarcity thereof – could again emerge as a game-changer in a few years. But if poly producers young and old successfully maintain a high quality level and drive their costs down to less than 10% of the total bill of module materials, the type of poly spot-price inflation seen in the mid-2000s may not rear its head again, and the sandy stuff will play its part on the crystalline side of the grid-parity achievement game.

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