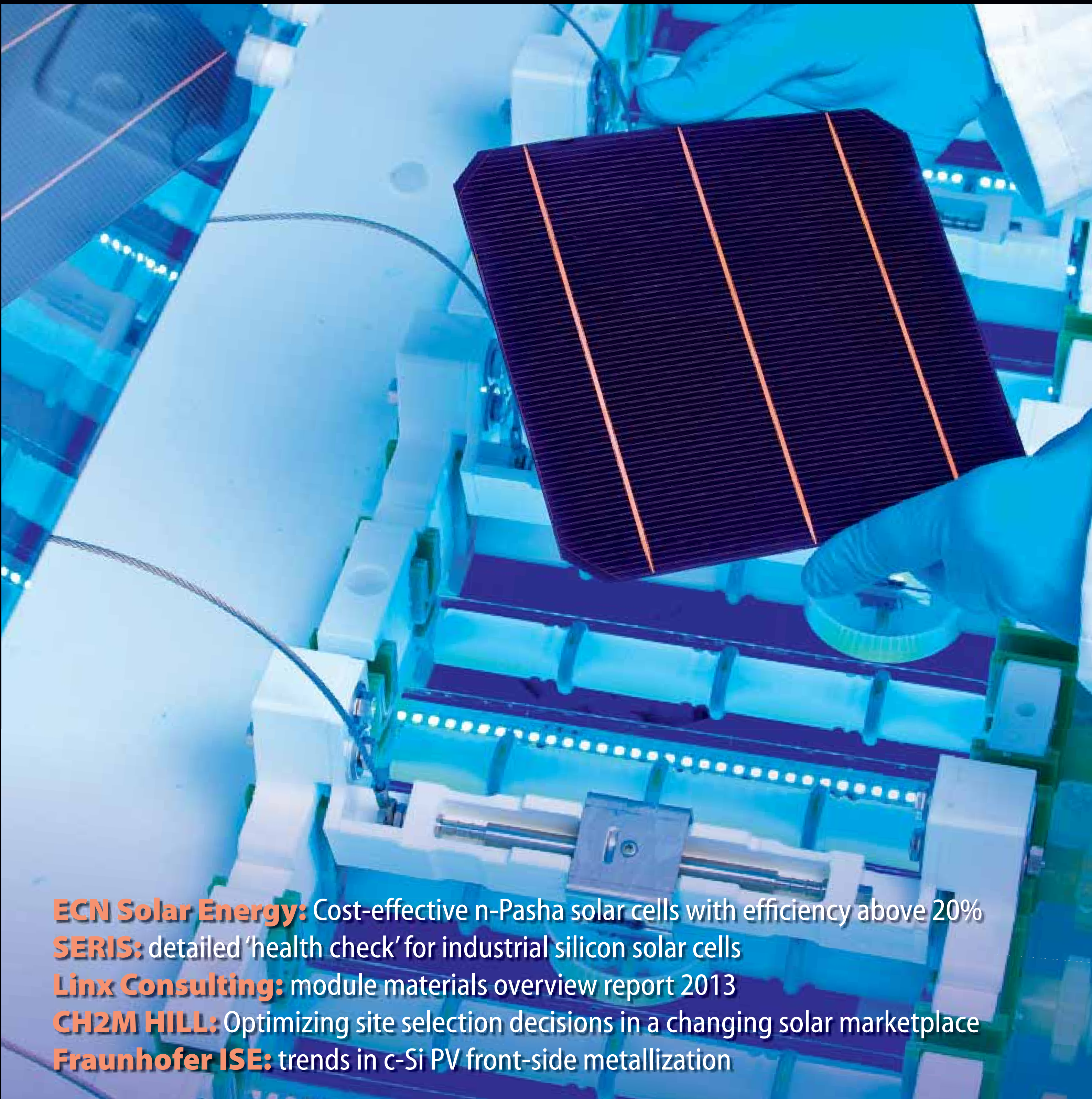
Twentieth Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS



ECN Solar Energy: Cost-effective n-Pasha solar cells with efficiency above 20%
SERIS: detailed 'health check' for industrial silicon solar cells
Linx Consulting: module materials overview report 2013
CH2M HILL: Optimizing site selection decisions in a changing solar marketplace
Fraunhofer ISE: trends in c-Si PV front-side metallization

Second Quarter, May 2013 www.pv-tech.org

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Dr Dusit Kruangam, Chairman,
Thai Photovoltaics Industries Association
Key issues for the Thai Photovoltaics Industry

Ms Gladys Mak, Director of FiT SEDA Malaysia,
Sustainable Energy Development Authority of Malaysia
The Malaysian approach: FiTs, targets and becoming a manufacturing hub

Mr Craig O'Connor,
Director for Renewable Energy & Environmental Exports, Ex-Im Bank
Developing solar energy markets: obstacles, opportunities and lessons from India

Mr Edward Douglas, Investment Director, Armstrong Asset Management
From boardroom to deployment:
a developer's guide to investor requirements in the Southeast Asian market

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Photovoltaics International

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The picture was taken by Michael Eckmann.

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Foreword

In the first quarter of 2013 a number of solar module companies have noted marked increases in shipments and in some cases have been sold out. This has been driven by strong deployment in Japan, a rush to beat imminent Italian tariff cuts and a boom in the UK large-scale solar segment to beat another subsidy cut. The oversupply situation continues for now but the increase in deployment is allowing some module companies to stabilise and even increase prices to achieve order profitability for the first time in 18 months.

The question remains: has the latest round of consolidation in the supply chain enabled a more sustainable growth curve for the solar industry or is this a blip fuelled by subsidy?

Whether you are a glass half empty or full person, the fact remains that orders are up across the board, new markets are coming on stream and analysts' predictions are increasing again. Optimism is starting to creep into even the most conservative of organisations.

Here at *Photovoltaics International*, we always strive to bring you the very best technological information in each and every issue. In particular this issue we look at ECN's (p.33) n-Pasha cells which are now in volume production at world leading manufacturer Yingli Solar.

The exceptional people at SERIS (p.48) have worked hard to create a practical methodology for process engineers to check the 'health' of their cells coming off the line, which will show where cost and efficiency gains can be made in the cell processing stage.

We also go back to the drawing board with Solliance (p.61) as we discover if the promise of CIGS technology can be realised in the near future. Mark Thirsk at Linx Consulting highlights the current trends in module assembly materials (p.104).

With utilization rates consistently over 90% at top module manufacturers it is becoming clearer that we are looking at a new capacity buy cycle at the end of 2013 or first quarter 2014. That means that senior engineers and CTO's are right now looking at the best available technology and processes available in the market place. In this context *Photovoltaics International* has never been more relevant for your business and I hope that you find this latest edition as valuable as ever.

Sincerely,

David Owen
Publisher
Solar Media Ltd

Photovoltaics International

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

Editorial Advisory Board

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

Gary Yu, Senior Vice President, Operations

Mr. Yu served as Trina Solar's Vice President of Manufacturing since May 2007 and in July 2010 was promoted to the position of Senior Vice President of Operations. Mr. Yu has 17 years' manufacturing management experience in semiconductor-related industries. Before joining Trina Solar, he was Managing Director of Wuxi Lite-On Technology, an LED assembly company based in China. Prior to Wuxi Lite-On Technology, he served as a Director of Manufacturing for 1st Silicon Sdn. Bhd. in Malaysia, prior to which he worked at Macronix International, a semiconductor integrated device manufacturer in Taiwan. Mr. Yu has a master's degree in Industrial Engineering and Management from National Chiao Tung University in Taiwan and a bachelor's degree in Chemical Engineering from Tunghai University.

Takashi Tomita, Senior Executive Fellow, Sharp Solar

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

Dr. Peng Heng Chang, CEO, Motech Industries, Inc.

Dr. P.H. Chang was elected CEO of Motech in March 2010. Dr. Chang has over 30 years of experience in management at multinational technology companies and in-depth knowledge in Materials Engineering. Prior to joining Motech, Dr. Chang was VP of Materials Management and Risk Management, VP of Human Resources and Senior Director of Materials Management at Taiwan Semiconductor Manufacturing Co. (TSMC); VP of Administration at Worldwide Semiconductor Manufacturing Co. and Professor of Materials Science and Engineering at National Chiao Tung University in Hsinchu, Taiwan. Dr. Chang also worked for Inland Steel Co. and Texas Instruments in the US prior to 1990. He received his Ph.D. degree in materials engineering from Purdue University in 1981.

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

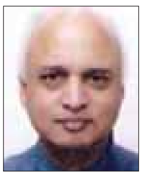
Professor Eicke R. Weber is the Director of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg. Weber has earned an international reputation as a materials researcher for defects in silicon and III-V semiconductors such as gallium arsenide and gallium nitride. He spent 23 years in the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

Dr. Zhengrong Shi, Executive Chairman and Chief Strategy Officer, Suntech

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

Dr. Sam Hong, President and COO of Neo Solar Power

Dr. Hong has more than 30 years of experience working in the solar energy industry. He has served as the Research Division Director of Photovoltaic Solar Energy Division at Industry Technology Research Institute (ITRI), a research organization that serves to strengthen the technological competitiveness of Taiwan, and Vice President and Plant Director of Sinonar Amorphous Silicon Solar Cell Co., which is the first amorphous silicon manufacturer in Taiwan. In addition, Dr. Hong was responsible for Power Subsystem of ROCSAT 1 for the Taiwan National Space Program. Dr. Hong has published three books and 38 journal and international conference papers, and is a holder of seven patents. Dr. Hong was the recipient of Outstanding Achievement Award from the Ministry of Economic Affairs, Taiwan, and was recently elected as chairman of the Taiwan Photovoltaic Industry Association.



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

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

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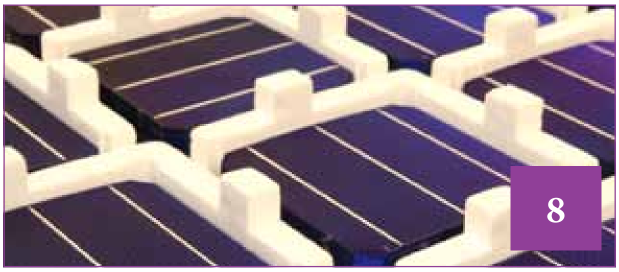


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Fab & Facilities

Centrosolar to dispose of PV glass operations; 2012 revenue down 22%

PV manufacturer and project developer Centrosolar is to dispose of its solar glass operations due to falling market prices and sales volumes. The main determining factor for Centrosolar's final decision to dispose of its glass operation was its deterioration from US$2.8 million in the previous year to negative US$16 million in 2012. The company said in a press statement: "These impairments have been necessitated by the downward revision of the group companies' targets as a result of the difficult situation in the industry, and also because the cost of capital underlying the valuations have been raised." The revenue of Centrosolar reached US$290 million, down approximately 22% on the previous year's total of US$384 million, though it noted sales of its modules were up slightly on last year. The mainly price-driven fall in revenue was behind the reduced gross profit, which is by and large responsible for the downturn in the operating result at EBITDA level from negative US$13.3 million in the previous year to negative US$21 million in 2012.

Centrosolar is to dispose of its solar glass operations due to falling market prices and sales volumes.

Capacity Expansion News Focus

Ebitsch Energietechnik to construct US$2.5 million facility in Brazil

German renewable energy company Ebitsch Energietechnik is to construct a solar PV factory in São José de Mipibu, in the Brazilian state of Rio Grande do Norte.

Ebitsch Energietechnik's managing director Horst Ebitsch and the German secretary of state of economic development Roger Marino met last week to discuss the company's investment options. The first phase will require an investment of US$2.5 million. Ebitsch Energietechnik estimates annual revenue of US$8 million and the creation of 20 direct jobs and 40 indirect. The state is also planning to build a renewable energy technology park in partnership with the Federal University, energy company Petrobras and research institutions.

Solar Frontier to restart module production at Miyazaki plant

Japanese thin-film PV manufacturer Solar Frontier, part of oil refiner Showa Shell, is planning to restart its module production line at its Miyazaki No.2 Plant in Kiyotakecho, Miyazaki, Japan, in July. The decision to restart the line has been driven by Solar Frontier's plans to launch a new range of products for the Japanese market. Pending the final decision of product models to be manufactured, Solar Frontier will make minor equipment modifications to enable the manufacture of new products which will be sold in Japan.

Source: Solar Frontier

Solar Frontier is planning to restart its module production line at its Miyazaki No.2 Plant.

TS Solartech to expand Malaysian plant

Malaysian solar cell manufacturer TS SolarTech has announced plans to expand its 60MW plant to 640MW by 2015. TS Solartech, a 60% owned subsidiary of investment company Tek Seng, said it had invested US$38.5 million to build the existing facility in Bukit Minyak Science Park on the mainland of Penang. Tek Seng Group Executive Chairman Loh Kok Beng said TS Solartech had partnered with German company, Schmid in this venture. The factory expansion is expected to cost an additional US$1.54 million.

Sunerg plans expansion with new production line

Italian PV manufacturer Sunerg Solar is to open a second production line at its factory in the region of Umbria. The company said that despite problems in the international PV industry, it was sufficiently confident of its own product to raise its annual production capacity to 100MW. The new line has a capacity of 70MW and is fitted out with equipment from German providers Teamtechnik, Reis Robotics and NPC-Meier.

APEC opens Saudi PV factory

Arabian Power Electronics Company (APEC), a power electronics manufacturer based in Al Khobar, Saudi Arabia has opened a new manufacturing facility that will produce PV systems and inverters as well as other power electronics equipment.

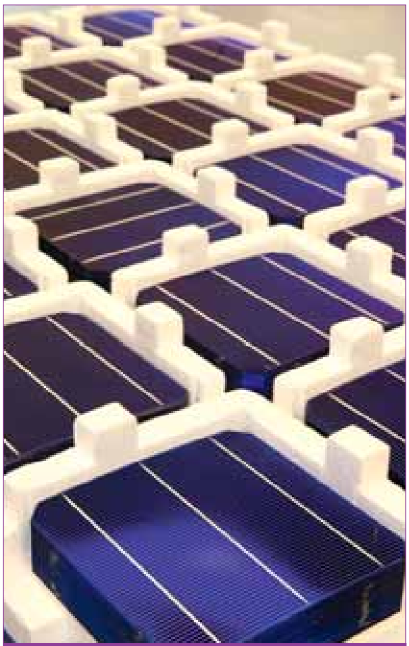
The APEC plant is a joint venture between APLAB Ltd. (Thane, India) and Eram Group (Al-Khobar, Saudi Arabia) that will focus on the manufacture of products required to operate in the unique environmental conditions of the region.

KACO targets 100MW of inverter business in Japan in 2013

PV inverter manufacturer KACO new energy has opened a sales and support office in Tokyo, Japan, to support its business growth in the country. The company has an exclusive distribution agreement with GREEN TEC, which is a full systems supplier in the Japan. KACO said that the agreement between the companies initially intended to enable 50MW of inverter sales but due to the growth in the Japanese market the target in 2013 had been increased to 100MW in PV inverter sales. The new office is designed to support planning, commissioning and servicing of joint PV projects, as well as providing technical training. KACO has recruited Toshihiro Hiraishi, a trained electrical engineer, to head up the new office.

Innotech Solar to ramp module production capacity to 100MW

Innotech Solar (ITS), a Scandinavian-German module manufacturer, is to ramp up its module production capacity from 60MW to 100MW and could even expand to 170MW. According to Thomas Hillig, vice president of module sales and marketing at ITS, the uncertainty surrounding the possible duties on Chinese modules has been driving demand for its modules. Under the company's business model, ITS buys cheap, low-efficiency solar cells and restores their performance to full capacity in order to keep costs low. Aside from buying EVA from the Japanese market leader, the company only uses components supplied by European brand manufacturers.



Source: Innotech Solar

Innotech is to ramp up its module production capacity from 60MW to 100MW.

Business News Focus

Suntech's manufacturing subsidiary in Wuxi forced into bankruptcy proceedings by banks

Suntech Power Holdings has revealed that a group of eight Chinese banks have filed a petition for insolvency and restructuring of the company's main manufacturing subsidiary, Wuxi Suntech. The struggling company said that it would not file an objection against the petition, kick-starting insolvency and restructuring proceedings as the company had over US$2.0 billion in debts. Wuxi Suntech is expected to apply to the court to continue operations under the supervision of the administrators, according to Suntech Power Holdings.

ABB secures 200MW of PV inverter orders in India

ABB has expanded PV inverter manufacturing in India to meet current orders of over 200MW for utility-scale power plants in the country. A new production line in Bangalore came online at the end of 2012, with an annual nameplate capacity of 500MW for PVS800 central inverter product range, according to the company. The company said that over 100MW of its central inverters have been used in PV projects in the country since the end of 2011.

Shakeout News Focus

JA Solar cuts capacity as business flat-lines

JA Solar's strategy of shifting sales from solar cells to modules has been achieved but at the cost of flat-lining business that started in 2011 and is expected to continue in 2013. With flat-lining shipments and a need to preserve cash, management noted that it had retired 300MW of solar cell production capacity and 300MW of module production capacity in the fourth quarter of 2012. Total solar cell capacity is claimed to be 2.5GW in 2013, while module capacity is said to be 1.8GW. Before the capacity cuts, JA Solar had an annual solar cell production capacity of 2.8GW, while module production capacity stood at 2.1GW. Wafer production remained unchanged in 2012 at 1GW. The company did not say at which production locations the capacity cuts had occurred.

Bekaert takes US$153 million charge on restructuring PV wire sawing business

Bekaert said in its 2012 annual report that it had taken a US$153 million charge on restructuring its solar wafer wire sawing business. A year ago, industrial materials firm, Bekaert announced massive jobs losses in its solar wafer wire saw business due to overcapacity with the loss of 1,250 jobs.

Solar Systems brings Mildura CPV demonstration facility online

Solar Systems, an Australian concentrating PV (CPV) systems manufacturer, has announced the operational start up of its solar demonstration facility in Mildura in the Australian state of Victoria.

According to Solar Systems, a wholly-owned subsidiary of Silex Systems, the grid-connected facility represents the largest CPV solar power plant in Australia. The facility will be used to demonstrate the company's proprietary Dense Array CPV solar conversion system. When fully operational, the system will have a capacity of 1.5MW and will generate enough electricity to power up to 500 homes. All electricity generated by the plant will be sold to Diamond Energy after signing a power purchase agreement on December 17, 2012.

The facility and its associated product development programme has received strong financial support from the Victorian state government with a US$10.4 million funding package while the Australian Federal Government has also provided additional financial support. In the next phase, the company will expand the facility to 100MW with construction expected to commence in late 2014.

Suntech's Arizona plant faces permanent shutdown

Suntech Power Holdings has decided to permanently close its module assembly plant in Arizona with the loss of 43 jobs, citing US government imposed duties on imported solar cells and aluminium used in solar module frames. The Arizona plant was established in October 2010 and had reached production of 50MW per year in 2011. However, the company said that in November 2012, production was scaled back to only 15MW after the imposition of tariffs made module costs uncompetitive. Suntech will close the facility on April 3, 2013. Suntech was the only Chinese module manufacturer with a production plant in the US.

Location Briefing

Pflugerville Community Development Corporation

PFLUGERVILLE
Community Development Corporation

About Pflugerville, Texas

Located in Central Texas near Austin, Pflugerville is well positioned to compete nationally and internationally in the global solar energy market. On average, the area receives more than 300 days of sunshine each year and has more than 5,000 acres of land available near major highways. The city, county and state governments all actively support renewable energy. Pflugerville, with its 50,000-plus residents and expected to double by 2025, has one of the most highly educated workforces in the region.

Solar power in Texas

Though the Texas heat might cause some to complain during the summer, it is that bright Texas sunshine that is the source of an abundance of renewable energy in the form of solar power. Most days, Central Texas is sunny, receiving nearly 2,650 hours (more than 60% of the possible total) of bright sunshine per year.

Land and infrastructure

Though Pflugerville has grown quite rapidly during the last decade, more than 5,000 prime acres of land are available and ready for development—a significant portion of which is shovel ready. Much of this land is near major roadways, including Interstate Highway 35, the main trade corridor for the United States, Canada and Mexico. State Highways 130 and 45 run through the middle of the city, offering an alternate north-south route to IH 35 and a new east-west route through the Austin area and beyond. These highways provide the access that many companies need to transport products or people directly to a desired destination, or to a port where cargo can be shipped out of the country.

Experienced, available workforce

In addition to various renewable resources, Central Texas also has a large available workforce experienced in manufacturing. The Austin area is home to a variety of manufacturing facilities, warehouse and distribution businesses, as well as a highly competitive supply chain management industry with experienced third party logistics services companies. These businesses offer a large, diverse and highly capable talent pool.

A well-educated workforce is also renewed annually by the various colleges and universities in Central Texas, including a world-class research institution—the University of Texas at Austin—and also Texas State University, St. Edward's University, Southwestern University, Concordia University and Austin Community College.

City staff, including planners, city engineers and the city manager, as well as Pflugerville's local elected officials, are welcoming and helpful to businesses looking to locate or expand in the community.

Key features and benefits

Eligible businesses can take advantage of Triple Freeport exemption, which allows manufacturing and distribution centres to make and distribute products without having to pay property taxes on certain inventories. Pflugerville is one of the only cities in Central Texas to offer Triple Freeport exemption.

A wide range of state and local programmes are available to qualified new developments, corporate relocations and expansions, including:

- Emerging Technology Fund
- Tax Abatements
- Triple Freeport Tax Exemption
- Fee Waivers
- Texas Enterprise Fund
- Foreign-Trade Zone
- Expedited Development Process

What they say

With plenty of sunshine, a business-friendly climate, a talented and educated workforce, available land and a great transportation infrastructure, Pflugerville is an ideal location for any renewable energy company to prosper.

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Optimizing site selection decisions in a changing solar marketplace

Dick Sheehy & **Nate Monosoff**, CH2M HILL, Portland, Oregon, USA

ABSTRACT
Whether in the USA as a part of a manufacturing resurgence or elsewhere in the world, solar producers need to be smarter than ever about where they choose to locate new operation centres. Solar manufacturing site selection demands analytical rigour. The intent of this article is to share strategies and tools that can help owners make the best-informed choices about where to locate new manufacturing operations.

Introduction

In the last few years things have been tough for the solar industry. It has been buffeted by recession-reduced demand, surprising new discoveries of fossil fuels, evaporating government incentives and brutal price wars. Yet through it all, this battered industry is deeply rooted for long-term viability.

We can all debate how fast the solar industry will grow and change in view of its many challenges, but the industry's growth at some rate is a strong bet, as energy resources become increasingly critical to modern life, and solar manufacturing technology continues to make steady progress towards and beyond grid parity.

In short, solar is here to stay, and despite all the volatility in the solar manufacturing marketplace, those who figure out how to manufacture solar products profitably will enjoy the benefits of solar's ultimate market expansion.

Bolstering optimism about the global solar industry's long-term fortune is increasing enthusiasm and discussion in the USA of 'reshoring' or 'insourcing' solar manufacturing. This trend is driven by multiple factors, including transportation costs, decreases in US energy costs, aggressive US state incentive programmes, and increases in Chinese labour cost and trade policies. In 2010 President Barack Obama set a goal of doubling American exports around the world by the start of 2015. In 2011, for the second straight year, the number of manufacturing jobs in the USA increased, after declining every year since 1998. Since December 2009 the manufacturing sector has added 300,000 jobs, including 50,000 in January 2012 alone, the biggest monthly increase in a year. President Obama has proposed lowering tax rates for manufacturers to fuel the reshoring trend.

Site selection process

Business cost drivers around the globe vary widely; taxes, government incentives, land costs, labour laws, labour costs, power costs, regulatory issues, infrastructure conditions, logistics and supply chain considerations are all critical business issues, varying site to site. Some approaches and methods for improving site selection decision-making processes are presented here.

> "The site selection process can be broken down into project definition, location screening, location analysis, site analysis and due diligence."

The site selection process (Fig. 1) can be broken down into five general phases:

1. **Project definition:** define the geographic search area and the facility, site, cost, infrastructure and risk criteria against which locations and sites will be evaluated.

2. **Location screening:** utilize site selection models and client's preferences to identify locations for further study.

3. **Location analysis:** collect data and refine analytical models; evaluate qualitative criteria; rank and select locations for site analysis.

4. **Site analysis:** identify and analyze sites in priority locations.

5. **Due diligence:** review in detail a site's development feasibility (incentives, environmental, zoning, infrastructure, costs, etc.).

Each of the five site selection steps is described below.

Project definition

The site selection processes begins with a **project definition** stage. This process develops a detailed understanding of a manufacturing facility's operating parameters and requirements, and determines the criteria against which the locations and sites will be judged, and the relative importance of each criterion.

Location screening

Once the key site selection criteria have been defined, the next step is **location screening**. CH2M HILL utilizes a proprietary total cost of ownership (TCO) model and utility and site resource model (SRM) to efficiently evaluate and rank locations and narrow the search. Decision-making methodologies can also be used at this stage, to provide a framework for defining, weighting and scoring qualitative criteria.

Location analysis

The location screening lays the groundwork for the **location analysis** to follow. Requests for proposals (RFP) are prepared and sent to locations of interest. The responses, which typically include preliminary incentive offers, are then analyzed, and locations are re-evaluated from a financial and qualitative perspective. The outcome of this phase is a shortlist of preferred sites.

Site analysis

Site analysis is when the process begins to focus on details. The goal of site analysis is to identify and assess potential sites in a target region. If necessary, a follow-up site RFP will be sent to state and local economic development officials in a target region. The RFP will specify detailed site requirements, including size, topography, access, zoning, cost, development review, development constraints, site improvements and environmental concerns. On the basis of a desktop review of sites and data from the TCO model and SRM, sites are ranked and the top sites are visited. A more detailed assessment of the sites is conducted based on the site visits and additional research into site development costs and potential development constraints. At this stage, analysis is performed at a high level of detail. The thorough understanding of a manufacturer's requirements and priorities, developed in the project definition stage, ensures the best fit between site and project. A preliminary development schedule, TCO model and SRM will be developed for the top sites. On the basis of this analysis, a final site ranking will be performed, and negotiations can be initiated with site owners and local and state governments for the top sites. During these negotiations, site studies and surveys (wetlands, endangered species, past practices, cultural resources, natural resources, archaeology, noise, traffic, and impacts on visual air and water) are carried out.

Due diligence

Lastly, the **due diligence** chapter commences, with negotiation and finalization of incentive and infrastructure agreements, environmental investigations and contracts leading up to site acquisition.

How does plant location influence financial performance?

The solar industry is mature enough to have accumulated solid data for benchmarking solar manufacturing costs in different international locations. These data are an invaluable asset for objective comparison and prediction of business competitiveness. Projects should develop a discounted cash flow model to assess the impact that geographic location has on project net present value (NPV) and unit production cost. These models make the site selection process objective and focused on the factors that have the most influence on financial performance.

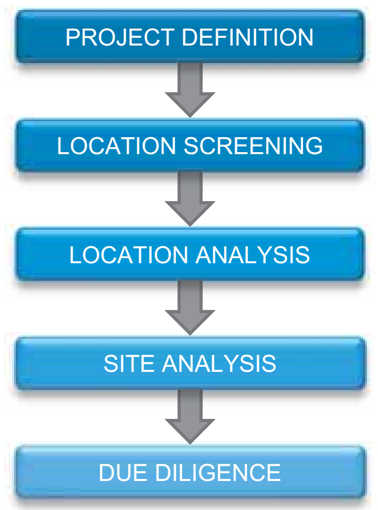

Figure 1. A process of identifying, evaluating and eliminating sites.

Schedule is another critical factor to consider for site selection projects. A number of functions related to site development are notoriously delay-prone, such as environmental permitting, the site development approval process, site and infrastructure development, and facility design and construction. Understanding the local manifestations and risks associated with these factors is important, because a large greenfield or redevelopment project in the USA can trigger a number of challenging environmental regulatory programmes that can have a significant impact on schedule and cost. Environmental regulations and permitting programmes vary from state to state and are often more restrictive and involved than federal government environmental programmes. Environmental permitting and site-related environmental review and approvals can result in schedule delays of nine months or more. However, these schedule impacts can be minimized, or possibly avoided, through proper investigation and planning early in the project life cycle.

> "Yet another consideration that must be included in the site evaluation equation is business interruption risk."

Yet another consideration that must be included in the site evaluation equation is business interruption risk. Some of these risks are hazard related – such as threats of natural disaster, security and infrastructure reliability and vulnerability – while a range of other risks pertains to such financial factors as fluctuating labour costs and workforce availability, and unforeseen increases in energy and tax policy.

Site selection net present value (NPV) model

The best quantitative site selection tool is a project NPV model that efficiently forecasts and compares project cash flows over the life of the project, for each location and site under consideration. The key is designing the model to efficiently focus on costs that change by geography while holding other variables constant.

For solar manufacturers considering US locations, key cost factors that can vary considerably by geography include taxes (sales, property and income), incentives, labour, site and infrastructure development, construction and transportation costs. On the basis of a plant's specific capital and operating cost structure, the NPV model forecasts the estimated cash flow of these costs for each site under consideration.

The resulting total cost of plant ownership, on an NPV basis, provides an objective and normalized financial comparison between site options. The model also provides useful financial insight into the sensitivity that each of the site-specific cost variables has for project NPV.

An NPV model can also be a valuable tool for state and local incentive negotiation and evaluation. Tax structures and incentive packages can vary significantly among states as well as among cities and counties within a given state.

An example of a cost comparison summary (of some of the high-ranking variables only) by location is shown in Fig. 2, based on seven different locations, over a 10-year period of plant operation.

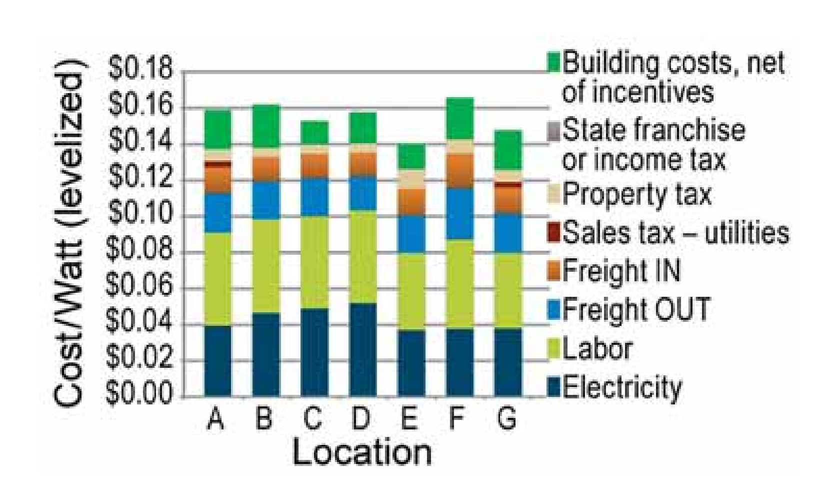

Figure 2. NPV of costs by location of items with significant variability.

> "Location can have a huge impact on a facility's start-up and operating costs and ultimate success or failure."

Conclusion

Location can have a huge impact on a facility's start-up and operating costs and ultimate success or failure. While the solar industry continues to face uncertainties and risks, owners can find reassurance in the numerous tools and approaches available to guide them in successful site selection efforts.

About the Authors

Dick Sheehy manages CH2M HILL's Advanced Planning and Site Selection Services group. He has more than 25 years of experience in evaluating site locations and developing projects for advanced technology industries, including many in the solar industry, and has led many projects providing master planning services for communities and firms around the world. He is a former director of economic development for the State of Oregon in the USA, where he was directly involved in recruiting high-technology companies and developing and implementing incentive programmes for industry.

Nate Monosoff specializes in providing business and strategic consulting services to start-up and mature industrial and technology clients in the USA, Asia and Brazil. In consultant, engineer and/or project manager capacities, he has provided business consulting, master planning, business location and economic development services as well as technology and market analysis for national, regional and local governments and industrial clients. He has expertise in the development of specialized cost modelling and feasibility studies and tools to support high-technology investment decisions.

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Materials

Suntech's Chinese suppliers feel the pain of bad debts

Reports have cited that at least five stock listed suppliers to Suntech Wuxi, which filed for bankruptcy restructuring in March, have declared provisions for bad debt from the collapsed subsidiary of Suntech Power Holdings. The reports claim that total debts from the five suppliers amounted to US$68.7 million. The largest debt was said to be held by mono-crystalline wafer supplier, Tianjin Zhonghuan Semiconductor which is said to be owed approximately US$28.3 million.

Suntech Wuxi has declared provisions for bad debt from the collapsed subsidiary of Suntech Power Holdings.

Financial Results

LDK Solar brings forward Q4 2012 financial reporting

Struggling PV manufacturer, LDK Solar has brought forward the release of its fourth quarter 2012 financial results and conference call to 18 April 2013.

The company had previously stated it would release results on Monday, April 29 almost six months after releasing third quarter 2012 results at the beginning of December 2012.

Daqo New Energy running out of money; polysilicon sales plummet

China-based polysilicon producer Daqo New Energy reported fourth quarter 2012 sales of only US$6.2 million, compared to US$21.1 million in the prior quarter. For the full year 2012, Daqo reported a gross loss of US$37.4 million, compared to gross profit of US$87.2 million in 2011. Gross margin in 2012 was negative 43.1%, compared to positive 37.6% in 2011. Daqo said that at the end of 2012 it had only US$17.3 million in cash and cash equivalents, a decrease of US$36.5 million from the prior quarter due primarily to debt repayments and the capital spending on plant upgrades at its Xinjiang facility.

STR Holdings pinning business recovery on PID solutions

Encapsulant supplier STR Holdings is pinning hopes for a recovery in sales on a range of new potential induced degradation products having taken a hit last year with the loss of its largest customer First Solar. STR reported fourth quarter revenue of US$16.1 million, down 56% year-over-year and 30% from the previous quarter when sales were US$23.1 million. The significant revenue decline was primarily due to volume shipments declining by approximately 43%, and an ASP decline in 2012 of 23%.

GCL-Poly posts significant loss from polysilicon and solar wafer sales

GCL-Poly Energy Holdings reported around a US$432 million loss from its solar materials business in 2012, which includes polysilicon and solar wafers. The solar materials segment generated annual sales of approximately US$1.69 billion, down from approximately US$2.6 billion in 2011.

Polysilicon prices at Wacker fell 50% in 2012

Increased polysilicon shipments in 2012, partially offset a 50% price decline, resulting in polysilicon-based revenue at Wacker declining nearly 22% last year. Wacker's polysilicon division had 2012 revenue of US$1.49 billion but EBITDA declined 43% to US$558 million. Management were slightly upbeat about 2013 business prospects, noting that is was selling higher volumes of polysilicon than previously expected, though prices were said to be "stable" yet continue to be a "low level." Wacker noted that construction of its new polysilicon plant in the US was ongoing but had slowed down to aligning capacity growth with market demand. Charleston's production start-up is now planned for mid-2015, according to the company. However, the extended start-up timetable will allow Wacker to optimise and debottleneck the facility, enabling total capacity to increase by at least 10%, taking nameplate capacity over 20,000MT per annum. Overall, Wacker's nameplate polysilicon production will reach 72,000MT by the end of 2015.

ReneSola sold out until July; posts record quarterly results

China-based solar wafer and module manufacturer ReneSola has revealed it is sold out of modules until June 2013 as it reported record quarterly and annual shipment results. The company expects module shipments to far exceed capacity, leading the company to outsource production to third party manufacturers, notably 400MW or more in Europe to beat the potential anti-dumping duties on Chinese made modules. For full-year 2012, the company reported a gross loss of US$35.7 million compared to a gross profit of US$96.1 million in 2011. However, ReneSola reported a net loss for the year of US$203.4 million. The company expects 2013 total solar wafer and module shipments to be in the range of 2.7-2.9GW, with module shipments expected to be in the range of 1.4 to 1.6GW.

Order Focus

GTAT wins follow-on polysilicon technology and equipment deal

Tawian-based polysilicon producer, Powertec Energy Corporation has signed a follow-on deal with GT Advanced Technologies to purchase polysilicon technology and equipment for a second-phase capacity expansion. GTAT said that a memorandum of understanding has been signed that will see Powertec start placing orders in the second half of 2014. Design work for the plant expansion was said to have already started.


Source: GT Advanced Technologies

Powertec Energy Corporation has signed a follow-on deal with GT Advanced Technologies.

Bayer sells silver nanoparticle technology to Clariant

An aqueous-based silver nanoparticle ink technology developed in the last 10 years by chemicals giant Beyer has been acquired by high-tech chemicals specialist Clariant International. The silver nanoparticle ink technology has only found a few markets such as RFID chips production and specific flexible substrates in the display industry but Clariant expects to develop the technology for a wider market including photovoltaics applications, most likely related to ink jet printing for flexible thin-film PV.

Business News Focus

Major new pact signed between GCL-Poly and Yingli Green

GCL-Poly will use Yingli Green's PV modules for its project pipeline that stands at around 1GW in a major new three-year strategic agreement encompassing polysilicon and wafer supply, through to R&D initiatives on material quality and cost reductions. The new pact secures sufficient material requirements for Yingli Green to increase module shipments and supply large volumes of modules to GCL-Poly's projects over the next few years. Although material quantities were not disclosed, the deal is probably the largest of its kind in the industry, creating significant opportunities to drive down material costs.

Yingli Green was said to have plans to also build a 'global network procurement platform' to meet its volume and cost reduction needs.

SiC Processing liquidator appointed

The local court in Amberg has appointed attorney Christopher Seagon as the administrator of silicon wafer slurry specialist, SiC Processing. The company said late last year that it had been granted "self administration" and sought to restructure operations. No concrete plans for SiC Processing have yet to be revealed after its financial position started to unravel after key European customer REC closed its wafer operations in Norway in 2012.

DSM offers light trapping lamination sheet via SolarExcel acquisition

PV materials start-up, SolarExcel based in the Netherlands has been acquired by major industrial materials form, DSM for an undisclosed sum. Still under development since 2007, SolarExcel had been working on a light trapping textured polymeric sheet material that could be laminated to the top glass used in PV modules, both crystalline and thin-film.

Hemlock sues SolarWorld over polysilicon supply contracts

According to the Oregonian newspaper, Hemlock Semiconductor has filed a law suit against SolarWorld's subsidiary, Deutsche Solar over alleged failure to honour polysilicon 'take or pay' contracts. The report said that Hemlock Semiconductor filed suit Thursday March 7 in the federal court of Bay City, Michigan, USA. The disputed supply contract discrepancy was said to be valued at US$83 million. The Oregonian claimed that the law suit cited threats made by SolarWorld's CEO, Frank Asbeck that unless Hemlock agreed to change the supply agreements, he would have placed Deutsche Solar into bankruptcy, avoiding payment liabilities. It was also claimed that Asbeck threatened


Source: GCL-Poly

GCL-Poly has signed an agreement to use Yingli Green's PV modules for its project pipeline.


Source: SolarWorld

Frank Asbeck, CEO SolarWorld, was rumoured to have made threats against Hemlock Semiconductor.

to buy back Deutsche Solar from administrators and continue operations free of any claims.

MEMC to morph into SunEdison

MEMC Electronic Materials has said it plans to drop its name that has been in existence for decades and take on its subsidiary SunEdison as the corporate moniker. The move was said to better reflect the business model changes and future developments of the company, which has morphed from originally being a leading polysilicon producer to semiconductor and more recently into a leading PV project developer, via the acquisition of SunEdison several years ago.

Source: SunEdison

MEMC Electronic Materials is to take on the name of its subsidiary SunEdison.

SiC Processing to prepare restructuring plan

The local court in Amberg, Germany court has appointed Dr Hubert Ampferl, partner of Nuremberg-based law firm Dr Beck & Partner, as supervisor of SiC Processing, which is operating as 'debtor-in-possession' during insolvency proceedings. The slurry recycling specialist has until March 19 2013 to propose a restructuring plan that will be put forward to creditors in a meeting to be held in mid April.

Hemlock Semiconductor's polysilicon sales worsen due to overcapacity and trade disputes

Dow Corning reported first quarter 2013 revenue of US$1.26 billion, down from US$1.48 billion in the fourth quarter 2012 and down 17% from the first quarter of 2011.

The company also reported a net income of $62.1 million, down slightly from US$69 million in the prior quarter and down 6% from the same quarter a year ago.

Dow Corning said that its polysilicon segment, Hemlock Semiconductor had realised the largest reduction in revenue in the quarter. The company does not break out polysilicon sales separately.

Hemlock Semiconductor's performance has worsened to polysilicon overcapacity

J. Donald Sheets, Dow Corning's Executive Vice President and Chief Financial Officer said: "Hemlock Semiconductor's performance continued to worsen as the solar polysilicon industry deals with excess inventories and awaits resolution of the global trade disputes."

"In the first quarter, we made some tough decisions to reduce Dow Corning's cost structure to enable us to continue to invest in developing innovative products that bring value to both our customers and to Dow Corning. While we expect the difficulties we're facing to continue through the year, Dow Corning's strategy for long-term success is clear, and our foundation is financially strong," added Sheets.

Wacker's polysilicon plants reach 90% utilisation as sales increase 10%

Stronger than expected demand for high-purity polysilicon led to Wacker reporting a 10% increase in sales and plant utilisation rates reaching 90% in the first quarter of 2013.

However, the company reported first quarter 2013 polysilicon sales of €235.4 million, down 36% from €366.6 million in the same quarter a year ago, but up approximately 10% from the fourth quarter of 2012 - the lowest quarterly sales level in recent history.

EBITDA decreased by 65% year on year, to €52.5 million. EBITDA had declined 47% to €78 million in the fourth quarter of 2012. The decline in revenue and margins were due to continued pricing pressure and reduced plant utilisation rates in the early part of the quarter.

Wacker had previously reported polysilicon price declines of over 50% in 2012. However, Wacker noted in its latest quarterly report that polysilicon prices were at low levels, but that prices now appeared to have "bottomed out".

Wacker forecast that capital expenditure would be below €600 million in this year, and unlike previous years would probably not be funded from the company's expected cash flows during the year. Net financial liabilities would continue to rise during the year, while net cash flow would remain negative, the company said.

The company said in its quarterly report that around 60% of first-quarter capital expenditure was focused on the continued construction of its US polysilicon plant in Charleston, Tennessee.

European Commission launches anti-subsidy solar glass investigation

The European Commission has initiated an anti-subsidy investigation into imports of solar glass from China.

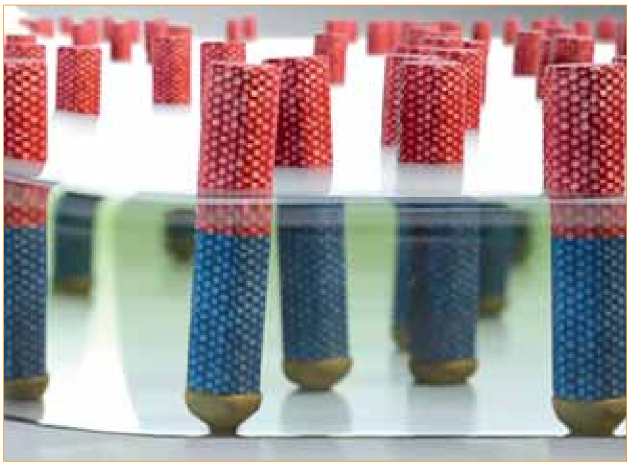
The complaint was lodged by EU ProSun Glass, led by GMB Glasmanufaktur Brandenburg, which claims solar glass from China is being subsidised in China and then sold in the EU at prices below market value and causing material injury to the EU solar glass industry.

EU ProSun Glass is not affiliated with the original EU ProSun that filed anti-dumping and countervailing claims against Chinese cell and module manufacturers last year. The commission said EU ProSun Glass' complaint was a "stand-alone investigation concerning a clearly distinct product".

EU ProSun Glass claims to represent at least 25% of the European glass manufacturing industry, required by EU law to trigger a trade investigation. The commission said the complainant had brought sufficient evidence of possible subsidies provided by the government of China and injury suffered by the industry as a result to warrant the opening of an investigation.

Product Reviews

Sol Voltaics



Sol Voltaics' gallium arsenide nanomaterial to be low-cost ink process for solar cell efficiency gains

Product Outline: The start-up company Sol Voltaics has unveiled 'SolInk,' which is claimed to be an economic nanomaterial that promises to increase the efficiency of crystalline silicon or thin-film solar modules by up to 25% or more. Gallium arsenide nanowires are fabricated via a high-throughput process called 'Aerotaxy,' invented by company founder and Lund University professor Lars Samuelson.

Problem: Gallium arsenide solar cells cost far more to produce than crystalline silicon or thin-film cells, therefore confining the material to niche market segments.

Solution: With SolInk, module manufacturers can make commercially feasible, high-efficiency gallium arsenide solar modules or multijunction solar modules combining gallium arsenide and crystalline silicon. SolInk also enables light concentration without the use of optics or mechanical components. Nanowires need only cover a small portion of the surface area of a crystalline silicon or thin-film solar cell to achieve substantially all of the benefits of adding gallium arsenide. Sol Voltaics' researchers claim that indium phosphide nanowires covering just 12% of the substrate surface produced a solar cell with an efficiency of 13.8%. The results were certified by the Fraunhofer Institute.

Applications: Crystalline silicon and thin-film solar cells.

Platform: Aerotaxy creates nanomaterials by suspending and mixing active materials in carrier gas streams. The active materials bond to form larger, uniform structures while in flight: nanowires are literally grown in air. In this way, Aerotaxy can generate tens of billions of nanowires per second on a continuous basis. The finished nanowires can be integrated into a solar panel or other products, or can be stored indefinitely.

Availability: Sol Voltaics anticipates producing functional solar cells with gallium arsenide nanowires for demonstration by the end of 2013. Commercial production is expected to begin in 2015 and move into volume production in 2016.

Virtual Industries

Virtual Industries' new WAFER-VAC wafer handling system offers wide applications

Product Outline: Virtual Industries, a supplier of manual vacuum handling solutions, has made available its new general-purpose wafer vacuum handling tool, the 'WAFER-VAC' system with an 8" moulded wafer tip (WV-9000-MW8).

Problem: Providing scientists, engineers and R&D personnel with safe and easy to use substrate and solar cell handling devices ensures clean-room protocols and experiment integrity, and minimizes wafer and cell breakage.

Solution: The WAFER-VAC is a general-purpose wafer vacuum handling tool that plugs directly into 110 Volt 50/60 Hz. The compact unit handles a wide variety of wafers, solar cells and other substrates. The long-life diaphragm vacuum pump generates up to 10" of mercury, with an open air flow of 2.3 litres/min. The unit connects to ground automatically with a three-wire power cord.

Applications: General-purpose wafer vacuum handling tool.

Platform: The WV-9000 is Class 100 clean-room safe and comes standard with a long-life pump and push-button wafer tip pen – VWP-500-2.5mm. Additionally, it has a footprint of 7¼" x 3" x 2½" and comes with a 6' clear coiled vacuum hose.

Availability: April 2013 onwards.

ITRPV 4th edition review: Materials matter

Mark Osborne, Senior News Editor, Photovoltaics International

ABSTRACT

Over the past two years the PV industry has been in disarray as massive global overcapacity has sent prices tumbling. In this context, technological innovation to reduce the costs of base materials and products has become increasingly important. The latest edition of the International Technology Roadmap for PV published in March offers insights into the latest developments as manufacturers continue to seek ways of cutting costs. This paper explains some of the key dynamics identified in the roadmap.

Introduction

The 4th edition of the International Technology Roadmap for PV (ITRPV) [1] was introduced at the 2013 PV Fab Managers Forum in March after a second year of industry turmoil. Chronic structural overcapacity throughout the supply chain has further shaped an industry that has been chasing rapidly declining average selling prices (ASPs) with manufacturing cost-reduction strategies. However, ASP declines have continued to outstrip cost declines, resulting in the majority of companies remaining loss making (Fig. 1). The latest edition of the ITRPV reflects current industry dynamics with further

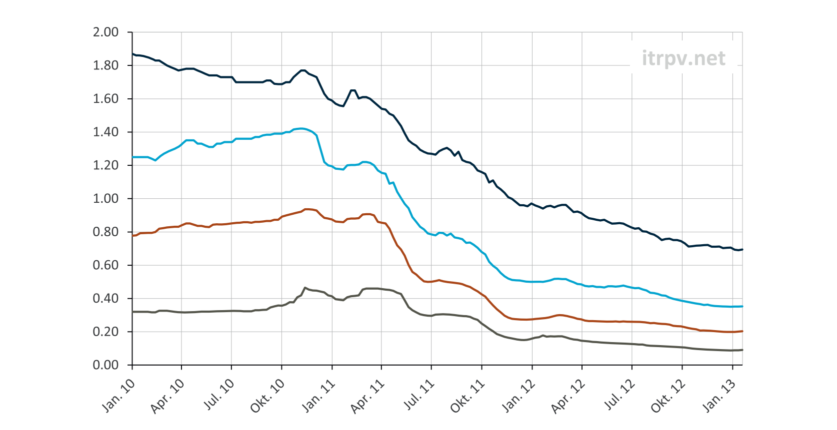


Figure 1. ASPs of different product types.

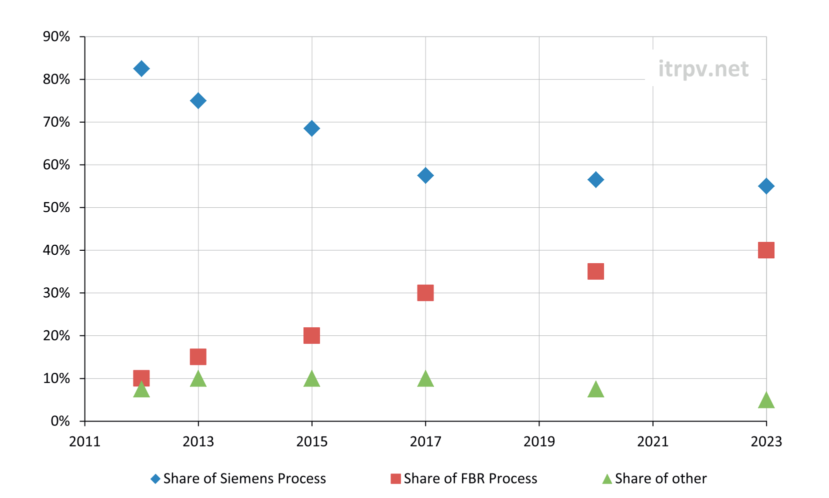


Figure 2. The changing share of polysilicon production methods.

acknowledgment that cost-reduction strategies dictate technology adoption. Where new technology is adopted, notably in cell efficiency gains, the mantra is 'implementation without production cost increases.'

Much of the cost reductions seen at the wafer, cell and module stages of PV production over the last two years have been material based. Not surprisingly, the rapid reduction in polysilicon ASPs has been a significant contributor.

"Much of the cost reductions seen at the wafer, cell and module stages of PV production over the last two years have been material based."

Vertically integrated PV module manufacturing leader Yingli Green saw its overall silicon costs (multi and mono) fall 50% in 2012, down from US$0.30/W in the first quarter of 2012 to US$0.15/W in the fourth quarter.

However, non-silicon costs (multi and mono) fell from US$0.57/W in the first quarter to US$0.47/W in the fourth quarter, an approximately 15% annual reduction. The latest ITRPV notes that module ASPs declined to US$0.69/W in mid-January 2013, still below manufacturing cost levels even for one of the leading low-cost producers.

Polysilicon

Polysilicon ASPs fell below production costs for all but the large-volume suppliers in 2012. Though contract prices hovered around the US$25/kg level, small producers had costs around US$10/kg higher, while spot market prices plummeted to below US$17/kg at the end of 2012.

The result has been a short-term rebalance of polysilicon supply and demand. Bernreuter Research has forecast that PV installations could reach between 35GW and 37GW in 2013, driving a renewed demand for polysilicon that could push polysilicon spot prices to between US$20/kg and US$25/kg by the end of 2013. Significantly, many smaller suppliers would still be unable to restart production if prices rebounded to the forecast range.

The scenario also indicates that cost-reduction strategies for major polysilicon producers remain crucial to profitability and acceptable margins to reinvest in the future should PV demand growth continue without being impacted by potentially crippling polysilicon price rises.

The ITRPV acknowledges that further purity level gains of polysilicon would not lead to significant cost reductions. Major polysilicon producers already exceed purity levels required (6N) for p-type multicrystalline solar cells in such quantities that 9N polysilicon is priced lower than 6N material, negating any cost reductions.

The ITRPV instead expects that the fluidized bed reactor (FBR) technology, as used by REC and soon to be produced by MEMC and Samsung under a joint venture facility in South Korea will increase its share against higher cost and higher purity 'Siemens' processing (Fig. 2). GCL-Poly, China's largest polysilicon producer, also has plans to produce FBR-based material in the near future.

REC recently stated that the FBR polysilicon cash cost was US$12.5/kg in the fourth quarter of 2012, when its plants were fully utilized. The company said that it was targeting a cash cost of US$11.5/kg by the fourth quarter of the year, yet management acknowledged that the target would be tough to meet. Like GCL-Poly, REC expects FBR cost saving to come primarily from improved utilization of the silane gas capacity.

REC's FBR-based polysilicon production continues to run at an annualized capacity of about 16,500MT. Polysilicon nameplate capacity at GCL-Poly remained at 65,000MT in 2012, although the company produced 37,055MT of polysilicon, an increase of 26%, compared with 29,414MT produced in the preceding year.

It is still early days for FBR adoption and the potential for further cost reductions. The ITRPV forecasts that FBR technology is expected to account for only around 15% of polysilicon production in 2013, increasing 30% in 2017. By 2023, FBR production's share is expected to have climbed to account for 40% of polysilicon production.

Wafering

In tandem with polysilicon price declines, solar wafer ASPs declined in excess of 50% year on year. GCL-Poly, the largest producer by nameplate capacity (8GW), recently reported its solar wafer ASP in 2012 was US$0.25/W, down from US$0.54/W in 2011. The price decline year on year was 53.7%.

Wafer producers not shielded by the significant technical know-how barrier and high upfront building costs of polysilicon plants are under extreme pressure to reduce production costs, which have failed to keep up with ASP declines in 2012.

According to the ITRPV: "A significant improvement in cost reduction in the wafering process is expected by the introduction of diamond wire sawing, especially for mono wafers. Diamond wire sawing is expected to become widespread for mono-Si wafering, however the field is open for mc-Si wafering. Other new wafer manufacturing techniques, especially kerf-loss technologies, are not expected to show notable market shares due to the maturity of the established sawing technologies."

Much emphasis is being placed on the introduction of diamond wire sawing to reduce wafer costs, as traditional cost-reduction routes such as crucibles, graphite parts, slurry and sawing wires are only expected to decline in price by between 5 and 10% per annum, forcing the pricing level of diamond wires to be reduced 25% by 2023 from today's pricing level.

Efforts by major suppliers such as Meyer Burger and Applied Materials are ongoing in this field. Wafer producers have championed diamond wire, but improvements in slurry recycling techniques, for example, have proved to be lower hanging fruit to date.

"The ITRPV projects diamond wire-based sawing will become the dominant sawing technique for mono wafers from 2017."

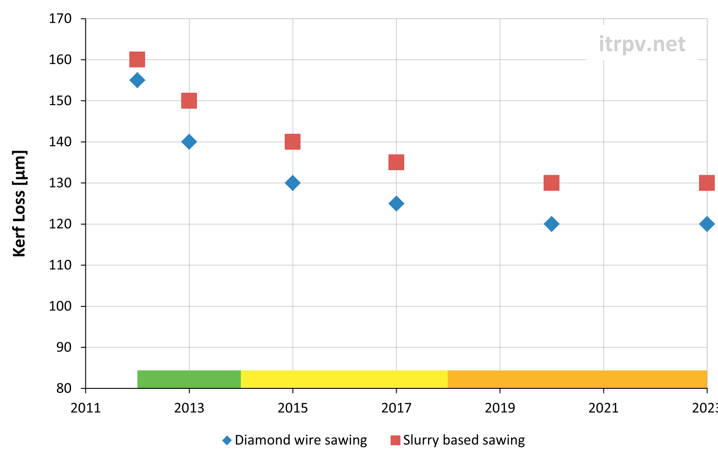


Figure 3. The changing thickness of wafers.

However, the ITRPV projects diamond wire-based sawing will become the dominant sawing technique for mono wafers from 2017. The key problem for multi wafers has been the lack of enthusiasm by module manufacturers to adopt thinner wafers.

The ASP declines for polysilicon, and the need to add processing steps and better align wafer handling at both the cell and the module processing stages, offset material savings. Previous editions of the ITRPV expected wafer thicknesses to have been reduced to 160 microns in 2013. The latest edition acknowledges this would not happen, as the vast majority of wafers remain around 180 microns (Fig. 3). One of our reference models, Yingli Green, ended 2012 using 180 micron-thick wafers and 130 micron-thick saw wire.

Structured wire, a more evolutionary technology compared to diamond wire, is seen by the ITRPV as having significant throughput advantages, though remains slurry dependent.

The gap between wafer manufacturers' desire to reduce thickness and that of cell and module manufacturers to limit processing costs remains a challenge to be overcome.

One area within the wafering segment that is seeing fast adoption because of ASP declines is the move to larger ingot sizes. The latest ITRPV edition acknowledges an accelerated trend to 'Gen 6' ingot size for multi wafers (Fig. 4), which can lead to 1,000kg ingots. The Yingli Green reference model employs a variety of ingot sizes from 400kg to 500kg in 2012. The ITRPV noted that Gen 6 ingot technology had already been commercialized in 2012, increasing throughput by around 250%, compared with Gen 5.

The rise and fall of quasi-mono

Quasi-mono casted ingots and wafers gained a lot of attention in 2010–11. The lower-cost multicrystalline ingot process was billed to offer mono-like quality and performance characteristics without the associated higher production costs of conventional mono techniques. However, quasi-mono was not included in the second edition of the ITRPV but was referenced in the third edition.

However, the latest edition is fairly dismissive of quasi-mono technology, noting that its "lack of maturity" would limit adoption. Yet manufacturers such as ReneSola have continued to develop and ramp the technology in 2012, while selective module suppliers have continued to display quasi-mono modules.

Yet the exit from the DSS market by GT Advanced Technologies in December 2012 puts further doubt on the viability of the PV industry's migrating to quasi-mono wafers, which was seen by the company as a key driver of future furnace sales and upgrades from the struggling wafering sector.

Instead, the ITRPV is banking on a conventional mono wafer production increasing significantly in coming years, taking 50% of the market by 2023. Other niche mono-like combinations are not expected to gain traction.

N-type mono wafers are a key part of the driving force for mono wafers. The ITRPV expects this wafer material to account for over 30% of the market by 2023, as it offers a better path to advanced cell designs and higher efficiencies.

The latest edition of the roadmap also continues to acknowledge the efforts by wafer producers to incrementally increase the p-type wafer efficiencies, a trend expected to continue for several more years and take p-type high-performance wafers to over 30% of the market by 2015.

On the mono wafer front, a key driver emerging is the adoption of full-square mono wafers around 2015.

> "Continuous innovation is set to continue to meet cost-reduction goals and higher cell/module efficiencies."

Overall, the latest edition of the ITRPV continues to recognize the significance of cost-reduction drivers of base materials and products, while understanding that continuous innovation is set to continue to meet cost-reduction goals and higher cell/module efficiencies. However, ITRPV co-chair and REC Silicon vice president for R&D, Dr. Stein Julsrud, was recently cited by SEMI to have wanted more silicon suppliers to engage with roadmap efforts to gain industry-wide alignment.

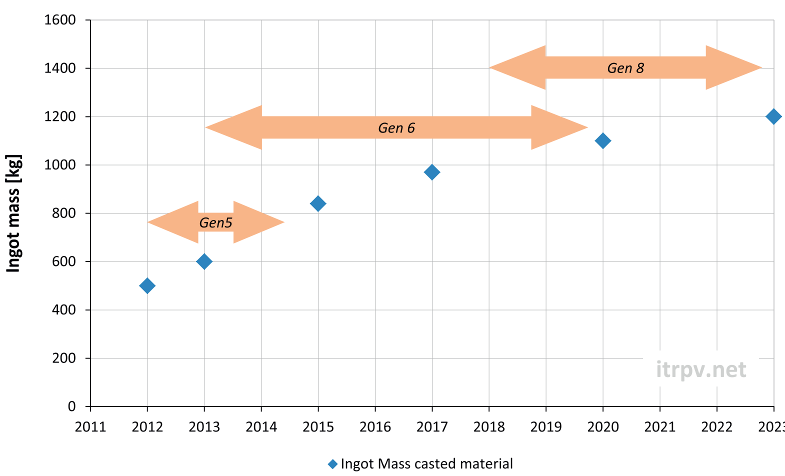


Figure 4. Ingot size trends chart.

Reference

[1] SEMI PV Group Europe 2013, "International technology roadmap for photovoltaic (ITRVP): Results 2012", 4th edn (March) [available online at http://www.itrpv.net/Reports/Downloads/].

Module materials overview report 2013

Mark Thirsk, Linx Consulting LLC, Mendon, Massachusetts, USA

ABSTRACT
Module assembly drives as much as a third of the total module cost and can have a significant impact on overall module performance in terms of efficiency and module lifetime. This paper reviews some of the newest moduling material trends, and the outlook for the module market.

Introduction

The economic headwinds over the last four years have created turmoil in the PV industry. Unstable demand, dramatic price reductions, variable subsidy support and a turbulent time for all supply chain participants have resulted from the global recession which began to bite in 2009. As 2013 moves into the second quarter the challenges of the last few years remain very much the same, with only anaemic growth forecast in many regions of the world.

The economic downturn has propelled national and regional governments into austerity, leading to cuts in spending on PV subsidies and renewable energy initiatives; but, despite the economic challenges, the global PV industry has shown continued growth in installations on an ongoing basis. In fact, there has never been a significant contraction in the volume of installed generation capacity to date. Growth in 2012 topped double digits, and because of the continued enthusiasm for financial support in certain countries, growth of capacity installation will continue through 2013. This impressive performance belies the vicious cycle which is occurring throughout the module supply chain, and which is affecting all players in the supply of materials and equipment to the PV moduling industry.

This vicious cycle stems from the global economic conditions. As regional and national governments struggle to manage the fiscal situation, subsidy programmes come under pressure and subsidies are reduced. Reduced subsidies result in lower demand for solar installations, and thus lower demand for modules, inverters and other critical components. In an industry that is growing so quickly, scale has been an important part of the strategy of most market leaders. To achieve this scale, capacity additions must be pursued aggressively, and are financed with the expectation of a large market that can absorb the increased production. The resulting overcapacity drives all players to reduce costs, but maintain production in an effort to amortize sunken capital. Inventories grow, driving the entire distribution network to push down pricing to the point of nearly nonexistent profits. The resulting cost pressure within the manufacturing chain is passed to all suppliers, and margins collapse in a race to maintain sales volume.

Many hoped that in 2012 we had reached the sales price bottom and were seeing some return to pricing stability for modules. While there is some evidence that module price declines are slowing, it is extremely unlikely that there will be significant price appreciation through 2013. Economic conditions throughout the world remain challenging, and even in regions where growth appears healthy, such as China, economic warning signs are appearing.

Against this troubling background the solar module market has effectively shaken out to three significant module technologies, accounting for the vast majority of demand. Crystalline silicon modules (both polycrystalline and monocrystalline) dominate the installed volumes, with thin-film cadmium telluride modules meeting most of the remaining demand. The next technology segment is met by CIGS modules from multiple small suppliers. In the rest of this article, these three technologies will be discussed, with a focus on crystalline silicon modules in technology.

Module technology trends

At each step of the production of a crystalline silicon PV module the raw materials dominate the overall production cost. This remains the case in the conversion of finished silicon cells into an assembled module, and materials contribute about 80% of the overall module cost. The materials required can be broken down into a very short list:

- Tab and stringer materials
- Encapsulant or adhesive
- Backsheet
- Front and back glass
- Frames

Modules have maintained a relatively constant design, and most of the changes occurring within module technology are incremental improvements of the performance of individual components. Changes within each technology step, and the materials involved, over the past 12 to 36 months are summarized below.

Tab and stringer materials

As drivers for the reduction of silicon usage continue, tabs and stringers have become the primary conductors for both front and rear sides. By reducing the printed solder bonding area on the cells, and ensuring that the bonding is aligned, the amount of silver paste used for front and rear busbars can be dramatically reduced. While little has changed in the technology for standard stringers, the availability of copper-clad backsheets for use in back-side contact architectures is enabling this technology to be developed, although it features in only a small percentage of module designs.

Credit: aleo solar

The drive to reduce silicon usage has increased the importance of tabs and stringers as primary conductors.

Encapsulant

There have been changes in basic polymers used for encapsulants as well as improvements in the most commonly used EVA-based encapsulants. Suppliers are offering polyvinyl butyral (PVB), olefin and silicone-based encapsulant technology as high-performance alternatives to EVA. Meanwhile, EVA encapsulants with ultrafast cure times, high dimensional stability, and high transmission and sodium ion barrier properties have all been developed to improve more traditional module designs.

Credit: Solar-Fabrik

Basic encapsulant polymers have been changed and EVA-based encapsulants improved.

For many thin-film module designs, the thermoplastic encapsulant has been replaced by EVA. Edge-sealing technologies mitigate the moisture sensitivity of the thin-film absorber. This design has replaced the glass/glass designs used in many CIGS modules, and is favoured by Frontier Solar, the largest CIGS supplier. However, the First Solar CdTe module design has remained with strengthened front glass and tempered back glass encapsulated with EVA, but still using an edge seal.

Backsheet

Similarly to encapsulants, there have been incremental improvements in backsheet performance, as well as the development of replacement materials for components of laminated backsheets. Supply shortages of polyvinyl fluoride (PVF) in the last two to three years have led to the adoption of other fluoropolymers such as polyvinylidene fluoride (PVDF) or solution-coated fluoropolymer protective layers. Among other factors, cost reduction has helped to drive a reduction in the number of fluoropolymer layers in backsheet laminates, with products becoming available with a single fluoropolymer on the outside, or even laminated polyethylene terephthalate (PET) backsheets with each layer offering different functionalities. These PET-only backsheets have been aided by the development of additives to the PET to improve weathering and reduce UV degradation.

Credit: Madico

Modifications such as replacement materials for laminated backsheets have driven gradual performance improvements.

Improvements in heat radiation, internal reflectivity or transparency for bifacial modules have also been achieved, allowing increased module efficiency.

Front glass

Traditional moulded glasses account for significant cost and weight within the module design. Some progress has been made in reducing glass thickness in order to decrease both cost and module weight. To reduce glass defects some module makers, although only a minority, have migrated to float glass to achieve higher efficiencies.

Notably, for very high efficiency modules, the front glass is increasingly being coated with anti-reflective materials, which can achieve up to a 4% improvement in light transmission. Although anti-reflective coatings have been expensive in the past, cost reduction has brought the price down to a more economically favourable level.

Frames

An increasing number of glass and backsheet modules are offered as frameless options. Concerns about moisture ingress remain: some manufacturers have used polyisobutylene (PIB) sealants, while others maintain that standard encapsulants are acceptable. Many frameless modules rely on a front and rear glass design for better protection of the cells; however, an increasing number of frameless module designs are being promoted, with a significant number of designs using front and back glass.

Credit: ET Solar

A growing number of modules are now offered as frameless options.

Another major influence in module manufacturing is the advent of much-improved testing. Luminescence imaging of assembled modules has become accurate enough to diagnose systematic defects and has resulted in a vast improvement in module quality. As the old adage goes, "You can't fix what you can't see." Many production faults, from microcracks in cells to hot spots and connection faults, can be visualized, and these can be addressed in production.

Manufacturing concerns within the moduling supply chain

Turbulent business conditions in 2011 and 2012 have resulted in significant numbers of players at all levels of the supply chain moving into loss-making territory, and many into bankruptcy. The surviving supply chain participants have gone through many rounds of cost reduction, and are still challenged to realize value for differentiated products.

Some of the trends for cost reduction are common to many players. These approaches include reducing overheads, increasing productivity, adopting best-in-class manufacturing practices, debottlenecking existing manufacturing, optimizing sales and distribution, and shutting down out-of-date or inefficient manufacturing locations. All of these benefit the industry in the long run by setting low-cost benchmarks for the supply chain. Consolidation of a number of suppliers has resulted in a smaller number of overall players in many markets.

Some of the material-specific improvements include moving from the supply of polymer films in the form of rolls, to precut sheets, which enables module manufacturers to save scrap material and increase productivity; the polymer film supplier is often in a better position to recycle scrap material than the module maker, thus reducing cost per module. Fast-curing EVA encapsulants and thermoplastic encapsulants offer cost savings to module makers through improvements in productivity and reduced investment in laminating systems. Although attractive under normal conditions, these approaches are less effective at present, since overcapacity within the moduling industry reduces the need for productivity improvements.

Consolidation of suppliers delivers the benefit of increased purchasing power within a smaller number of surviving suppliers, offering attractive pricing for volume purchases of raw materials. This reduces raw material cost volatility, but cannot eliminate it. Many of the raw materials for moduling, such as EVA and PVF, suffer from external market forces, which leads to high resin cost volatility, just as metal prices have seen price spikes in recent years. At times when margins are narrow, increases in raw material costs are passed on to module makers by suppliers. Several suppliers have reported favourable drops in raw material costs in 2012, which have helped them deliver price reductions, although in a commodity market it is likely that these trends may reverse.

Perhaps the biggest concern, and the most visible structural change within the industry, has been the shift of the supply chain to China. The reduction of supply base capability in Europe, and its migration to China, has been responsible for significant cost reductions, as lower capital and labour costs facilitate lower prices. While this migration of the supply base to China was regarded with suspicion by many module purchasers, Tier 1 module makers proved that they could deliver a reliable supply of high-quality modules, often incorporating brand name materials in module construction that are well regarded by purchasers. Of increasing concern is the fact that as prices have continued to fall, the necessary cuts in cost have been achieved by the substitution or dilution of high-quality materials with lower-cost, lower-quality replacements. This trend has resulted in reports of reduced module quality, which is evidenced by the trend of banks and installers in global markets to increase testing of incoming module construction techniques and materials. Increasing failure rates have been seen by multiple installation companies when substandard materials, which pass standard certification but not rigorous real-world conditions, are found in modules. It is expected that Tier 1 and Tier 2 module suppliers will see it is beneficial for them to move to high-quality materials in order to maintain their brand reputation and optimize the cost of quality; struggling module suppliers, however, may not be able to.

Other structural influences on cost

As margins have narrowed, and the market is constrained by weak demand, technology improvements have been adopted to add value and differentiate products. Even though there has been a significant increase in the pace of innovation within both cell and module manufacturing, decision times for implementation and qualification can still take months or years. This presents a significant challenge for material suppliers in delivering performance improvements while realizing a return on investment for the improvements delivered. Adding to this challenge, moduling companies do not have deep enough pockets to fund the qualification of many performance-enhancing technologies, and have sometimes requested that suppliers aid in paying for the qualification and certification of improved products, pushing the cost load into the supply chain.

Another effect of pricing close to cash cost is that the squeeze on innovation results in a slowing of improvements to materials and manufacturing processes. A characteristic of the solar industry used to be that innovation was spread throughout the supply chain, and novel processes were delivered by materials suppliers, equipment makers or research consortia as well as module makers themselves. As margins have tightened, this engine for improvement has begun to stall, and development budgets will remain hard to find for the foreseeable future. Related to this trend is the challenge of capacity reinvestment. Although many manufacturers recognize that overcapacity and oversupply exist, ROI targets force them to continue production despite weak demand. Products manufactured under these conditions often do not meet company reinvestment thresholds, and as end markets grow, suppliers are unwilling to make the substantial capacity investments to deliver needed products at market costs. Even with an expanded global supply base, this will become a concern for the industry as key suppliers delay capacity expansions necessary for delivering scale economies in the future.

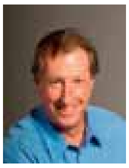
Conclusions

The continuing global recession has taken its toll on the PV industry, although with a broadening global customer base, and more countries and states implementing subsidy programmes, growth has continued. Unit growth is expected to continue in the short term.

The old adage that power (and power density) is king remains true within the solar industry. Challenging times have been met by the solar module manufacturers with a readiness to adopt and implement improved technologies throughout the supply chain, and especially in moduling. This has facilitated the adoption of many new technologies that have gone some of the way in delivering cost reductions needed to compete in these tough times, and locked in improved practices and technologies that in turn lock in these lower costs.

Unfortunately, a compromise in material quality is endangering the ability of both suppliers and installers to achieve a win-win in their projects. Low-quality panels will endanger the profitability of either the supplier or the buyer in the long run, until it is realized that money can be made by all parties with high-quality products.

About the Author



Mark Thirsk is a managing partner and co-founder of Linx Consulting, which provides market-defining analysis and strategic insights across major markets in electronic materials. He has over 25 years' experience in economic and business forecasting, strategic planning, technical marketing, product management and M&A, spanning many segments and processes in electronic materials. Mark has served on the SEMI Chemicals and Gases Manufacturers Group (CGMG) since 1999, acting as chairman between 2001 and 2003. He holds a B.Sc. (Hons.) in metallurgy and materials science from Birmingham University and an MBA from The Open Business School, and has authored multiple publications in both academic and trade publications, as well as contributing to several patents.

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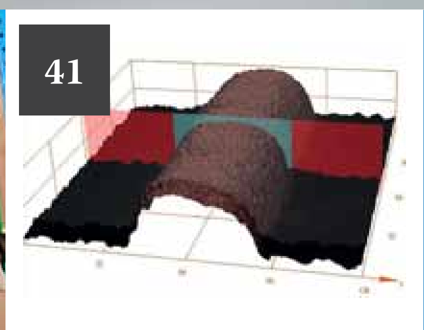
Cell Processing



News

First Solar to manufacture copper-based crystalline silicon solar cells

Leading thin-film and PV project developer First Solar has rocked the solar industry with the acquisition of US-based monocrystalline start-up TetraSun. Having exited R&D into competitive CIGS thin-film technology and rejuvenated its commitment to CdTe technology, First Solar plans to start "tentative" production of TetraSun's copper-based monocrystalline cells in the second half of 2014. First Solar did not say what the capital investment would be, or where the solar cells would be produced and what the initial nameplate production capacity would be.

First Solar has acquired US-based monocrystalline start-up TetraSun.

Production Update

SunPower treading water on a sea of red ink

The newly dubbed 'X-Series' modules come with SunPower's latest 'Maxeon Gen 3' solar cell technology, which has conversion efficiencies of over 24%. SunPower had previously said that the solar cells had entered production in March 2012.

However, SunPower management said in its most recent quarterly conference call that the ramp of the cell technology enabled the company to significantly reduce costs.

As part of the restructuring plan, production was reduced to support the need for reducing high inventory levels. The company reduced cell production in the fourth quarter to 153MW, down 32% from 227MW in the third quarter. Total cell production in 2012 stood at 925MW.

Management did however reiterate that its Maxeon Gen 3 technology was in volume production. The technology uses a new copper-based interconnect between the backside of the wafer and the backsheet, intended to lower production costs and boost conversion efficiencies via lower resistance and better conductivity. The technology also enables the use of thinner wafers, reducing breakage rates.

The introduction of the Gen 3 technology into volume production meant that the company was able to reduce its polysilicon consumption per watt. SunPower used 4.2 grams per watt of polysilicon in the fourth quarter of 2012, down from 4.5 grams per watt in the first quarter of 2012.

Management also noted that due to manufacturing cost reduction plans the blended cost per watt was claimed to have declined by more than 25% in 2012, resulting in its cost per watt falling faster than its ASP decline.

Hanwha SolarOne sees massive shipment swing away from Germany to Japan

Chasing higher margin business in Japan, India and Thailand in the fourth quarter of 2012 resulted in Hanwha SolarOne's sales in Germany plummeting to only 8% of total sales, down from 39% in the third quarter. Management noted in the call that utilisation rates reached approximately 68% in Q4 2012, yet due to the clear order visibility, utilization rates in Q1 2013 would be around the 75% mark, equating to quarterly module production of approximately 300MW. Management expects the utilization rate to reach around 100% in the second quarter (400MW), remaining at that level throughout the year.

Following the likes of Yingli Green and Canadian Solar, the company does not plan to add new capacity in 2013 and said that capital spending would be around US$50 million this year. Such low-levels would suggest the majority of spending is equipment and facility maintenance based. However, management noted that it would continue to automate back-end module assembly steps as part of quality control and headcount reduction efforts in those steps. Production costs were said to have US$0.64/W in Q4 2012, supported by material cost reductions and higher utilization rates. Production cost reductions in 2013 are focused on higher cell efficiencies, lower material costs and improved process technology and automation. Management said that non-processing costs in 2012 were between US$0.52/W and US$0.53/W, with the expectation of reducing these to mid-US$0.40/W range by the end of the year.

Hanwha SolarOne said it does not plan to add new capacity in 2013.

Canadian Solar reports annual loss of US$195 million; shipments to increase in 2013

Falling solar module prices continued to impact Canadian Solar's financial results as the company more than doubled losses year–on–year. The company reported a full-year loss from operations of US$142.5 million and a net loss of US$195.1million for 2012. It reported full-year net revenue of US$1.3 billion, compared to US$1.9 billion in fiscal year 2011, due primarily to continued ASP declines. Solar module shipments in 2012 were 1,543MW, up 16.6% from 1,323MW in fiscal year 2011. Management said there were not any plans to add capacity in 2013, but noted that they were constantly monitoring the situation. However, the company highlighted that it had met its ambitious "all in" module manufacturing cost reduction targets for the year. Manufacturing cost per watt ended the year at US$0.55/W. The company had guided US$0.55 to

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US$0.60/W, earlier in 2012. Noting that polysilicon prices were rising, management only guided that on processing cost reductions the company was aiming for a few cents reduction in 2013, though this was only guided in connection with polysilicon prices remaining stable this year in the region of US$20/kg. The company said that its ELPS solar cell technology capacity stood at 120MW at the end of the year, but did not say whether this would be expanded in 2013.

Profitability to dog Trina Solar in 2013

Losses were the theme at tier 1 solar module manufacturer, Trina Solar in 2012 and will prove a similar story this year after the company released fourth quarter and full-year financial results. Trina Solar reported 2012 net revenue US$1.30 billion, a decrease of 36.7% from US$2.05 billion in 2011. Total shipments were 1.59GW, an increase of only 5.4% from 1.51GW in 2011. The company said that it did not expect to increase capacity in 2013 from 2012 levels.

Annualized in-house ingot and wafer production capacity at the end of 2012 was said to be approximately 1.2GW and its PV cell and module production capacity was approximately 2.4 GW. The company noted non-silicon costs in the fourth quarter were around US$0.51/W with the goal of reducing those by more than 10% in 2013. Trina Solar had previously announced a target of US$0.50 per watt by the end of 2012. The company said that it was using around 5.4 grams of polysilicon per watt by the end of 2012.

Source: Trina Solar

Trina Solar's total shipments were 1.59GW.

Source: China Sunergy

CSUN has said it had made great strides in its cost reduction and higher conversion efficiency strategies.

Yet management acknowledged that they had seen polysilicon prices flatten and had increased slightly since December 2012. Cost reductions in 2013 were said to come mainly from reduced material consumption and less wafer breakage and improved yields. Higher utilization rates, notably in the second-half of the year would also contribute to cost reduction targets.

Going in hand with the evolving project business, management acknowledged that its recently announced frameless PDG5 modules is optimized for reliable performance to ultimately reduce costs but were designed to be used in projects that experienced harsh environmental conditions.

China Sunergy guides over 50% module shipment increase for 2013; 60% shipments to Europe

Europe will remain China Sunergy's (CSUN) single largest market for its PV modules this year, despite a selective exodus from EU countries by a number of other China-based module manufacturers before the completion of an investigation into anti-dumping by the EU Commission. Central to CSUN's commitment to Europe is due to its joint venture solar cell and module assembly facility in Turkey. Management noted that it expected to ship between 550MW and 600MW of modules in 2013, 60% within Europe.

Other than being one of the few companies actually expanding capacity in 2013, CSUN said that it had made great strides in its cost reduction and higher conversion efficiency strategies during the year. Management noted that the batch average conversion efficiency of its 'QSAR' cells remained at 19% in the fourth quarter but actually topped 19.7% in the lab. QSAR production lines were said to have been upgraded in the fourth quarter to accommodate the volume ramp of its 'QSAR II' solar cells in January of this year. As of the end of March, the company said that its average efficiency of the QSAR II production lines reached a new record of 19.2% and peak efficiencies actually surpassed 20%. Management noted that it was targeting average efficiencies of 19.5% for QSAR II production lines in 2013.

Yingli Green to ship an extra 1GW in 2013; module prices rising

A net loss in 2012 of nearly US$500 million was overshadowed by Yingli Green's shipment guidance for this year increasing by a massive 1GW. Yingli Green said that 44% of revenue came from China in the fourth quarter of 2012, yet expects a further 40% increase in module shipments into the domestic market in 2013. The company expects significant market share growth in Japan, while growth will also be seen in certain European markets, the USA and emerging markets. Based on global PV installations expected to be in the range of 30-32GW in 2013, Yingli Green is targeting around a 10% global market share. Yingli Green held combined manufacturing capacity at 2,450MW at the end of the year. Overall non-silicon costs declined to US$0.47/W, down from US$0.53/W in the third quarter of 2012.

Overall silicon costs were said to have declined to US$0.15/W, down from US$0.17/W in the prior quarter. Management guided that overall non-silicon costs would be below US$0.45/W by the end of the fourth quarter of 2013. Continued material cost reductions, production optimization and higher utilization rates were said to be behind the expected cost reductions.

News

Order Focus

Japanese domestic solar cell sales in Q4 2012 surged by 147%

Sales of solar cells in Japan in the fourth quarter of 2012 soared by 146.9% compared with the corresponding period one year earlier, statistics by the Japan Photovoltaic Energy Association reveal. Domestic shipments between October and December 2012 amounted to 1,003MW. In the same three-month period, Japanese imported solar cells amounted to 342MW whilst solar cell exports reached 111MW. The surge in domestic sales has been largely attributed to the Japanese subsidy scheme.

Solar3D touts market entry in 2014

US-based three-dimensional solar cell start-up Solar3D is planning to produce a manufacturing prototype of its cell technology in 2013 to prove the technology was viable with its claimed high conversion efficiencies in advance of selecting a manufacturing partner to volume-produce the cells. Solar3D said that market entry was planned for sometime in 2014.

Source: Solar Frontier

Sales of solar cells in Japan in 2012 have soared by 146.9%.

Business News Focus

Meyer Burger sales fall 51%; new order intake down 73%

Meyer Burger Group net sales in 2012 fell 51% to CHF645.2 million (US$684 million) on the back of overcapacity across its fields served in the PV industry. The company has posted a net loss of CHF115.9 million (US$123 million) and plans to issue new shares to raise CHF150 million to strengthen its liquidity position on the back of further declines in sales expected in 2013, due to an approximately 73% decline in new order intake in 2012 compared to 2011.

Meyer Burger reported a 2012 new order intake of CHF223.4 million (US$236 million), down from CHF876.8 million in 2011. The order backlog at the end of 2012 stood at CHF 405.5 million, down from CHF 909.9 million in the same period a year ago. On a regional basis, 81% of 2012 net came from Asia, primarily China, according to the company. A single China-based customer accounted for 22.6% of 2012 sales (CHF145.8 million) in 2012.

Research & Development

DEK Solar claims up to 40% silver paste reduction with fine screen printing

Tests conducted by DEK Solar and DuPont Microcircuit Materials (MCM) have resulted in silver paste consumption reductions and possible conversion efficiency gains of 0.5% when using fine line screen printing of conventional crystalline solar cells. DEK Solar said that test results with DuPont's metallization paste technology showed a significant total reduction of silver consumption of up to 40%. Silver paste remains the second highest material cost next to polysilicon in the making of crystalline solar cells.

DuPont expects solar module production to fall in Q2 to prevent inventory build

According to Ellen Kullman, chair of the board and chief executive officer of DuPont, overall global PV module production is set to decline around 15% in the second quarter.

Kullman noted that the expected decline was in contrast to the second quarter of 2012, which experienced a strong uptick in production in anticipation of stronger sales in the second half of the year. However, increased demand was muted and the production surge created an inventory build.

Responding to analyst questions during a conference call to discuss first quarter 2013 financial results, the executive noted that the fall in production in the second quarter is expected to lead to sequential quarterly growth through the second-half of the year, though its internal forecast for module production year-on-year would be flat.

"Now the second quarter of last year was a very strong year," commented Kullman. "There was lot of over production in hindsight in that second quarter and that's why this year were stating that in the second quarter that's going to be off some, 15%, the module production will be off 15%. Worse we are forecasting the PV installed will be flat for the year, and so what that means is there has to be some progression coming through the year and it will improve in the third quarter and improve again in the fourth quarter."

JA Solar starts production of MWT solar cell technology from ECN

JA Solar has started production of its metal wrap-through (MWT) solar cells in China as a precursor to plans to be announced about its next-generation solar cell technology.

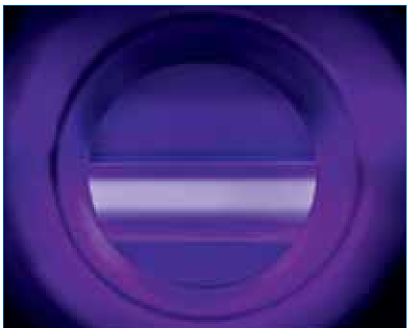
The tier 1 PV manufacturer previously joined forces with ECN in 2010 to commercialise MWT technology. Yingli Green has also been a long-term partner with ECN on MWT and other cell technologies.

JA Solar claimed that its MWT-based monocrystalline and multicrystalline cells had an average conversion efficiency of 19.6% and 18.1%, respectively. However, the cells have produced peak conversion efficiencies of 20.0% for monocrystalline and 18.6% for multicrystalline-based cells.

"MWT is at the core of the next generation of module technology, and represents a significant breakthrough in terms of power output and conversion efficiency," said Mr. Yong Liu, CTO of JA Solar. "Mass production of MWT cells marks a significant milestone in JA Solar's ongoing technological leadership in the global solar industry."

Oxford Instruments seminars to discuss nanoscale plasma processing

Plasma etches and deposition systems manufacturer Oxford Instruments has announced two one-day seminars in Beijing and Taiwan which will focus on nanoscale plasma processing. The events are scheduled to take place later this year on 14 May in Beijing, China, and 16 May in ITRI, Hsinchu in Taiwan. Each one-day programme will cover a range of topics from atomic layer deposition, photovoltaics, deep silicon etch, power devices, HBLED and ion beam technologies.



Source: Dennis Schroeder / NREL

Oxford Instruments is hosting a one-day programme which will cover a range of topics from atomic layer deposition and PV.

Product Reviews

MKS Instruments

MKS Instruments' 'MultiTherm 1000' offers multi-zone temperature control

Product Outline: MKS Instruments' MultiTherm 1000 temperature controller features uniform temperature control across multiple zones and excellent uniformity of heat distribution across combined process areas while preserving system costs and real estate.

Problem: Uniformity is a key process attribute in advanced temperature control applications, which reduces out of spec product and can boost productivity and reduce fault detection requirements for solar cell processes.

Solution: The first in the MultiTherm line and latest addition to the MKS control platform family, the MultiTherm 1000 is offered with 'EtherCAT' connectivity to provide high-speed data exchange and seamless integration into an EtherCAT network. In addition, MultiTherm features heater diagnostics which provide an alarm for heater failure or degradation to reduce the chance of costly process damage. Its safety interlocks allow the integration of over-temperature and EMO switches into the system. Its heater power routing with internal fusing is a cost-reducing feature that eliminates the need for additional hardware.

Applications: Wide range of thermal processing applications.

Platform: MultiTherm 1000 features 16 precision sensor input channels accepting RTDs (resistance temperature detectors) and thermocouples, and provides 16 PWM output channels with built-in SSRs for up to 2A, 220VAC. Built-in PID makes the unit ideal for dynamic control applications where extreme temperature stability is required.

Availability: April 2013 onwards.

VITRONIC

Camera system from VITRONIC provides retrofit solar cell colour classification

Product Outline: The VINSPEC solar VCOFLC1 camera system from VITRONIC enables exact and reliable front print and color inspection.

Problem: Tier 1 solar cell manufacturers require high-quality solar cells. Especially sorting into different colour classes is a main scope at Asian factories. Therefore many Asian solar cell producers are considering how to retrofit their existing production plants.

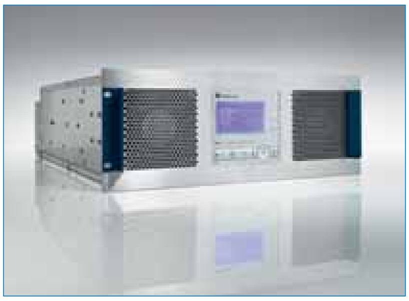
Solution: The new VINSPEC solar VCOFLC1 camera system combines front print and colour inspection, and performs exact and reliable quality inspection and cell classification. Claimed to be easy to operate and calibrate, the system from VITRONIC provides a standard calibration tool to define the colour classes and borderlines. Even if several cell testers have to be operated and tool matching is required, the set-up process needs to be done only once and the classification rules can be copied to all other testers.

Applications: The inspection system can be used for both mono- and multicrystalline silicon cells. Its throughput achieves more than 2,400/h, and the sorting pureness is claimed to be higher than 99.8%.

Platform: The sensor box consists of a colour line scan camera with four 4,096 pixel lines, a white LED illumination module, a backlight and a computing subsystem. The software provides automated, fast tool calibration and tool matching, a graphical user interface comprising yield control tools for rapid intervention and process adjustments, statistics and visualization of all quality-relevant features of current and recently tested cells.

Availability: April 2013 onwards.

HÜTTINGER Elektronik



HÜTTINGER Elektronik's TruPlasma RF 3012 demonstrates an 80% degree of efficiency

Product Outline: The high-frequency generator TruPlasma RF 3012 unites an 80% degree of efficiency with an exceptionally robust design, according to HÜTTINGER Elektronik.

Problem: Efficiency and a robust design have been two demands of RF process power supplies that are claimed to have not been met. Users had the choice between stable, but less efficient, generators with class A/B amplifier technology or efficient yet sensitive power supplies with a class E switch-mode power supply.

Solution: In a typical PECVD coating system, in which passive SiN_X coatings are applied to wafer-based solar cells, a generator often runs 22 hours a day, 365 days a year. At current power prices, the increased efficiency generates cost savings of approximately €3,500 per year per power supply.

The TruPlasma RF 3012 has an output power of 12 kilowatts with a frequency of 13.56 megahertz and is ideally suited for PECVD, etching and RF sputter processes in the flat panel display, solar and semiconductor industries. The user can design these production steps very efficiently with the TruPlasma RF 3012, thus achieving significant cost savings.

Applications: Wide range of uses including PECVD coating systems.

Platform: The TruPlasma RF 3012 is equipped with an innovative class D converter topology that allows an 80% degree of efficiency. The reduction in power loss also means the TruPlasma RF 3012 has a reduced need for cooling. This opens up additional savings potential in cooling water usage and reduced infrastructure investments. The high degree of efficiency also contributes to adherence to CO_2 emissions goals in production, an important contribution to environmental protection.

Availability: March 2013 onwards.

Cost-effective n-Pasha solar cells with efficiency above 20%

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ABSTRACT

This paper presents recent developments of ECN's n-Pasha (passivated on all sides H-pattern) solar cell technology. The n-Pasha cell, currently being produced on an industrial scale by Yingli Solar, is a solar cell fabricated on n-type Cz material with homogeneous diffusions, dielectric passivation and printed metallization on both sides. The metallization is applied in an open H-pattern to both sides, which makes it suitable for bifacial applications. In order to improve both cell performance and the cost of ownership of n-Pasha solar cells, the ECN R&D team has focused on several aspects of the device design and processing. By reducing metal coverage and improving the quality of the front-side metallization, tuning the back-surface field (BSF) doping and improving the front- and rear-surface passivation, it has been possible to obtain an average efficiency of 20%, with top efficiencies of 20.2%. At the same time, the amount of silver used for metallization has been decreased by over 50% and is now similar to that used for p-type solar cells. Furthermore, it is shown that with the ECN n-Pasha cell concept, wafers from the full resistivity range of n-Cz ingots can be used to make cells without losses in efficiency. Combining the improved efficiency and the reduction in cost makes the n-Pasha cell concept a very cost-effective solution for manufacturing highly efficient solar cells and modules.

Industrial solar cells and modules on n-type base material

The fourth edition of the International Technology Roadmap for Photovoltaics [1] predicts a clear shift from p-type to n-type mono-Si within the mono-Si market. The market share for n-type mono will be equal to that of p-type mono in 2017, and will exceed it the following years. Compared with p-type material, n-type Cz material is known for its stable high carrier lifetimes because of the absence of light-induced degradation (LID) [2,3] and its higher tolerance of the most common metallic impurities, such as Fe [4,5]. These longer lifetimes are consequently reflected in higher efficiencies. Indeed, the highest-efficiency crystalline silicon modules currently on the market are based on SunPower Maxeon technology [6], which incorporates n-type Cz material. Using this technology, SunPower fabricates interdigitated back contact (IBC) solar cells with efficiencies of over 24%, which enables module efficiencies of up to 21% to be achieved [7]. IBC solar cells feature both the emitter and the back-surface field (BSF) at the rear of the solar cell. Metal contacts are formed solely on the rear, which means that the complete front surface is available for capturing the light. Since the p-n junction is located at the rear of the cell, the IBC cell must be fabricated on Si wafers with a long effective minority-carrier diffusion length in order that all the carriers reach the emitter. Excellent front-surface passivation is therefore required as well. The production cost of these high-efficiency cells is quite high owing to the use of many complicated processing steps [8]. Using its heterojunction with intrinsic thin layer (HIT) technique, Sanyo Electric Corporation has obtained very high efficiencies with n-Cz material as well: efficiencies above 23% were reported in 2009 [9], and recently these efficiencies have improved even further [10]. In this case, the high-efficiency processing also leads to higher production costs than for standard (p-type) solar cells [8].

> "The n-Pasha cell structure itself is simple, while still enabling cell efficiencies above 20%."

ECN's aim is to develop high-efficiency, low-cost and robust solar cell and module concepts that can be easily adopted by industry. One of ECN's cell concepts using n-type silicon is the n-Pasha (passivated on all sides H-pattern) solar cell concept [11]. Compared with the established n-type solar cell techniques described above, the n-Pasha cell concept can be implemented using processing steps that are similar to those found in the production of common p-type solar cells. The n-Pasha cell structure itself is simple, while still enabling cell efficiencies above 20%. This novel cell concept was first introduced to the market in 2010 under the brand name Panda [12,13] by the company Yingli Solar in collaboration with Tempress BV and ECN. Efficiencies of over 19% were reached in 2011 with this cell concept, both by Yingli and by ECN. In 2012 ECN reported efficiencies of up to 20%, obtained by the implementation of improved processing that is currently also being carried out at Yingli [13,14,15]. Furthermore, Yingli demonstrated that their Panda cells show no LID and have a lower temperature coefficient than standard p-type solar cells [13].

Despite the obvious advantages of n-type base material in terms of longer bulk carrier lifetime and subsequent higher efficiencies and an absence of LID, the majority of industrial solar cell and module manufacturers are still using p-type mono- or multicrystalline silicon as their base material. One reason for this is the n-type Cz base material itself: because of the higher segregation coefficient of phosphorus compared with boron, the resistivity range of phosphorus-doped n-type ingots is typically wider than that of boron-doped p-type material. This larger range poses additional challenges for the cell architecture for n-type solar cells, or increases the cost of the solar cells as a result of yield loss if only part of the resistivity range can be used [16]. The second reason is that the cost of n-type cell production is higher than for p-type cell processing. For most concepts, including the n-Pasha cell concept, an additional BBr_3 diffusion step to form a boron emitter is necessary. More importantly, the silver consumption is higher for n-type cells. Because of the absence of the (cheap) aluminium on the rear side, both the emitter and the BSF have to be contacted by a silver grid. However, the costs of printing a full-area layer of aluminium on the back side, which today are still significant, are of course absent for the n-Pasha cell concept.

Recent developments at ECN to lower the cost per watt (€/Wp) of the n-Pasha cell concept are discussed in this paper. In the first part, the n-Pasha cell concept and the steps that were taken to increase efficiency are summarized. In the second and third parts, two main factors having a bearing on the costs of n-type solar cells are described, namely the n-type Cz material

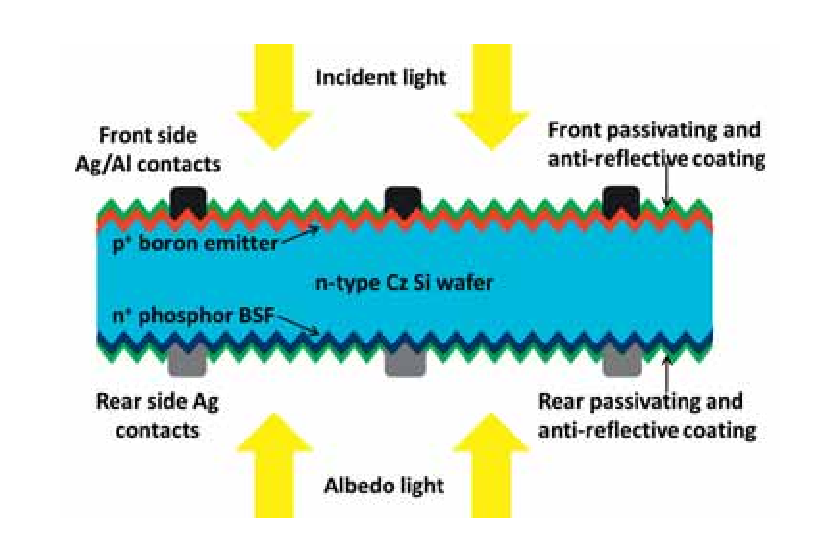

Figure 1. Cross section of the ECN n-Pasha cell, featuring an n-type Cz Si wafer with a boron p+ emitter and a phosphorus n+ BSF. Yingli's Panda cells are also based on this structure.

itself and the silver consumption. Measures that can be taken to lower the costs are illustrated. It is shown that the efficiency of n-Pasha solar cells is high and stable over a wide resistivity range, and that the costs relating to the silver metallization can be significantly reduced while maintaining, or even increasing, the solar cell efficiency. The combination of the improved efficiency and the cost reduction makes the n-Pasha cell concept a cost-effective solution for manufacturing highly efficient solar cells and modules.

ECN's n-Pasha cell concept

The basic configuration of the n-Pasha solar cell is shown in Fig. 1. At ECN, the n-Pasha cells are fabricated on 6-inch n-type Cz Si wafers. All the processing steps used for the n-Pasha cell are suitable for industrial-scale implementation. The first processing step is the texturing of the wafers with random pyramids using alkaline etching. The boron emitter and phosphorus BSF are formed using an industrial tube furnace from Tempress [17]. A 60Ω/sq emitter is made using BBr_3 as the precursor. The BSF is created using $POCl_3$ as the precursor and provides additional lateral conductivity on the rear side. This results in a satisfactory fill factor despite the open rear-side metallization, even for cells processed on high-resistivity base material (~10Ωcm). Consequently, the BSF is an important element of the cell design, providing a solution for reducing the performance sensitivity to variations in n-type wafer resistivity. Both the front and rear sides are coated with SiN_x layers for passivation and anti-reflective purposes. The metal grids are then printed, and the contacts on the emitter and the BSF are formed during a single co-firing step. Direct soldering to both the front and rear metallization is possible, so no additional metallization step is necessary to enable interconnection in creating a module.

The open front- and rear-side metallization ensures that the bowing of the cells will be considerably reduced when (very) thin wafers are used, which is a distinct advantage in view of the bowing that occurs with full aluminium BSFs on p-type solar cells. Furthermore, the dielectric coating on the rear side results in an improved surface passivation compared with the conventional full aluminium rear side of a p-type cell, while the optical properties of the dielectric layer can be tuned to achieve optimal (anti-) reflective properties. If the cells are arranged in a standard monofacial module, the refractive indices can be tuned to obtain maximum reflection in combination with the module back-sheet foil. On the other hand, the open rear-side H-patterned metallization makes the n-Pasha concept highly suitable for bifacial cell and module technology. In this way, an even higher module output power and an increased annual energy yield can be realized when the cells are appropriately placed in the field. Recent results have shown that the output power of bifacial n-Pasha modules can be increased by almost 20% if the bifacial modules are placed in front of a reflecting surface [14].

> "The open rear-side H-patterned metallization makes the n-Pasha concept highly suitable for bifacial cell and module technology."

Efficiency improvements of n-Pasha

The processing improvements that have led to the achievement of 20% efficiency of n-Pasha cells have already been described in several publications in 2012 [14,15]. In this section, a brief summary of these steps will be given and the latest results presented.

Front-side metallization

Besides being one of the major cost drivers of solar cells, the front metallization is also a very important parameter of n-Pasha cell efficiency. When the metal-covered area is decreased, the short-circuit current (I_{sc}) and the open-circuit voltage (V_{oc}) will

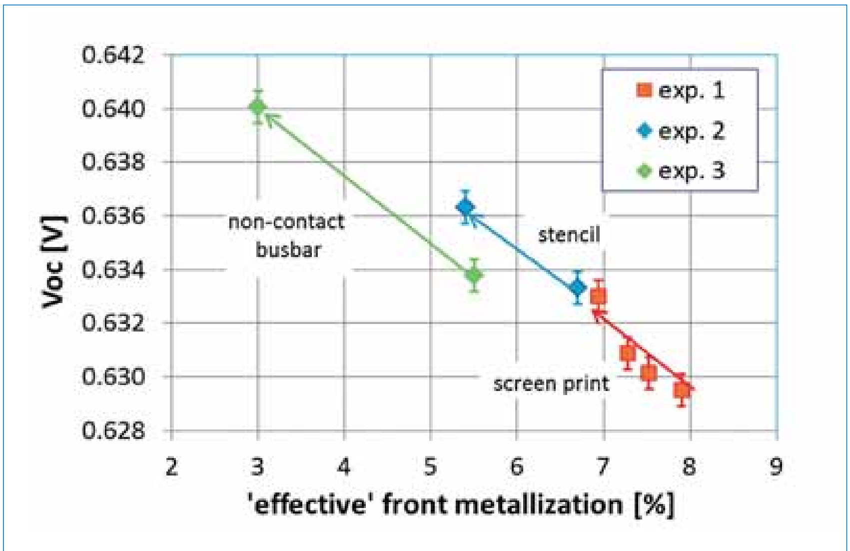

Figure 2. The gain in V_{oc} as a result of improved metallization. The total metallized area is gradually reduced by 2.5% in experiments 1 and 2, resulting in an increase in V_{oc} of 6mV. The reduced recombination under the 2.5% area covered by non-contacting busbars in experiment 3 (performed on a different material) also resulted in an increase in V_{oc} of 6mV, for an 'effective' front metallization of only 3%.

increase as a result of reduced shading losses and reduced recombination below the metal area [18,19]. The challenge is to keep the resistive losses at a minimum and thus maintain a high fill factor (*FF*).

Recent improvements in the front-side metallization of n-Pasha cells can be summarized in the following three steps, each tested via three different experiments and illustrated in Fig. 2; for each experiment, groups of approximately 20 cells were processed. In the first experiment (red squares) the line width of the screen-printed fingers was reduced from 125µm to 100µm, while in the second experiment (blue diamonds) the line-width was reduced even further, to 60µm, by using stencil printing of the fingers instead of screen printing. The advantages of stencil printing for front-side metallization of n-Pasha cells are described in more detail in previous publications [15,20]. The main feature of stencilled fingers is the higher aspect ratio compared with screen-printed fingers, which enables the use of much thinner fingers with only a small loss in fill factor [20]. The stencil process has undergone several endurance tests and its robustness has been demonstrated in an industrial run of 2000 cells [15]. Standard industrial printers can be used for the stencil process; all stencilling at ECN was done using standard Baccini printers.

In experiments 1 and 2 the total front metal coverage was reduced from 8% to 5.5%, a reduction of 2.5%. V_{oc} improved by 6mV (1%) as a result of the decrease in contact recombination. Because of reduced shading losses, I_{sc} also improved significantly, as expected, by 0.3A – equating to approximately 2.5% of the total I_{sc}. With only a small loss in *FF*, the combined experiments 1 and 2 resulted in an efficiency gain of 0.5% absolute.

The third experiment, performed on a different material, was aimed at reducing the recombination under the front contacts by applying a so-called non-contacting busbar paste [21]. Since the three busbars of the n-Pasha solar cell cover around 2.5% of the total cell area, eliminating recombination losses in this region will result in an 'effective' metal area for V_{oc} of only 3%. A gain in V_{oc} was observed similar to that when the metal coverage was reduced from 8% to 5.5%: the data for experiment 3 show an increase of 6mV or 1% relative, as can be seen in Fig. 2 (green diamonds) No significant change in I_{sc} was observed, since the total metal coverage of the cell remains the same. In addition, no significant differences in *FF* were observed, resulting in an efficiency gain of 0.15% absolute.

Diffusion and passivation

Efficiency improvements due to an improved BSF, which resulted in lower BSF doping, have also been reported in previous publications [14,15]: the results presented were typically averages over groups of 10–15 cells, with top efficiencies of up to 20%. To implement such an improved processing step in industry, the results need to be stable both within and between large batches of wafers. ECN has recently improved the front- and rear-side passivation, which has stabilized the processing in such a way that the variation in V_{oc} is drastically reduced.

The average values for V_{oc}, and the variation in the results, are shown in Fig. 3 for four different experimental groups. All the groups were processed using material from the same part of a single n-Cz ingot (with similar resistivity). Improved metallization, stencilled fingers and a non-contacting busbar on the front side were applied to all cells. The first group, with the original heavily doped BSF, yields efficiencies of around 19.4% and a V_{oc} of 640mV; the variation in V_{oc} is typically 6–7mV, equating to around 1%. The improved, more lightly doped BSF (indicated by 'BSF' on the x axis) results in a higher average V_{oc}; however, there is also an increased variation in voltage of more than 12mV. By subsequently implementing an improved rear passivation (rear pass) and front passivation (front pass), it is possible to reduce the variation from 12mV to 7mV, and even improve it further, to just 4mV. Besides there being an improvement in the stability of the processing, the average V_{oc} also increases with the improved front and rear passivation: a combined increase in V_{oc} of over 10mV (1.6%) is obtained compared with the reference.

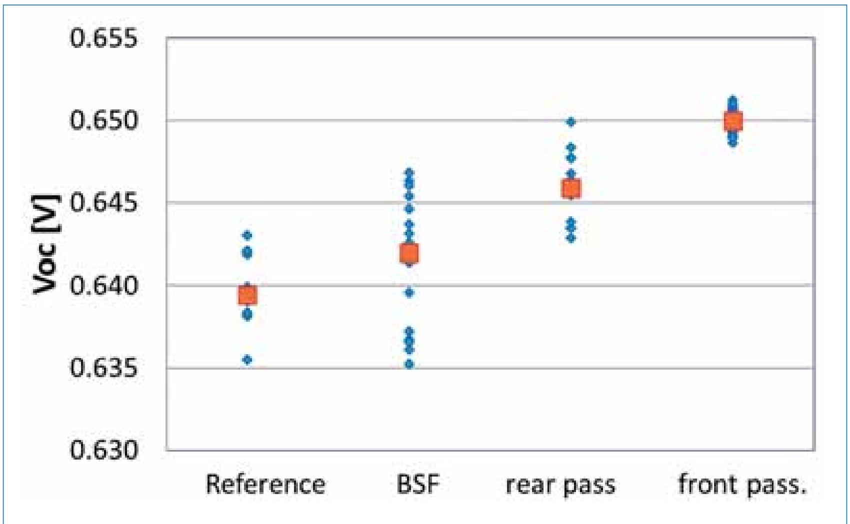

Figure 3. The increase in V_{oc} as a result of processing improvements for n-Pasha: starting from a reference 19.5% n-Pasha cell (640mV), the BSF, rear-side passivation and front-side passivation were subsequently improved. The variation in the resulting V_{oc} increased with the improved, more lightly doped BSF, but decreased for the subsequent improvements in rear- and front-side passivation.

The variation in I_{sc} increased less dramatically when the new, more lightly doped BSF was implemented. Nevertheless, it was possible to reduce the variation from 0.09A (1%) to only 0.06A by using the improved rear- and front-side passivation. Combining the more lightly doped BSF with the improved front- and rear-side passivation, a total increase of 0.1A (1.2%) was obtained compared with the reference. The resulting gain in efficiency was 0.4–0.5% absolute.

To further assess the stability of the high-efficiency processing, two large batches of wafers were processed at ECN. These batches consisted of material from two different industrial suppliers, with resistivities ranging from 3 to 5.5Ωcm for material A, and from 3 to 4.5Ωcm for material B. Both resistivity ranges were measured after a high-temperature step to annihilate the thermal donors in the material. Material A had a lower material quality, which was evident from its shorter bulk lifetime and resulting lower efficiency. The processing was carried out at ECN using industrial tools, along with the improved metallization, diffusion and passivation processes described above.

The results for both batches of wafers, including the standard deviation of the cell parameters, are shown in Table 1. For material B in particular, high efficiencies were obtained, but, more importantly, the spread in cell parameters (especially I_{sc} and V_{oc}) for both materials was very small. Average efficiencies of 19.5% (material A) and 19.7% (material B) were obtained, with top efficiencies of 19.8% and 19.9% respectively. The variation in this case is indicated by the standard deviation: for the efficiency this amounts to only 0.13% for both materials.

Impact of the material

One factor that needs to be taken into account when manufacturing solar cells from n-Cz base material is the larger range of resistivity in n-Cz ingots compared with

	I_{sc} [A]	V_{oc} [V]	*FF* [%]	η [%]
Material A				
Over 252 cells	9.25	0.649	77.4	19.5
Best cell	9.30	0.652	78.7	19.8
Std dev	0.02	0.002	0.03	0.13
Material B				
Over 107 cells	9.25	0.650	78.0	19.7
Best cell	9.31	0.653	78.7	19.9
Std dev	0.02	0.002	0.04	0.13

Table 1. Results for the processing of large batches of materials.

that in p-type ingots [16]. This difference is due to the high segregation coefficient of phosphorus in the Cz crystal growth process. Typical resistivity ranges for n-Cz material are 0.5–2Ωcm at the tail and reaching up to 8–10Ωcm (or even up to 12Ωcm) at the seed of the ingot. The base resistivity variation will influence the cell parameters: higher values of I_{sc} and lower *FF*s are predicted for higher base resistivities [18].

To check the dependency of ECN n-Pasha cell performances on base resistivity, cells were fabricated from n-Cz material taken from different parts of a single ingot; the base resistivity varied between 2.5 and 10Ωcm. For these experiments n-Pasha cells were made using both the original, heavily doped BSF and the improved, lightly doped BSF with the improved front and rear passivation. Every cell had the improved metallization on the front side. The *I-V* results shown in Fig. 4 represent the average values of approximately five cells per group.

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The results for V_{oc} and I_{sc} are shown in Figs. 4(a) and 4(b): the higher values of I_{sc} and V_{oc} along the complete resistivity range are clearly visible for the lightly doped BSF as compared to the heavily doped BSF. As expected, the value of I_{sc} increases with higher base resistivity (and thus lower base doping) because of the lower recombination losses. At the same time, the value of V_{oc} shows only a very slight decrease with increasing base resistivity [22].

The values for V_{oc} and I_{sc} have been fitted using PC1D. The front-side parameters (S_{front}, emitter profile) have been kept constant, using a p^+ emitter with an R_{sheet} of 61Ω/sq. The same, high bulk lifetime has been assumed for all cases, while the base resistivity R_{base} has been changed. Compared with cells with the heavily doped BSF, cells with the more lightly doped BSF were fitted with less free-carrier absorption (represented by a higher internal reflection in the PC1D model), better passivation (lower S_{rear}) and lighter doping (higher R_{BSF}). As can be seen in Figs. 4(a) and 4(b), V_{oc} and I_{sc} can be fitted quite well within the measurement error.

The *FF* and efficiency values are shown in Figs. 4(c) and 4(d). The *FF* indeed decreases with higher base resistivity. However, the drop in *FF* is counteracted by the increase in I_{sc}, which results in a stable and high average efficiency of 19.8% between 2 and 10Ωcm for the lightly doped BSF case, and a stable efficiency of 19.4% between 2 and 10Ωcm for the heavily doped BSF case.

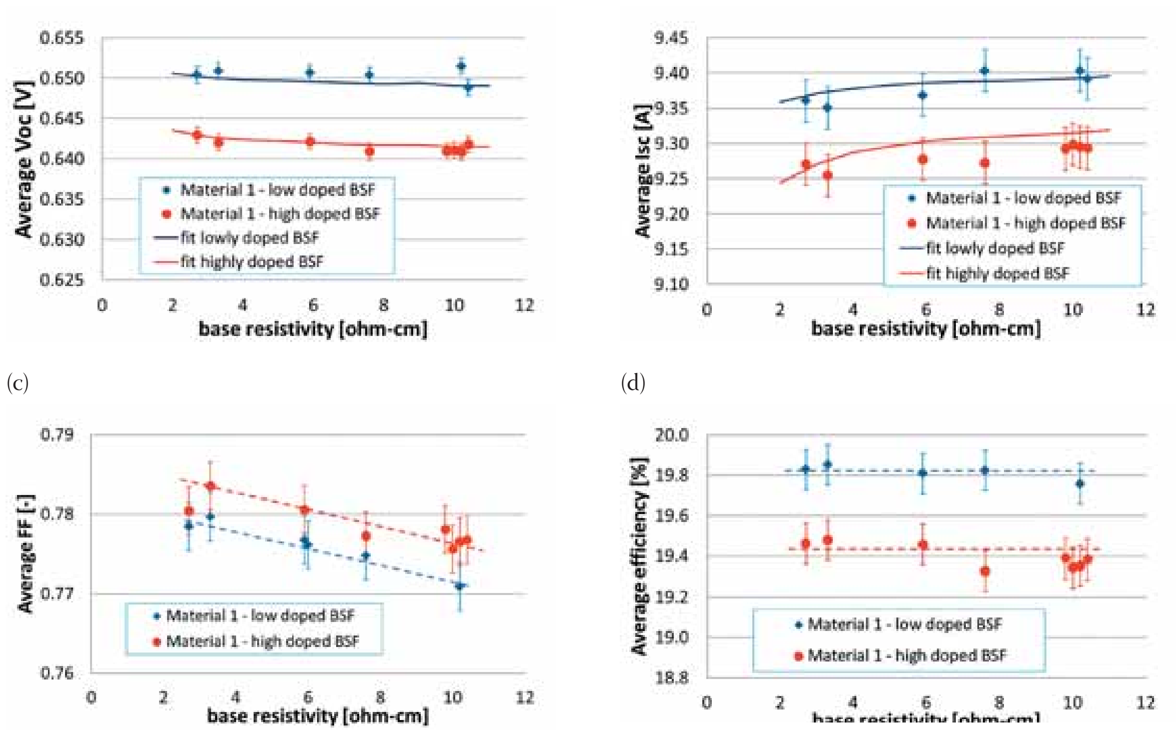

Figure 4. ***I-V*** **results for n-Pasha cells made using both the original, heavily doped BSF and the improved, lightly doped BSF with the improved front and rear passivation: (a)** V_{oc}**; (b)** I_{sc}**; (c)** FF**; (d)** η**.**

There is still room for improvement of the *FF* in the lightly doped BSF case: for all cells, with both lightly and heavily doped BSFs, the rear-side metallization pattern used was identical and optimized for the heavily doped BSF conductivity. On the basis of simulations it is expected that the *FF* for the more lightly doped BSF cells can be made comparable to that for the heavily doped BSF cells by optimizing the rear metallization pattern. Modelling indicates that the implementation of an improved rear metal-grid design with more, but smaller, fingers will increase the efficiency of the lightly doped BSF to an average of 20% for a base resistivity range of 2–10Ωcm.

Besides the dependency of the n-Pasha cell processing on base doping, n-Pasha cell processing using material from several different suppliers has been investigated. Material from eight different commercial suppliers was used for this investigation. The base resistivities of the materials varied between 2 and 10Ωcm. In this experiment, the efficiency of the n-Pasha cells depends on the material quality, or on the bulk lifetime, of the different wafers. Fig. 5 shows the average efficiency values for n-Pasha cells made with the high-efficiency processing using the eight materials. For materials 1, 3 and 6–8, average efficiencies of 19.8% were obtained. Materials 4 and 5 fared better, demonstrating average efficiencies of 19.9% and 20%. The best efficiency of 20.2% was achieved with material 2 (in-house measurement using a reflecting measurement chuck to simulate the situation in a module, and reference cells calibrated at ISE Cal lab). The average and best cell results for material 2 are summarized in Table 2.

These results show that the n-Pasha cell concept makes it possible to obtain high efficiencies using n-Cz material having a large variation in resistivity, and also using material from many commercial wafer manufacturers. This proves that the

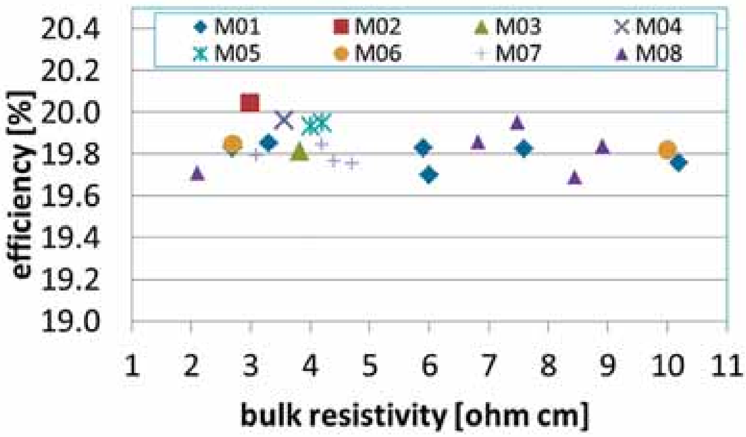

Figure 5. Average efficiencies for n-Pasha cells (with lightly doped BSF) fabricated using material from eight different commercial wafer suppliers.

	I_{sc} [A]	J_{sc} [mA/cm^2]	V_{oc} [V]	*FF* [%]	η [%]
Average	9.38	39.23	0.652	78.3	20.04
Best cell	9.40	39.33	0.653	78.8	20.23

Table 2. Average and best cell ***I-V*** **characteristics for material 2.**

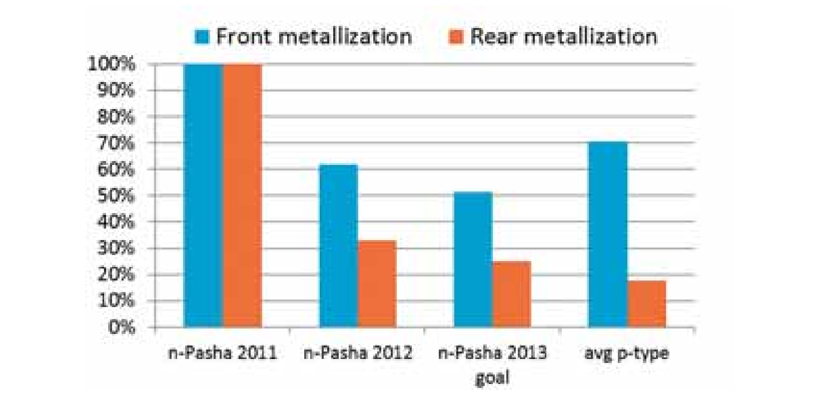

Figure 6. Relative Ag reduction for front and rear metallization of n-Pasha cells, and a comparison with the average Ag usage for p-type cells.

n-Pasha cell concept is an excellent route to creating high-efficiency industrial solar cells from n-type base material.

Cost reduction

Reducing Ag consumption has been a driving force in improving the cost effectiveness of n-Pasha solar cells. Fig. 6 shows the silver consumption on the front and rear sides of n-Pasha cells for 2012 and 2013, relative to the consumption in 2011; the average consumption for a conventional p-type solar cell is also shown. To make a fair comparison, the costs of the aluminium consumption for the p-type cells have been recalculated in terms of the equivalent milligrams of silver for the rear side, since the aluminium is absent in the case of n-Pasha cells.

For the front side of an n-Pasha cell, the silver consumption has been reduced by almost 40% relative in 2012 by: 1) adopting a stencil print [14,15], which allows thinner fingers without a loss in fill factor; and 2) replacing the standard busbar paste by the non-contacting busbar paste [21], which also has a lower silver content. Both changes have contributed to an efficiency gain of around 0.5% absolute as described above. The front-side silver consumption for an n-Pasha cell is now already less than the average consumption for the front-side of a conventional p-type cell.

For the rear side, the silver reduction that was realized in 2012 is even more extreme. Thinner fingers, and again an improved silver paste [23], have enabled a silver reduction of almost 70% without any loss in efficiency. ECN's goal for 2013 is to decrease the Ag consumption even further, to just 50% of the original consumption on the front and to just 25% on the rear, by further paste and pattern optimizations.

For solar cell manufacturers, the total silver consumption per output power (Wp) is very important for their cost of ownership calculations. This parameter can be seen in Fig. 7. The first two bars show the total silver consumption for n-Pasha cells made in 2011, with 19% average efficiency, and for n-Pasha cells made in 2012, with 20% average efficiency. In 2013, the silver consumption will be reduced further, as shown in Fig. 6; the aim is also, of course, to improve the efficiency to a value of 21%. The silver consumption target in 2013 is therefore calculated for both 20% and 21% efficiencies. The last bar on the chart shows the silver consumption for a typical p-type Cz solar cell with an average efficiency of 18.5%. The figures show that the silver consumption per Wp in 2012 for n-Pasha cells was comparable to that for p-type cells, but is expected to be lower in 2013.

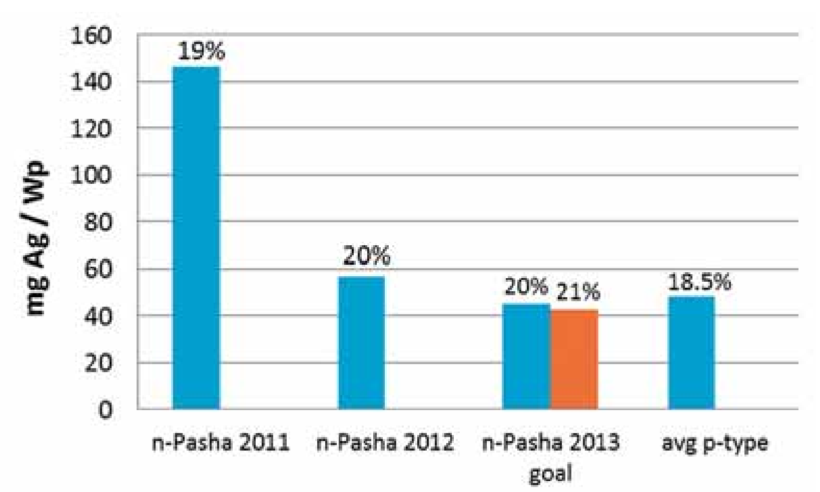

Figure 7. Silver consumption per cell per output power (Wp) for n-Pasha cells in 2011–2013, compared with p-type cells with average 18.5% efficiency.

"Silver consumption per Wp in 2012 for n-Pasha cells was comparable to that for p-type cells, but is expected to be lower in 2013."

Further developments in 2013 and beyond

The next steps to improve the n-Pasha cell concept even further will be to increase the cell efficiency to 21% and decrease the processing costs at the same time. The topics for development will be:

1. Further reduction of the silver consumption of the printed metallization, especially on the rear side, by printing and pattern optimizations.

2. Optimization of the emitter profile and front-surface passivation. Thanks to the improved rear diffusion, front-surface passivation and reduced front-side metallization, improvements will become more beneficial.

3. Reduction of the front-metal silver consumption, and at the same time improvements in I_{sc} and V_{oc} without a loss in *FF*, by introducing a metal wrap-through (MWT) cell concept [24,25]. An additional advantage of this MWT cell concept is the lower series resistance interconnection losses when the cells are interconnected to make up a module, which results in an improved cell-to-module ratio [26].
4. Further reductions in silver consumption by using only local Ag contacts on the rear side and connecting these by a full-area deposited layer of cheaper metal, such as aluminium. With this so-called PERT structure, higher values of I_{sc} and V_{oc} are expected as well.

Conclusions

The n-Pasha solar cell concept has been optimized in terms of both efficiency and cost. Improvements in front-side metallization, depending on the technology used (stencil vs. screen print) and the type of paste, resulted in a stable improvement in V_{oc} of ~10mV, an improvement in I_{sc} of 0.3A and a gain in efficiency of 0.5% absolute because of the reduction in metal coverage and contact recombination. Moreover, an optimized BSF diffusion in combination with front and rear passivation resulted in another stable improvement in V_{oc} of ~10mV and a 20% average efficiency, with 20.23% being achieved for the best cell.

> "The combination of efficiency improvement and cost reduction makes the n-Pasha cell concept a very cost-effective solution for manufacturing highly efficient solar cells and modules."

Stability of the process has been demonstrated for several large batches with >100 and >230 cells, and using n-Cz material of various qualities and from different suppliers. Special attention was given to the solar cell dependence on the base resistivity of the n-Cz material, which is also one of the major challenges for n-Cz. The high-efficiency n-Pasha process is stable in a wide resistivity range of 2–10Ωcm, and optimization steps have been identified, for example the use of a dedicated rear-contact pattern or *FF* optimization.

Significant steps have been taken with regard to silver reduction for both the front and the rear metallization of n-Pasha cells: the total silver consumption is now comparable to that of conventional p-type cells. The combination of efficiency improvement and cost reduction makes the n-Pasha cell concept a very cost-effective solution for manufacturing highly efficient solar cells and modules.

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Current trends in c-Si PV front-side metallization

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ABSTRACT

Despite considerable progress in screen-printing processes for crystalline silicon solar cell metallization, alternatives are still of interest because of their potential cost and performance advantages. Plating processes are one alternative that can be either combined with printed seed layers or used for full front-contact deposition. Although there are advantages to both approaches, there are also challenges that must be faced. Plating nickel and copper onto printed seed layers is very simple and involves only minor process modifications. With regard to undesired paste–electrolyte interaction, noticeable progress has been made during the past few months, bringing this process closer to industrial implementation. Plating nickel directly onto silicon offers the possibility of contacting emitters even with a surface-doping concentration as low as $8\times10^{18}cm^{-3}$, while achieving similar performance to that of an evaporated contact metallization. To obtain sufficient adhesion, an in-depth understanding of the interface processes during silicidation is necessary. Gaining this understanding has enabled high peel forces greater than 2N/mm to be realized using a standard solder-and-peel procedure at a 90-degree angle. Process simplification will make such a process highly attractive for solar cell metallization, which is all the more important, as high-efficiency concepts are appearing that require advanced metallization schemes.

Introduction

Getting ahead of screen printing for front-side metallization of industrial crystalline silicon solar cells is a moving target for alternative technologies. Screen-printing contact qualities have been achieved which a couple of years ago seemed to be unattainable for this technology. While novel approaches – such as metal inkjet printing [1], seed printing and plating [2], dispensing [3] and laser transfer contacting [4] – have been intensively discussed and have repeatedly demonstrated their technological potential to realize high-quality solar cell contacts, no cell manufacturer has so far been able to transfer any of these approaches to industrial production.

Paste reduction in front-side metallization

One of the factors influencing the development of contact technology is of course the currently very strained economic situation. Lately, there has not been capital to buy machines, and efforts to implement new processes have been made difficult. Instead, it has been easier to simply decrease the amount of paste needed per cell for front-side metallization. During the last two years, this quantity has been reduced from over 200mg per cell to the current amount of close to 100mg per cell. Fig. 1 shows the reported amounts of paste used per cell on the front side, taken from various publications over the last two years, together with an estimate of typical amounts used by technological leaders and mass producers in industry. This development is a consequence of the two strong drivers for PV cell manufacturers, namely the higher price of silver and the strong fall in module prices that has dominated the PV sector since 2009.

The decreasing trend in wet paste lay-down is a result of the combination of material improvements, printing process enhancements and cell process adjustments. The latest screen-printing paste generations yield quite dense silver layers and allow the printing of fine lines with a high aspect ratio, while offering improved capability for contacting high-performance emitters with low surface doping concentration [5]. At the cell level, emitters have been modified to provide high voltage potential while still meeting paste requirements [6]. Changes in busbar design have already been implemented by some manufacturers in order to further reduce recombination losses and paste consumption.

> "The decreasing trend in wet paste lay-down is a result of the combination of material improvements, printing process enhancements and cell process adjustments."

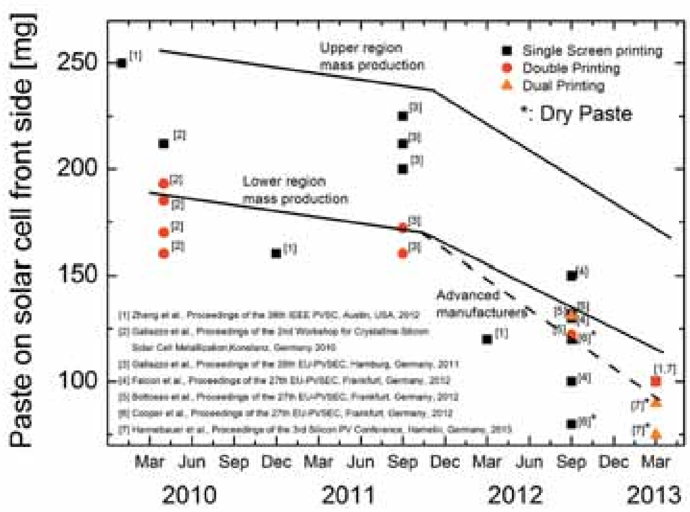

Figure 1. Development of wet paste lay-down for screen-printed front-side metallization of crystalline silicon solar cells 2010–2013. (Note: references given in the graph do not correspond to those in the Reference section of this paper.)

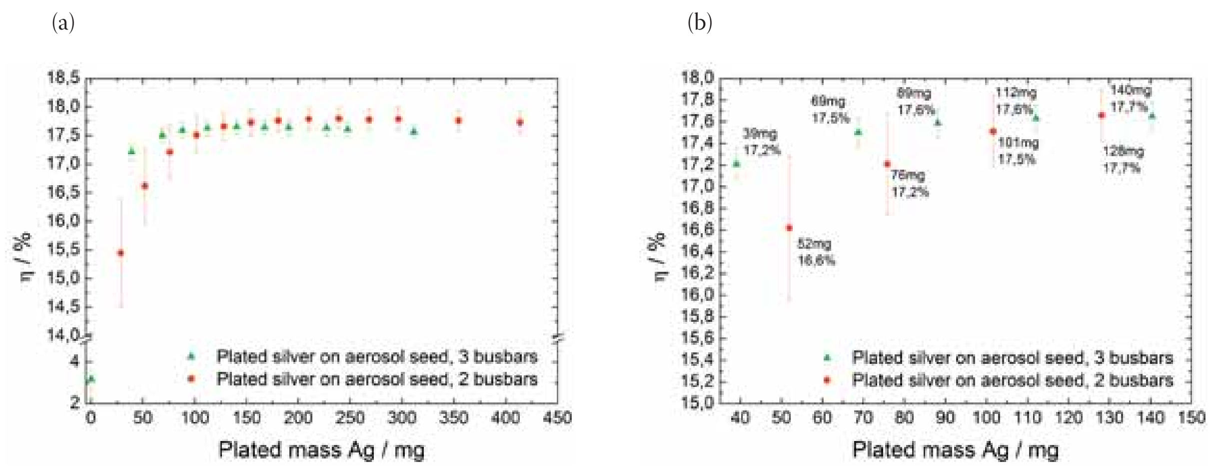

Figure 2. Dependency of cell efficiency on the mass of conductive material on the front surface, studied for the example of plated silver on top of a very thin aerosol seed layer [8]: (a) overview; (b) close-up of the region of strong influence.

Of course, at some point the laws of physics will dictate that a certain amount of material be present on the cell to allow the current to be transported without considerable power losses occurring. For today's industrial three-busbar solar cells with low paste lay-down (see Fig. 1), this point is no longer far off. The number of busbars plays a significant role in these calculations, and multi-busbar or wire electrode concepts can help to further reduce the required amount of silver [7]. The transition from two busbars to three has been a key factor in enabling the paste reductions described above.

Fig. 2 shows the evolution of the efficiency of solar cells with aerosol-printed seed layers (~4mg of silver in the seed layer for a 156 × 156mm^2 solar cell), reinforced by homogeneous, dense and highly conductive plated silver. Different trends can be derived from this investigation [8]. Generally, the two-busbar concept allows a slightly higher efficiency at the cell level; however, because of the longer contact fingers, more material is needed for that configuration. On the other hand, the three-busbar concept is more tolerant of smaller contact cross sections. Both concepts begin to lose efficiency if too little conductive material is present on the cell. Below a certain level, which depends on the metallization technology, the drop becomes very rapid, and process stability becomes critical. The close-up in Fig. 2 shows that after this point has already been reached, paste reduction is achieved, at least to some extent, at the cost of a decrease in efficiency. Less paste lay-down may lead to finer contact fingers and higher cell currents, but this can no longer compensate fill factor losses after a certain point. What this means in terms of yearly yield difference is dependent on the operation site of the module.

Idealized simulations with Fraunhofer ISE's tool GridSim 2D [9] indicate that a hypothetical, perfectly homogeneous and well-conductive screen-printed grid for an Al-BSF cell with a 90Ω/sq emitter and an efficiency potential of about 19% needs around 80mg of paste to reach maximum cell efficiency. The integration of processing and material costs into this tool has allowed the evaluation of not only the technological optimum for a grid layout, but also the economic optimum (minimum cost per W_p at the module level). Under the same assumptions, the economic optimum lies at ~60mg paste per cell, which already takes into account a reduced busbar coverage.

Replacements for silver

While the trend shows that considerable reductions in silver consumption have been possible by advanced screen printing, the question of material costs and availability remains open when considering the perspectives of PV. Technological improvements and scaling effects in mass production only allow, in the best case, a reduction in production costs as far as the material costs. Eventually, the material costs will be the dominant remaining cost factor at the end of the learning curve. At this point, silver will be one important obstacle to further cost reduction, which is especially true if the growth in PV production significantly increases the global demand for silver.

Since a replacement for silver is very difficult to realize with screen-printed and fired contacts (owing to the highly distinctive combination of the properties of silver – nobility, low melting point, high conductivity, etc.), various alternatives to screen printing are being explored. One of these is plating technology, which is under intensive investigation at various research institutions, such as the University of New South Wales in Australia, imec in Belgium and Fraunhofer ISE in Germany. Plating is a widely used industrial process in other fields, for example in microelectronics. In PV, plated nickel-copper contacts have already been successfully implemented by BP for the production of their Saturn cell [10].

Plating

The advantages of plating are its ability to deposit perfectly dense, highly conductive layers of multiple materials, at a very low temperature, at a relatively high speed and at low cost. Two process options for masking the plating process to form the grid on the front side of the solar cell are of particular interest: 1) plating on a thin, printed and fired silver seed layer; and 2) laser structuring of the anti-reflective coating and subsequent plating directly on silicon. As plated materials, nickel and copper are the most interesting combination: nickel is able to form an excellent contact to silicon and prevents copper diffusion, while copper is highly conductive and serves as the main current-carrying layer.

"The advantages of plating are its ability to deposit perfectly dense, highly conductive layers of multiple materials, at a very low temperature, at a relatively high speed and at low cost."

Plating on printed seed layers

Plating on a printed layer can act as a bridging technology, since existing production lines can be retrofitted by adding just the plating tools. Compatibility with printing technology is a major advantage of this approach, as all the above-mentioned progress in printing technology can be exploited. Besides

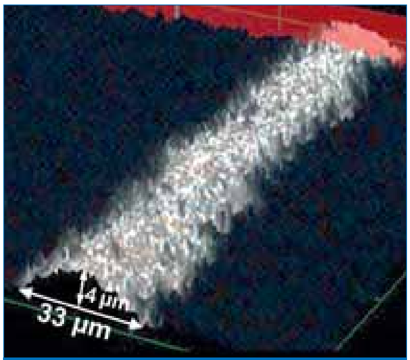

Figure 3. Results of fine-line screen printing to enable subsequent plating, achieved at Fraunhofer ISE [14].

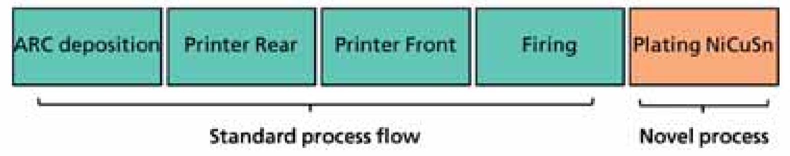

Figure 4. Back-end process flow for the seed and plate approach, which uses printed seed layers and reinforcement with nickel-copper plating. The standard back-end is shown in green, and the additional process in orange.

saving silver, the contact resistance between the silicon and the metal contact is significantly reduced by a combination of printing and plating [11]. While novel printing techniques – such as aerosol printing [12], inkjet printing [1] and high-throughput flexographic printing [13] – offer the highest potential here, the best choice in the current economic situation is to rely on screen printing, as the technique is already available in standard production lines. The latest results at Fraunhofer ISE show that it is possible not only to print very narrow lines with a few simple process adjustments [14] (Figs. 3 and 4), but also to achieve lay-downs as low as 20mg of paste per cell (156 × 156mm^2). When customized pastes with reduced silver content are used, costs can be further reduced by following this strategy.

While contact adhesion issues because of electrolyte influences on the paste have been a major concern in the past, recent results have shown that this can be remedied by simple process modifications [15]. One major influence is the pH of the electrolyte solutions used. The impact on adhesion is stronger when the plating chemistry used is more acidic. This is

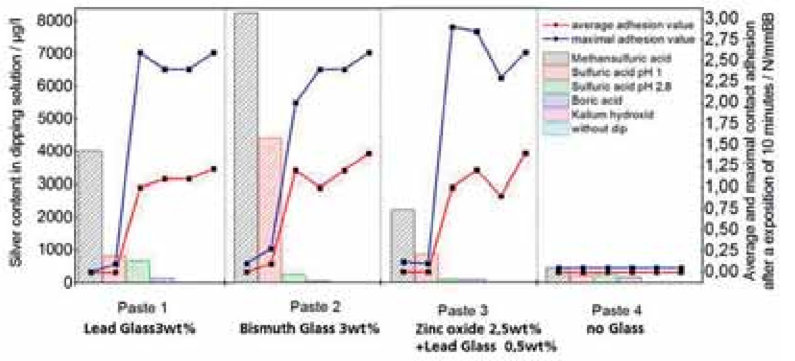

Figure 5. Peel force results for dipped solar cells after exposure to electrolyte chemicals. The bar chart shows the corresponding amount of silver dissolved from the glass into the dipping solution, evaluated by ICP-OES [15].

(a) (b)

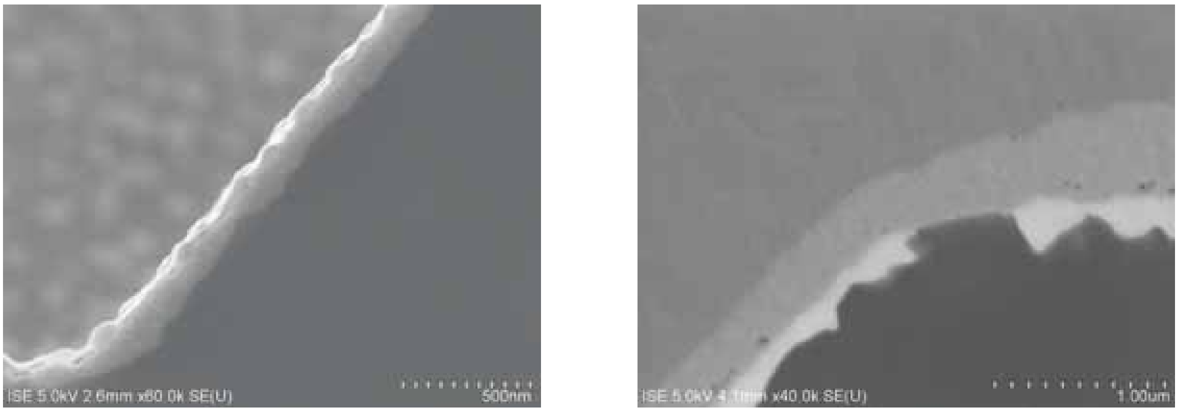

Figure 6. A study of the silicon–nickel silicide–nickel–copper interface: (a) cross-sectional view of a thin silicide layer formed in a single-step process – the formation depth can be accurately controlled by the thermal budget; (b): cross section of the full stack.

linked to dissolution reactions of typical compounds contained in the glass frit that are responsible for the adhesion of the printed seed layer, as shown in Fig. 5. If a low-acidity copper electrolyte is used, part of the problem is solved. For nickel plating, it is not sufficient to increase the pH of the bath. Higher plating rates and reduced process temperatures lead to improved adhesion for this process. Even more importantly, chlorides typically contained in nickel electrolytes strongly etch the oxidized silver layer between the glass frit and the silver bulk – a layer that is crucial for adhesion [16]. The use of chloride-free electrolytes yields similar nickel layer properties and provides the adhesion needed for module integration.

Direct plating

For directly plated contacts, metal–silicon adhesion has also been a major concern, hindering the adoption of this method. The reasons for the observed low adherence have so far not been entirely clarified. However, recent studies at Fraunhofer ISE have led to an improved in-depth understanding of the interface situation between plated metal and silicon [17]. In particular, the role of silicides, the conditions for their formation and the positive effects on adhesion are better understood. On the basis of these investigations, a two-stage process for contact formation has been developed, featuring etchback of unreacted nickel and replating. This process solves the adhesion issue that had existed until now. Two examples of typical interface situations, taken from the microcharacterization study, are shown in Fig. 6. High peel forces were repeatedly demonstrated (Fig. 7), indicating superior stability for this type of contact. Such two-step processes are known from the microelectronics industry [18] and, presumably, have also been used by BP solar [19].

Transferring the technique to solar applications demands that the processing steps involved be reduced. It is currently Fraunhofer ISE's key objective to simplify this relatively complex process sequence. Fast laser processing for ARC structuring and removal of etchback steps by full nickel consumption upon silicidation are among the first topics to be addressed. In addition, recent results indicate that much cheaper and faster light-induced plating (LIP) technology can be used to create such contacts instead of electroless plating for seed layer formation. Some simplifications, for example thermal contact formation after full stack plating, have already been studied, and promising results have been achieved [20]. After these features are implemented in the process sequence, a high compatibility with industrial needs will be achieved.

The efficiency potential of the direct plating process is even higher than that of plating on printed seed layers, as has impressively been demonstrated very recently by Schott Solar: an independently confirmed efficiency of 21.3% was obtained with an industrial-

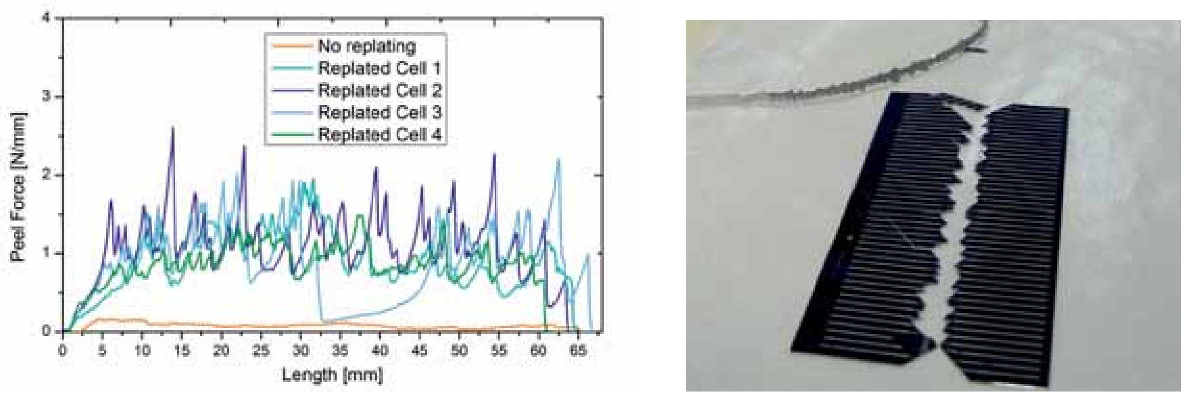

Figure 7. Peel force diagram of the contact system created by direct nickel plating onto silicon, followed by copper and silver plating. Standard cell connectors were soldered onto the busbars in an industrially typical process. Because of the progress in understanding the interface processes between nickel and silicon, it has been possible to develop a pre-treatment sequence that permits very high peel forces, even at 90-degree peel angles as shown in this graph.

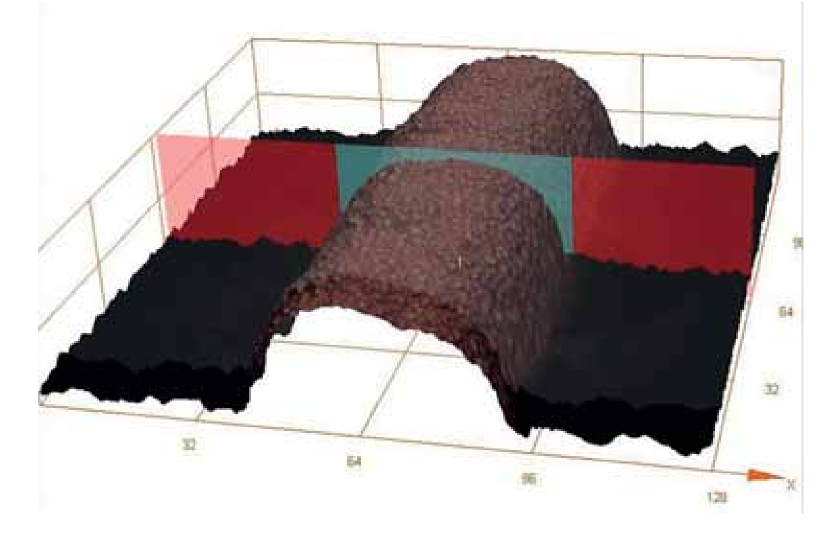

Figure 8. Example of a contact finger created by laser ablation and direct nickel-copper plating (contact width = 45µm and contact height = 22µm).

size p-type Cz PERC solar cell using this contacting system [21]. A yet further improved emitter with low surface doping concentration would allow the open-circuit voltage (V_{oc}) of such a cell to be boosted from the reported 662mV to 680mV, bringing the efficiency into the region of 22%. At Fraunhofer ISE, the ability to contact an emitter with a surface doping concentration of 8×10^{18} using plating technology has been successfully demonstrated, leading to a V_{oc} of up to 679mV [14]. The results match those of an evaporated titanium/palladium/silver stack. When such a homogeneous emitter is used, loss-free contacting can only be achieved using alternative approaches.

Depending on the type of ARC structuring technology, a plated contact will additionally offer the advantage that the entire area underneath the contact contributes to the transfer of current between metal and semiconductor. This makes it suitable for all kinds of metallization application. Very narrow contacts of down to 20µm can be created by laser structuring, simultaneously achieving high aspect ratios of about 1:2 (height:width), as copper electrolytes may be customized to plate upwards rather than sideways (Fig. 8). The optical width of such semi-roundish contacts is considerably lower – down to 20µm. The maturing of this technology will be greatly accelerated by the recent achievements mentioned above.

"The efficiency potential of the direct plating process is even higher than that of plating on printed seed layers."

Plating vs. screen printing

From an economic point of view, the two plating technologies have been benchmarked against an assumed very advanced screen-printing process (Fig. 9). The results indicate that the savings potential is not as attractive as two years ago, when silver consumption on the front surface was still considerably higher (Fig. 1), but the economic advantages are still striking. Moreover, the plating processes discussed above have not been fully

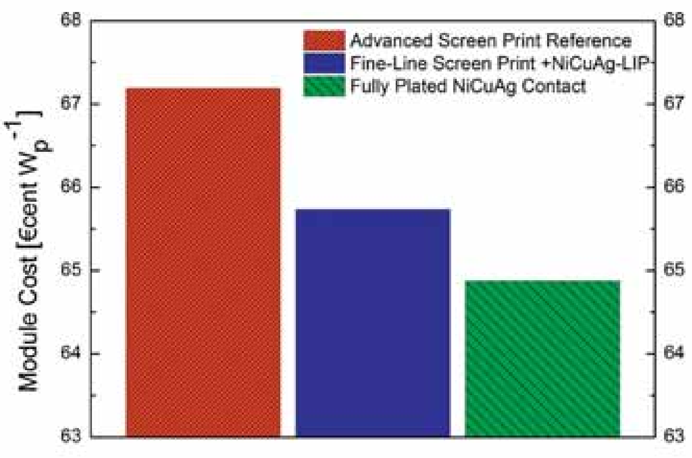

Figure 9. Comparison of the metallization costs for an advanced screen-printing process (cf. Fig. 1) with the two alternative approaches, featuring plating on printed seed layers and direct plating on laser-structured ARC. The calculations take into account machine costs, labour costs, depreciation, all infrastructure costs, waste treatment and so forth. Silver material costs were assumed to be €1000/kg.

optimized yet in terms of performance and cost. The scope for optimization of the plating processes, as offered in an industrial production environment, suggests a potential for further reductions in cost. If just the material costs are taken into account, which represents an idealized situation at the end of the learning curve, the savings potential is by far higher.

> "The scope for optimization of the plating processes suggests a potential for further reductions in cost."

Further perspectives and conclusion

In the light of the current developments in the PV industry it seems that, up until now, technological pioneers have profited more from such advanced metallization technologies than producers of standard cells. Tetrasun have reported an impressive 21.0% (125 × 125mm^2) with a process of plated copper on a seed layer [22], although the nature of the layer is not entirely clear. Kaneka have very recently reported 23.5% on a 156 × 156mm^2 heterojunction solar cell with electroplated copper contacts, profiting from the high conductivity of the plated layer and the low process temperatures [23]. And, of course, SunPower is using plated copper as the conduction layer for the contacts of all their back-contact back-junction solar cells. The recent progress in plating technology for solar cell metallization described in this paper will make this approach accessible to all PV manufacturers, and not just to the technological leaders.

As the journey towards high efficiencies is ongoing and this path is also opened for mass producers, novel metallization concepts will again be the focus of attention in high-volume crystalline silicon solar cell production too.

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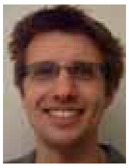
About the Authors



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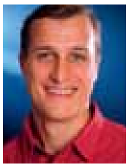

Achim Kraft studied electrical engineering at the University of Applied Science in Hanover. He received his master's degree in renewable energies from the University of Applied Science in Berlin, before joining Fraunhofer ISE as a Ph.D. student in January 2012. Achim is a member of the Plating Process Technology team, working on plated copper front-side metallization techniques for silicon solar cells. His research focuses on the interaction between electrolytes and printed contacts during the plating process.

Andrew Mondon studied crystallography and materials science in Freiburg, graduating with a diploma in 2010. The work for his diploma thesis was carried out at Fraunhofer ISE, where he has been working on electrochemical solar cell metallization since 2009. In June 2012 Andrew began working on his Ph.D., the topic of which is direct nickel copper metallization for crystalline silicon solar cells, with a particular focus on nickel silicide formation.

Andreas Lorenz studied printing technology at the University of Printing and Media in Stuttgart and graduated in 2006. From 2006 to 2012 he worked at manroland AG, Offenbach, as a research engineer and junior product manager for colour control systems. Since 2012 Andreas has been working as a Ph.D. student at Fraunhofer ISE in the field of printing techniques for solar cell metallization.

Laura Sutor received her B.Sc. in business and engineering from the Karlsruhe Institute of Technology in 2013, where she focused on the cost and effectiveness of copper metallization for solar cells. Laura is currently working towards her master's degree in business and engineering at the same institute, and is also at the Fraunhofer ISE in Freiburg.

Sebastian Nold studied industrial engineering at the University of Karlsruhe, Germany, and the University of Dunedin, New Zealand, and earned his diploma in industrial engineering at Karlsruhe in 2009. He has worked at the Fraunhofer ISE since 2008 in the field of cost calculation, technology assessment and economic evaluation of new concepts in the production of silicon solar cells. Sebastian is currently completing his doctoral thesis at the ISE on the economic assessment of silicon solar cell production along the PV value chain.

Dr. Stefan W. Glunz is the director of the Solar Cells – Development and Characterization division at Fraunhofer ISE. He received his Ph.D. degree in 1995 from the University of Freiburg, and his research focuses on the design, fabrication and analysis of high-efficiency silicon solar cells. Among other scientific and technological achievements, Stefan's group has set the current efficiency world record for solar cells on multicrystalline silicon.

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The cell doctor: A detailed 'health check' for industrial silicon wafer solar cells

Cell Processing

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ABSTRACT

In principle solar cells are very simple: they convert sunlight to electricity and can be characterized by a single number – the solar cell efficiency. Manufacturers obviously want to achieve this efficiency at the lowest possible cost, so it is critical that the efficiency/cost ratio be optimized. To this end, knowledge of where the biggest gains can be achieved is key. This paper presents an in-depth loss analysis method developed at the Solar Energy Research Institute of Singapore (SERIS) and details how various losses in a silicon wafer solar cell can be quantified, which is not done in the case of a conventional solar cell measurement. Through a combination of high-precision measurements, it is shown that it is possible to fully quantify the various loss mechanisms which reduce short-circuit current, open-circuit voltage and fill factor. This extensive quantitative analysis, which is not limited to silicon wafer solar cells, provides solar cell researchers and production line engineers with a 'health check' for their solar cells – something that can be used to further improve the efficiency of their devices.

Introduction

In the PV industry there is continual pressure to increase solar cell efficiency. However, it is actually not that important to know the theoretical maximum efficiency limit of a certain solar cell design; instead, it is more important to understand – and quantify – the loss processes that currently limit cell efficiency. Consequently there is a need for a full bottom-up solar cell loss analysis that is based on high-precision measurements and quantifies the losses for the most relevant solar cell parameters, specifically short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), fill factor (*FF*) and efficiency (η). In this paper, the work of Aberle et al. [1] is extended by further analyzing the losses limiting V_{oc} and *FF*. The results will be demonstrated using standard industrial aluminium-back-surface field (Al-BSF) silicon wafer solar cells from the R&D pilot line of the Solar Energy Research Institute of Singapore (SERIS).

> "It is more important to understand – and quantify – the loss processes that currently limit cell efficiency."

Standard high-precision measurements associated with the advanced loss analysis

The presented loss analysis is based on a set of high-precision measurements, i.e. secondary calibrated dark and light current–voltage characteristics (*J-V*) and full-area illuminated spectral response (internal quantum efficiency IQE and external quantum efficiency EQE), and effective carrier-lifetime measurements by the photoconductance decay method. A detailed quantification of the I_{sc}, V_{oc} and *FF* losses of the solar cell are provided, and thus the cell's most severe efficiency losses can be analyzed.

First, the electrical properties of the solar cell are determined. From the light *J-V* curve in Fig. 1(a), the standard solar cell parameters are derived, i.e. open-circuit voltage V_{oc}, short-circuit current density J_{sc}, fill factor *FF*, efficiency η, and maximum power point voltage V_{mpp} and corresponding current J_{mpp}. From the dark *J-V* curve in Fig. 1(b), the shunt resistance is determined by a linear fit in the –50mV to +50mV range. The series resistance under one-sun maximum power point conditions $R_{s,mpp}$ and the total recombination current (the effective saturation current density J_0) of the solar cell are then determined from the light and dark *J-V* measurements

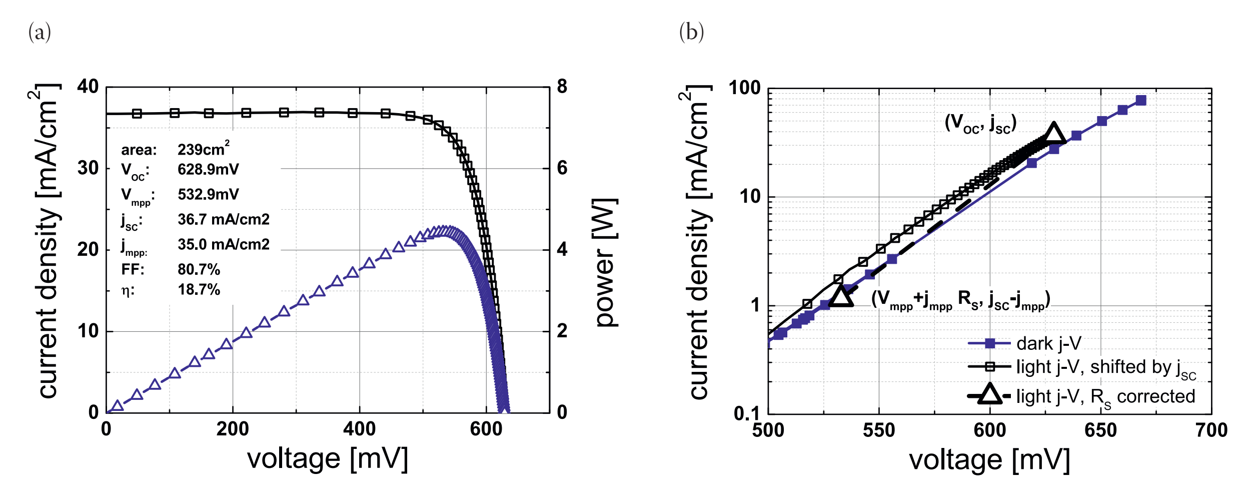

Figure 1. Current–voltage curve of a standard industrial p-type Al-BSF silicon wafer solar cell: (a) subjected to a one-sun illumination; (b) measurements taken in the dark.


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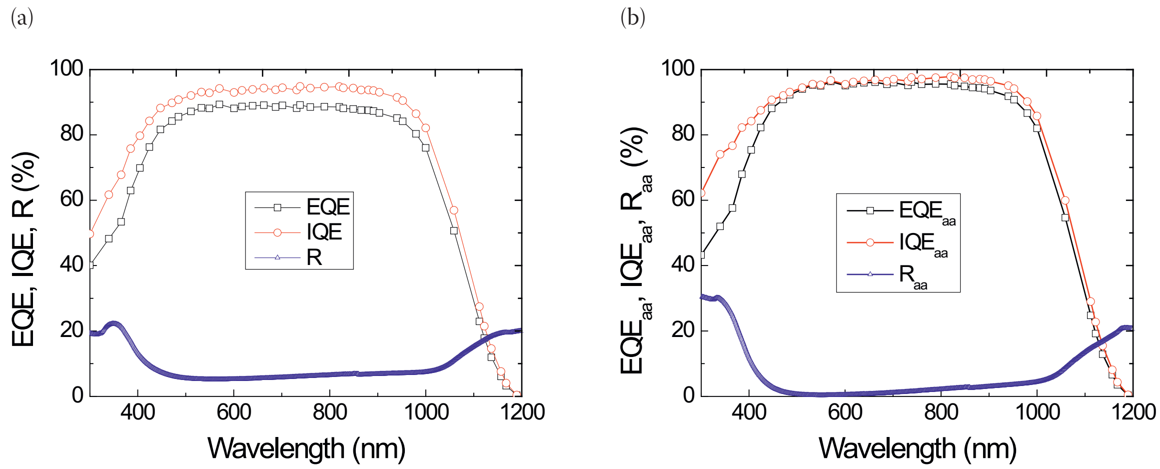


Figure 2. External and internal quantum efficiency and reflectance measurements of a standard industrial p-type Al-BSF silicon wafer solar cell: (a) full-area, and (b) active-area corrected.

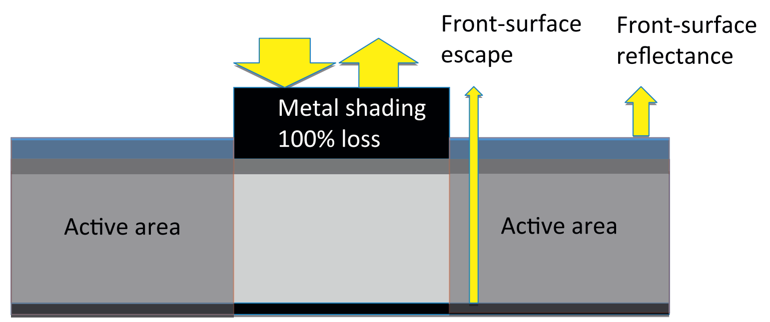


Figure 3. Schematic illustration of optical losses at the front of a silicon wafer solar cell.

using the method of Aberle et al. [2]. The experimentally determined full-area quantum efficiencies are then active-area corrected as shown in Fig. 2 (the correction is for reflection from the metallized areas as schematically depicted in Fig. 3).

In the following, the corresponding measurement results for a standard Al-BSF solar cell fabricated at SERIS (schematic shown in Fig. 6) are given.

Current losses

Quantification of the losses in the maximum power point current density (J_{mpp}) is carried out by applying a bottom-up loss analysis [1] that quantifies the seven most important current loss mechanisms, i.e. (1) front metal grid shading; (2) front-surface reflectance in the active area; (3) front-surface escape; (4) shunt resistance; (5) non-perfect active-area quantum efficiency; (6) forward bias current at the maximum power point ('diode recombination'); and (7) photon absorption within the front-side dielectric passivation/anti-reflective (AR) layer (i.e. silicon nitride SiN_x).

Current loss analysis

The various current losses are quantified at the maximum power point by applying relatively simple mathematical formulae [1]. The losses due to metallization, front-surface reflectance and front-surface escape (this is light that 'escapes' from the solar cell device without being absorbed – see Fig. 3) are calculated from the measurements and using the photon flux of the AM1.5G spectrum. The current losses due to shunt resistance and diode recombination are calculated from a one-diode model using the measured resistance at the maximum power point. The recombination losses in the solar cell are determined using the calculated IQE that is properly corrected for the non-ideal reflection by the front metal grid.

The resulting current losses for the investigated Al-BSF solar cell are shown in Fig. 4. It is clear from this that most of the current is lost by the non-perfect IQE of the solar cell, which explains the PV industry's interest in solar cell designs featuring a selective emitter and a passivated rear. The current loss due to metal shading is also significant, which is why all-back-contact solar cells and metal-wrap-through and emitter-wrap-through solar cells are attracting a lot of attention.

> "Most of the current is lost by the non-perfect IQE of the solar cell."

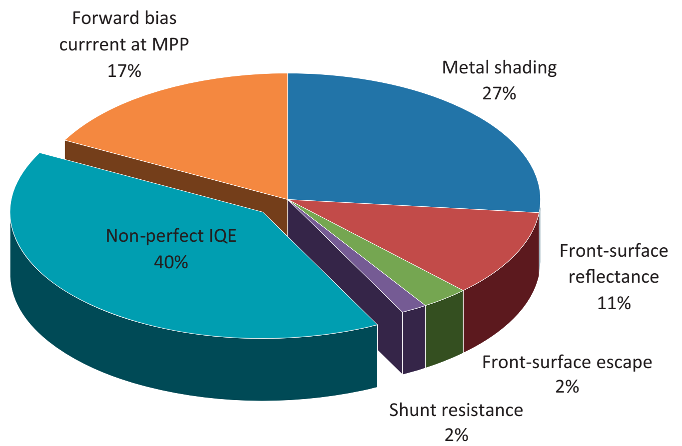


Figure 4. Pie chart of the relative current losses at the maximum power point for a standard industrial p-type Al-BSF solar cell. The total current losses amounted to 12.7mA/cm^2 in this specific case.

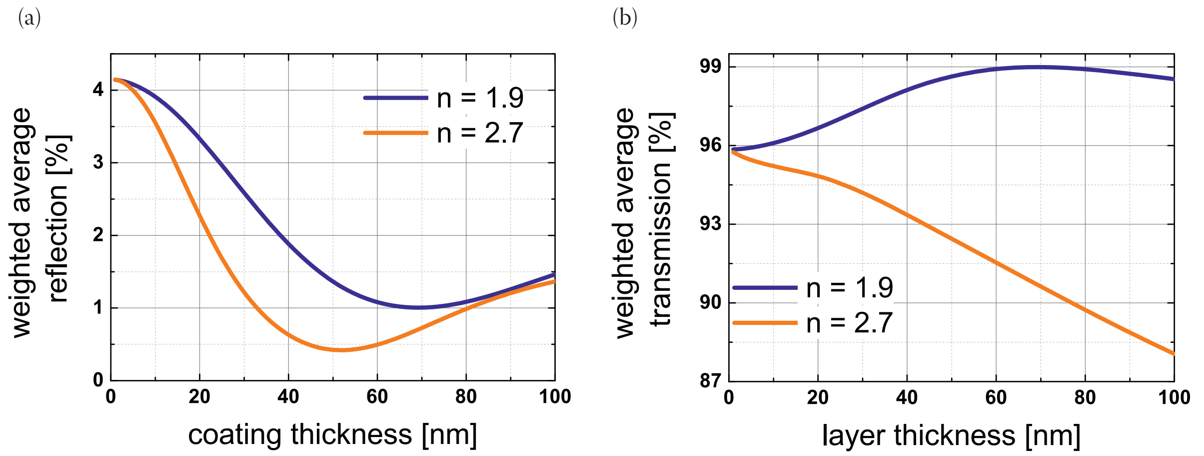


Figure 5. Investigation of two different coating materials with refractive indices n = 1.9 and n = 2.7 for a silicon solar cell with pyramidal texture and encapsulated with a material with refractive index n = 1.5: (a) calculated WAR, and (b) calculated WAT.

Absorption in the front-side silicon nitride passivation/anti-reflective coating

A current loss mechanism that is typically grouped under the 'non-perfect IQE' category is the parasitic photon absorption in the front SiN_x AR coating. Measuring the reflectance of the solar cell surface is not sufficient for an optimization of AR coatings to be performed if there is non-negligible absorption in the coating material. This is particularly important for AR coatings that are optimized for solar cells within PV modules. If account is taken of the optical properties of the encapsulation material and the glass cover sheet, the desirable refractive index for the cell's AR coating is actually higher than the refractive index for optimum reflectance in air. A higher refractive index is typically connected to a higher absorption coefficient and, consequently, causes higher parasitic absorption losses.

Unfortunately there is no direct way to measure the absorption in an AR coating once it is deposited onto a solar cell. Furthermore, the absorption losses occur in the short-wavelength range (< 500nm) and many of the materials used also absorb light in this region. Glass, ethylene-vinyl acetate (EVA) and silicon – either because of their large thicknesses or high absorption coefficients – absorb considerable fractions of the light. Moreover, these fractions are much larger than the fraction of light absorbed by the AR coating. This also makes an indirect extraction of the absorption by the AR coating from measurements very difficult.

The absorption by the AR coating can, however, be calculated very accurately if the optical material parameters – refractive index and absorption coefficient – are well known. For this purpose, a computer-based simulation method has been developed which allows the light absorption by the AR coating of a textured silicon wafer to be calculated. The method is based on work published elsewhere [4] and spectroscopic ellipsometry measurements of the optical parameters.

Rather than minimizing the reflectance from the solar cell surface, the method is used to maximize the fraction of light transmitted into the silicon. This can lead to significant differences in the assessment of the coatings. The example given in Fig. 5 shows the investigation of two AR coatings, with refractive indices of n = 1.9 and n = 2.7, on a silicon wafer with pyramidal texture and encapsulated with a material with refractive index n = 1.5 (corresponding to glass). The material with refractive index n = 1.9 has a very small absorption coefficient, while the material with n = 2.7 is considerably absorbent. Fig. 5 shows the weighted average reflectance (WAR) and the weighted average transmission (WAT). These two quantities represent the fraction of solar photons reflected or transmitted respectively, and are calculated via the expressions:

$$WAR = \frac{\int d\lambda\, \phi(\lambda) R(\lambda)}{\int d\lambda\, \phi(\lambda)}$$

$$WAT = \frac{\int d\lambda\, \phi(\lambda) T(\lambda)}{\int d\lambda\, \phi(\lambda)} \qquad (1)$$

where $\phi(\lambda)$ is the solar photon flux and $R(\lambda)$ and $T(\lambda)$ are the reflectance and transmission.

From the reflectance, which is the quantity that can be measured directly, the material with n = 2.7 appears to be more favourable. However, when looking at the transmission, it becomes clear that the material with n = 1.9 is the better choice. This is because the material with n = 2.7 shows a very strong absorption.

The example presented shows clearly that parasitic absorption needs to be considered in the optimization of AR coatings. As a general rule, if there is a choice between two AR materials, it is better to opt for the material with the lower absorption instead of the one with the more favourable refractive index. In the actual cell investigated in this paper, a coating material similar to the one with n = 1.9 was used. The contribution of AR coating losses to the non-perfect IQE is negligible for this material. However, the AR coating absorption will have a noticeable contribution in the case where higher index materials are required (for example if the cell is encapsulated or a stack is used).

"If there is a choice between two AR materials, it is better to opt for the material with the lower absorption instead of the one with the more favourable refractive index."

Voltage losses

The open-circuit voltage of a solar cell is determined by internal cell recombination. The open-circuit voltage which would result if there were only bulk recombination (for a given wafer type) is considered to be the upper V_{oc} limit of the investigated solar cell. There are then four main loss mechanisms for the open-circuit voltage of the solar cell: (1) front-surface voltage loss due to surface recombination at the non-contacted (passivated) regions of the cell; (2) front-surface voltage loss due to surface recombination at the contacted regions (metal contacts) of the cell; and (3, 4) rear-surface voltage losses due to contacted/non-contacted solar cell regions. The total recombination can be specified by a total recombination current

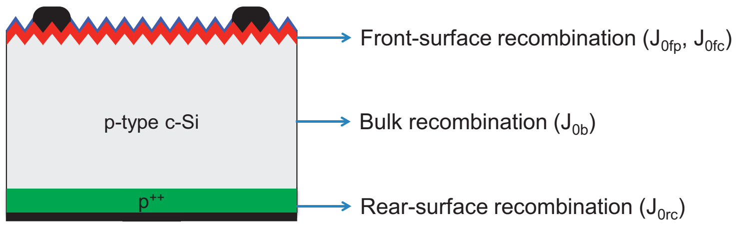


Figure 6. Sketch of a standard industrial Al-BSF solar cell, indicating the different solar cell regions which contribute to recombination losses.

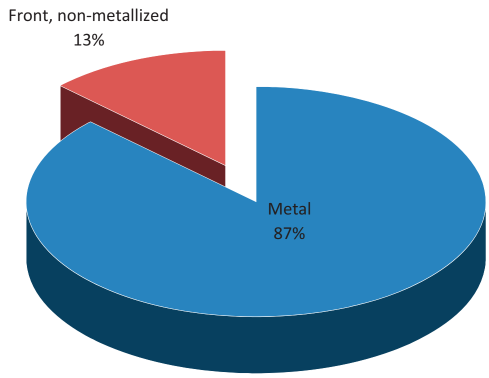


Figure 7. Voltage losses of a typical industrial p-type Al-BSF solar cell.

J_0 given by the equation

$$J_0 = J_{0b} + J_{0fp} + J_{0fc} + J_{0rp} + J_{0rc} \quad (2)$$

where J_0 is the sum of the individual components stemming from the bulk and the front and rear non-contacted/contacted regions respectively (see Fig. 6). The relationship between J_0 and V_{oc} is given by

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

Because the doping level and the bulk lifetime of the starting wafers are usually known (or the maximum bulk lifetime can be evaluated using the model of Kerr-Cuevas [6,7]), the bulk recombination current J_{0b} can be easily calculated [5–7]. This in turn provides an upper V_{oc} limit that can be achieved with the particular wafers used. The surface recombination current J_{0fp} of the passivated (non-contacted) regions of the solar cell can be extracted from photoconductance decay measurements performed on symmetrically passivated lifetime samples according to the Kane-Swanson method [3]. The total surface recombination current associated with the front and rear metal contacts J_{0fc} and J_{0rc} can then be determined. This subsequently allows the open-circuit voltage to be calculated using Equation 3, and this value can then be compared with the measured open-circuit voltage. Alternatively, the individual components J_{0fc} and J_{0rc} can be measured by means of lifetime-calibrated photoluminescence spectroscopy.

As an example, Fig. 7 shows the relative V_{oc} loss of a typical industrial p-type Al-BSF solar cell. As can be seen, the main voltage losses, as expected, are due to the metallized regions of the solar cell (i.e. the full-area Al-BSF). This explains why the PV industry is moving towards passivated rear surfaces and reduced front-surface metallization.

> “The main voltage losses, as expected, are due to the metallized regions of the solar cell.”

Fill factor losses

There are three main mechanisms for the fill factor *FF* losses of a solar cell: (1) loss due to series resistance (R_s); (2) loss due to shunt resistance (R_{sh}); and (3) loss due to non-ideal recombination. The two resistances R_s and R_{sh} (under maximum power conditions) are measured, and an advanced *FF* loss analysis [8] then allows the corresponding *FF* losses to be extracted.

Series resistance losses

The (measured) R_s of the solar cell under maximum power conditions can be broken down into more detail if the layout of the metal contact grid is known (see Fig. 8(a)). For simple contact-grid layouts (such as the H-patterned grid shown in Fig. 8(b)), there are several analytical programs available in order to calculate this breakdown [9].

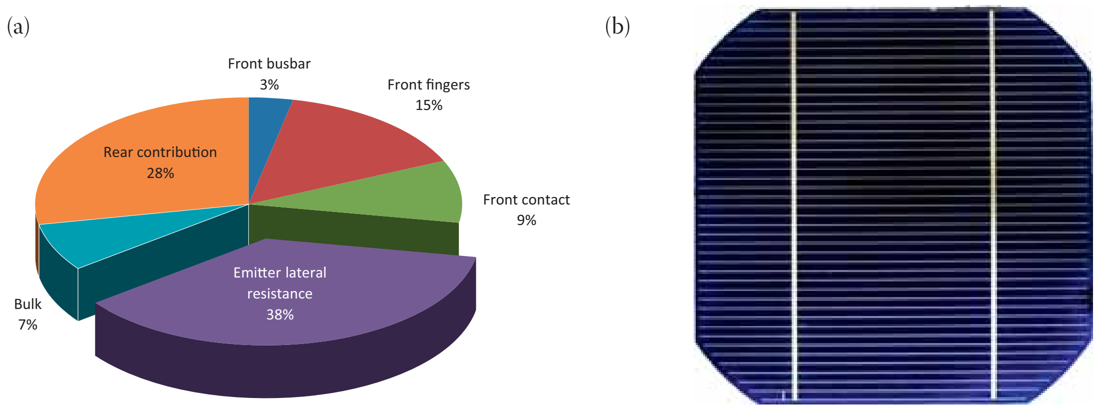


Figure 8. (a) Breakdown of measured series resistance of a standard industrial p-type Al-BSF solar cell processed at SERIS; (b) the simple H-patterned metal grid used. The total series resistance due to the front grid and the bulk were calculated to be 0.44Ωcm², and the remainder of the series resistance (0.16Ωcm² out of the total of 0.61Ωcm²) was attributed to the rear contact.

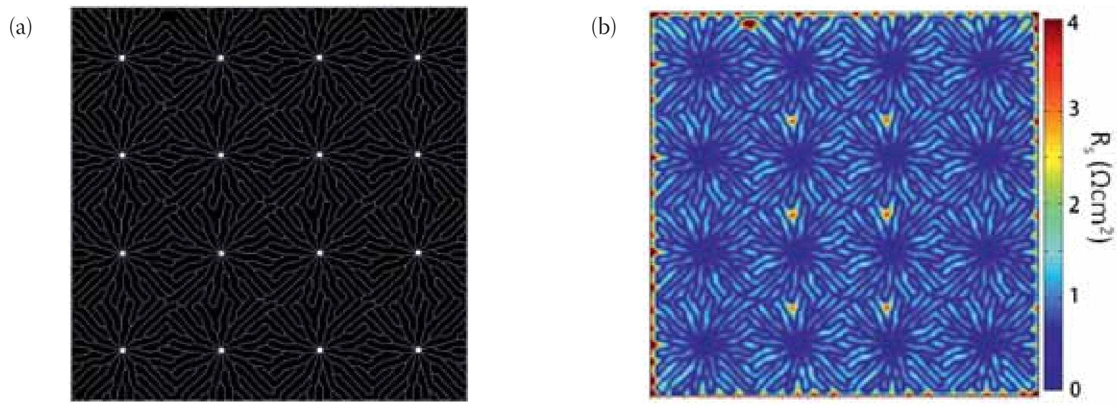


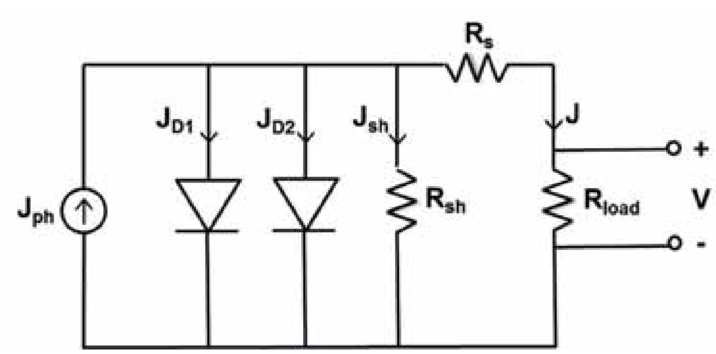
Figure 9. (a) Image of the front-side metal grid of a metal-wrap-through solar cell. (b) Corresponding local distribution of the series resistance of the solar cell under maximum power conditions, after being processed by the GRIDDLER software [10].

For more complicated (arbitrary) layouts, SERIS has developed its own software called GRIDDLER [10]. This software can import metal grid patterns from images and perform a meshing and a subsequent finite element analysis, for determining (for example) the percentage of R_s of the solar cell stemming from (1) the grid itself, (2) emitter lateral series resistance, (3) back-surface field lateral series resistance, and (4) bulk series resistance. Furthermore, a perturbation analysis allows the determination of how the grid patterns can be changed with the aim of attaining their optimum layouts.

Fill factor loss analysis

Taking the measured R_s and R_{sh} under maximum power conditions of the solar cell as input parameters, an advanced *FF* loss analysis [8] can be performed by describing the current–voltage characteristics of the solar cell via the two-diode model shown in Fig. 10. The *FF* of the solar cell is then determined by the diode saturation currents J_{01} and J_{02}, describing ideal and non-ideal recombination in the solar cell, as well as by the series and shunt resistances R_s and R_{sh}. To analyze *FF* losses, it is important to determine the relative contributions of these quantities.

An 'upper limit' fill factor FF_{J01} can be calculated by assuming only bulk recombination, in other words assuming no non-ideal second-diode recombination, no series resistance and an infinite shunt resistance. The loss in *FF* due to second-diode recombination currents (non-ideal recombination), and to R_s and R_{sh}, can then be calculated [8]. This is illustrated in Fig. 11 for the standard industrial p-type Al-BSF solar cell of Fig. 6. It is clear that R_s is the biggest contributor to the *FF* loss of this cell. However, for more advanced, higher-efficiency solar cells the contribution of the J_{02} component becomes larger. For such cells it is extremely important to know the root cause of the *FF* losses in order to devise the optimal strategy for improvement.



$$J = J_{ph} - J_{01}(e^{\frac{q(V+JR_s)}{kT}} - 1) - J_{02}(e^{\frac{q(V+JR_s)}{n_2 kT}} - 1) - \frac{(V+JR_S)}{R_{sh}}$$

Figure 10. Two-diode model of a solar cell, and the corresponding mathematical description of the *J-V* characteristics of the cell.

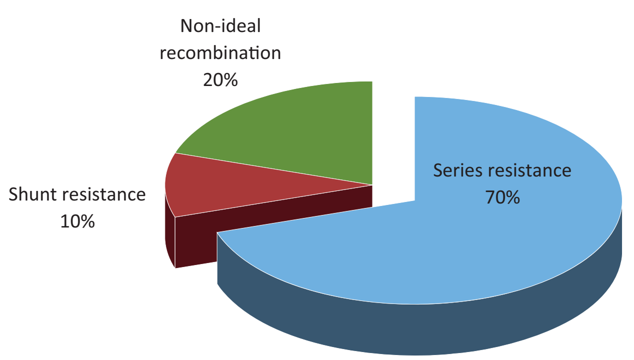


Figure 11. *FF* loss analysis of a standard industrial p-type Al-BSF solar cell.

"The loss quantification method enables the largest root causes of poor cell performance to be focused on first, before 'turning knobs' to fine-tune secondary effects."

Conclusion

As remarked by Lord Kelvin 140 years ago, "To measure is to know." In this paper it has been shown that current, voltage and fill factor losses for silicon wafer solar cells can be fully quantified by a combination of high-precision measurements and relatively simple modelling. This analysis results in a 'health check' for the solar cell under test and clearly illustrates the most effective route for the manufacturer of the solar cell towards achieving higher efficiencies. The loss quantification method has been found to be extremely useful at SERIS for optimizing various types of solar cell design, as it enables the largest root causes of poor cell performance to be focused on first, before 'turning knobs' to fine-tune secondary effects.

Acknowledgements

The authors thank their colleagues from the Silicon Photovoltaics Cluster of SERIS for their assistance in sample processing and characterization. SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).

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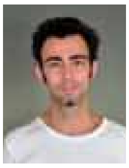
About the Authors

Dr. Bram Hoex is director and group leader in SERIS' Silicon PV Cluster. He holds a Ph.D. degree in applied physics from Eindhoven University of Technology and has extensive experience in the area of processing and advanced characterization of high-efficiency silicon wafer solar cells. In 2008 Bram won the SolarWorld Junior Einstein Award and the Leverhulme Technology Transfer Award for his work in the area of high-efficiency silicon wafer solar cells.

Prof. Armin Aberle is the CEO of SERIS at the National University of Singapore (NUS). His research focuses on reducing the cost of electricity generated with silicon solar cells (wafers and thin films). He is an editor of several journals and established the Silicon PV Department at ISFH in Germany in the 1990s. He then worked for 10 years in Australia, as a professor for photovoltaics at the University of New South Wales (UNSW). In 2008 Armin joined NUS to establish SERIS, with a particular responsibility for the creation of a Silicon PV Department.

Dr. Rolf Stangl is a senior research scientist at SERIS. He is a project leader for hybrid heterojunction solar cells and a competence team leader for electrical characterization/simulation. He was awarded his Ph.D. degree in organic solar cells for work conducted at Fraunhofer ISE in Freiburg, Germany, after which he worked for several years as a research fellow on silicon heterojunction solar cells at the Helmholtz Centre Berlin for Materials and Energy. After a sabbatical leave in Nanjing, China, Rolf joined SERIS in April 2011. He has (co-)authored many scientific papers and holds several patents in the area of wafer-based silicon solar cells.



Dr. Ian Marius Peters received his diploma in 2006 and his Ph.D. degree in 2009 in physics from the Albert Ludwig University of Freiburg, Germany. Between 2004 and 2011 he worked at Fraunhofer ISE, after which he joined the National University of Singapore (NUS) as a research fellow. Ian is head of the simulation group at SERIS, where he focuses on research in solar energy conversion, advanced optics and photonics, and material science. He has published more than 30 papers in peer-reviewed journals.

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Thin Film

NREL verifies First Solar's 16.1% total area module efficiency record leap

First Solar has made a significant leap in total area module efficiency that has been verified by the US Department of Energy's National Renewable Energy Laboratory (NREL). Easily surpassing its previous record of 14.4% efficiency, First Solar has pushed the bar to 16.1%. Importantly, the CdTe thin-film leader also set a record for open circuit voltage (VOC), reaching an NREL verified 903.2 millivolts. According to the company the VOC record is the first substantial improvement in CdTe-based VOC in over a decade R&D work across the globe. Recently, First Solar set a new world record for CdTe solar cell efficiency of 18.7%.

Source: NREL campus

The NREL has verified First Solar's 16.1% cell efficiency.

Record Cell Efficiencies

Magnolia Solar touts 13% flexible CIGS solar cell

In collaboration with the SUNY NanoCollege and US Photovoltaic Manufacturing Consortium, flexible CIGS thin-film start-up, Magnolia Solar has claimed it has demonstrated a solar cell with a conversion efficiency of 13%. The company did not state aperture area dimensions. Magnolia Solar said that is was also making progress on improving the CIGS solar cells and nano-structured anti-reflective (AR) coating technology, which employs an AR coating using oblique angle nano-structure growth, that is claimed to enhance energy absorption and minimizing reflection loss.

Alta Devices dual junction solar cell verified at 30.8% conversion efficiency

The US National Renewable Energy Laboratory (NREL) has verified a new 'dual junction' thin film solar cell technology from Alta Devices with a conversion efficiency of 30.8%. Alta Devices said that its new dual junction technology used a second junction with Indium Gallium Phosphide (InGaP) as the absorber layer on top of the base single junction cell. InGaP is known to use high-energy photons more efficiently than a single junction Gallium Arsenide (GaAs) cell. Alta Devices said that it was currently shipping its single junction Gallium Arsenide (GaAs) technology.

Spectrolab breaks world record with 37.8% efficiency

Manufacturer of space solar cells and panels Spectrolab has announced a 37.8% efficiency rate for its multi-junction solar cells. Spectrolab's cell efficiency was verified by the US Department of Energy's National Renewable Energy Laboratory. In June 2012, Lux Research predicted Spectrolab could reach 45% efficiency in five years and 50% in ten years.

Business News Focus

First Solar leads solar 'rally' with big increase in sales expected in 2013

Following a 22% increase in sales in 2012, First Solar expects that trajectory to continue in 2013. The leading thin-film and PV project developer guided total module shipments to be between 1.6GW and 1.8GW and net sales of between US$3.8 and US$4.0 billion for the current year. First Solar previously reported net sales for 2012 of US$3.4 billion. The company said that it expected to generate US$0.8 to US$1.0 billion of operating cash flow in 2013 and planned to allocate between US$350 to US$400 million in capital expenditures this year. On the back of these projections, and news that the company has acquired start-up TetraSun, which manufacturers copper-based monocrystalline cells.

Source: First Solar

First Solar guided total module shipments to be between 1.6GW and 1.8GW.

Avancis to convert part of Torgau production line to R&D centre

German thin-film module manufacturer Avancis is planning to convert part of its module production line in Torgau, Germany, into a research and development (R&D) centre. As part of the conversion, its small production plant, known as Fab 1, will begin operating as a R&D centre on 1 June while some of the company's research department from Munich will also transfer to the new centre. The R&D facility will focus on lowering production costs while generating high efficiencies. As a result of the decision to reduce the facility's production capacity, an undisclosed number of factory workers will not be offered extensions on their fixed term contracts.

Sudden departure of First Solar's executive vice president of global business

By mutual agreement, First Solar and Jim Brown, First Solar's executive vice president of global business have parted ways, according to an SEC filing issued today.

The departure comes only a day before First Solar prepares to hold its analyst event to discuss 2013 guidance.

Brown joined First Solar in 2008 as vice president, project finance and was later appointed in January 2012, as executive vice president of global business when the company restructured operations, combining its Utility Systems Business Group and Components Business Group under one structure. Prior to joining First Solar, Brown worked in banking for approximately 20 years covering project and structured finance for the energy and industrial sectors.

Spire sales hit by flood of used PV equipment

PV industry manufacturing overcapacity and a flood of used PV equipment on the market, due to bankruptcies and firms exiting the sector were behind Spire Corporation reporting a 70% decline in PV related sales in 2012. The specialist equipment supplier posted total 2012 revenue of US$22.1 million, down 62% from US$58.7 million in 2011. However, PV sales decreased 70% year-on-year to only US$15.3 million, compared to US$51.0

million in 2011. Spire noted in its 2012 annual report that the delivery of solar equipment to First Solar accounted for 12% of total net sales and revenues. The company said that it was seeking opportunities to gain revenue in other, unspecified solar markets, but was also looking at potential strategic alternative business activities to mitigate the chronically weak business environment in the PV industry. However, management noted that they expected the PV equipment market to start a recovery due to a new capacity buy cycle expected to begin in late 2013 or the first half of 2014.

Solar Frontier's CIS thin film modules added to UniCredit's bankability list

UniCredit Leasing has added Solar Frontier's CIS thin film modules to its bankability list of PV suppliers after quality tests were undertaken by Fraunhofer ISE. The Japan-based thin film producer has engaged with a growing number of commercial and utility-scale PV projects as it ramped its capacity over the last two- years. The company recently reported record financial results.

Source: Solar Frontier

UniCredit Leasing has added Solar Frontier's CIS thin film modules to its bankability list of PV suppliers.

DayStar Technologies names Lorne Roseborough CEO and interim chairman

PV manufacturer DayStar Technologies has announced the appointment of Lorne Roseborough as its new CEO and interim chairman. Roseborough succeeds outgoing CEO and chairman Peter Lacey. Lacey joined the company as chairman in September 2009. Most recently, Lacey took on the role of the company's president from February 2011 until September 2012.

SoloPower hits 'Valley of Death' point

Flexible-CIGS thin-film start-up SoloPower said it would be restructuring its operations which will involve a workforce reduction as it approaches volume production at its plant in Oregon, USA. The company said that the restructuring efforts would include job losses that were designed to lower operating costs and "address market conditions as the company transitions from an R&D focus to commercial manufacturing and sales."

The PV industry has seen a large number of module manufacturing start-ups fail in recent years, hit by the realities of an overcrowded marketplace but also the challenge in taking R&D efforts through to the critical and costly volume manufacturing phase, dubbed by industry observers as the 'Valley of Death' for such companies.

Oerlikon announces 6.4% increase in sales for 2012

The acquisition of Swiss silicon thin film equipment supplier Oerlikon Solar by Tokyo Electron has resulted in sales of approximately US$3.1

Source: Oerlikon

Oerlikon has announced a 6.4% increase in sales for 2012.

million in 2012 up from US$2.9 million in 2011. The sale of what is now TEL Solar led to a net inflow of US$245 millions in cash for the Oerlikon Group. The company said the sale substantially reduced the complexity of the Oerlikon portfolio and paved the way for an enhanced focus on its high-growth and high-margin businesses. The company experienced an EBIT of US$447 million representing an EBIT margin of 14.5%. This profitability level set a new record in the company's history, which Oerlikon said was driven by the strong performance of the textile and coating segments of its business and significant improvement in the drive systems segment. Despite a challenging global economic environment, Oerlikon was able to increase sales from continuing operations by 6.4%.

Order Focus

Bayer sells silver nanoparticle technology to Clariant

An aqueous-based silver nanoparticle ink technology developed in the last 10 years by chemicals giant Beyer has been acquired by high-tech chemicals specialist Clariant International. The silver nanoparticle ink technology has only found a few markets such as RFID chips production and specific flexible substrates in the display industry but Clariant expects to develop the technology for a wider market including photovoltaics applications, most likely related to ink jet printing for flexible thin-film PV.

Only 5% of order backlog at Manz related to solar

Diversification strategies at equipment specialist, Manz have led to weak solar segment sales in 2012 have resulted in the sector only accounting for 5% of its order backlog. The company reported preliminary 2012 revenue of US$241 million down, 23.5% year-on-year. Manz reported an EBIT loss of US$40.1 million, compared to a small EBIT profit of US$4.1 million. Not surprisingly, Manz noted that the losses were primarily related to its solar segment business. The solar segment sales were down 77.5% to US$21.4 million, compared to US$94.9 million in 2011.

Solar Frontier to restart module production at Miyazaki plant

Japanese thin-film PV manufacturer Solar Frontier, part of oil refiner Showa Shell, is planning to restart its module production line at its Miyazaki No.2 Plant in Kiyotakecho, Miyazaki, Japan, in July. The decision to restart the line has been driven by Solar Frontier's plans to launch a new range of products for the Japanese market. Pending the final decision of product models to be manufactured, Solar Frontier will make minor equipment modifications to enable the manufacture of new products which will be sold in Japan.

Spectrolab announces cost-efficient solar cell wafer

PV manufacturer Spectrolab has brought out a new solar cell wafer it claims will reduce customers' costs by 10 to 15%. Spectrolab, a subsidiary of Boeing, said it performs more than 50 separate tests on its wafers to create both solar space cells, which power satellites, and interplanetary spacecraft) and ground-based or concentrated photovoltaic solar cells (which provides electricity to the alternative energy market). These wafers are 50% larger than the previous Spectrolab wafers, allowing for more than three times more cells grown on each wafer, thereby reducing the cost for customers.

First Solar may recycle 100,000 Abound Solar CdTe panels

First Solar has said that it has contacted Abound Solar's trustees to begin discussions whether it can recover materials from up to 100,000 panels made by the bankrupt cadmium telluride (CdTe) module manufacturer.

Abound Solar was founded in 2007 and had received around US$300m in equity from investors including BP Alternative Energy by the time it was awarded a US$400 million loan as part of the US Department of Energy's 1705 programme in 2010.

Abound received around US$70 million of that loan to expand its manufacturing facility in Colorado and establish a new site in Indiana before it filed for Chapter 7 liquidation in July last year. The company blamed its failure on Chinese subsidies and listed US$82 million in liabilities and assets of US$136.1 million.

Source: First Solar

First Solar has proposed to recover material from Abound Solar.

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Product Reviews

MicroTech

MicroTech's TF 1200 production tool meets thin-film substrate cleaning requirements

Product Outline: MicroTech, a Silicon Valley wet process station supplier, has launched a product line specifically designed for high-throughput processing of thin-film solar cells. The modular design enables modules to be added for clean, develop, etch and ultrasonics process steps.

Problem: Substantial cost reduction and cell integration can be achieved by processing an entire array of solar cells on a single substrate.

Solution: The MicroTech TF 1200 production tool can process substrates up to 2 metres in size, and offers several benefits. The system demonstrates low water consumption with strict control and recycling of water through a patent-pending technology. It provides an effective particle-filtering system for improve uptime, while the modular design offers process flexibility and ease of change and is upgradeable in the field. Roller technology for substrate transfer is used, minimizing damage and contamination. The system uses a high-energy ultrasonic cavitation method for hard-to-remove materials and has a unique liquid-handling system that allows spray, puddle and immersion processes.

Applications: The MicroTech TF 1200 production tool can process substrates up to 2 metres in size.

Platform: MicroTech has developed and manufactured a series of modular systems that use the latest technologies to further reduce costs and save chemistries. Modules are available for all major solar thin-film process steps, including clean, develop, etch and ultrasonics. The unique equipment architecture allows its insertion into current process lines. Metrology options are also available to optimize and control process parameters.

Availability: January 2013 onwards.

Advanced Energy

Ascent DMS dual-magnetron sputtering unit from AE offers improved uniformity

Product Outline: Advanced Energy Industries' Ascent DMS dual-magnetron sputtering accessory offers repeatable, tunable film parameters and lowers cost of ownership in large-area glass, solar, flat panel display, AMOLED display and other industrial, dual-magnetron sputtering applications

Problem: Higher thin-film deposition uniformity and density is required to reduce material usage and improve cell efficiencies. Extracting maximum usage of sputtering targets enables lower manufacturing costs.

Solution: Designed to deliver 30 to 180kW of bipolar power – with independent power control to each cathode – Ascent DMS units allow process engineers to customize duty cycles to the wear profile of each target. This enables increased target-erosion uniformity and full utilization of each cathode for longer campaigns. A controllable pulse rise feature offers significant advantages for producing more uniform and higher density films, while unique power delivery options include selectable frequency, independent power-ratio regulation for each magnetron and power, current or voltage regulation. Overall, this technology is claimed to offer significant long-term material savings, boost yields and lengthen manufacturing uptime in order to bring superior yet affordable new products to market.

Applications: Thin-film sputtering processes.

Platform: Ascent DMS units deliver 30 to 180kW of bipolar power, with independent power control to each cathode.

Availability: April 2013 onwards.

Cost-efficient equipment for CIGS production

Ando D. Kuypers, **Raymond J.W. Knaapen** & **Mirjam Theelen,** TNO – Solliance, Eindhoven, The Netherlands, **Marc Meuris**, imec division IMOMEC – Solliance and Institute for Material Research (IMO) Hasselt University, Diepenbeek, Belgium, & **Maarten van der Vleuten** & **Wiro Zijlmans**, Smit Ovens, Son, The Netherlands

ABSTRACT

Even in the competitive and turbulent present-day PV market, thin-film PV modules based on copper indium gallium selenide (CIGS) have good prospects for capturing a growing market share. Three important factors support the survival and growth of CIGS technology on the market: 1) proven lab results demonstrate considerable room for improvement of conversion efficiency; 2) the potential for cost reduction is high (reduced equipment CAPEX as well as reduced material and BOS costs); and 3) a high degree of freedom in the choice of substrate material and shape enables efficient application of the technology. These factors should be realized using more-generic or standardized CIGS production equipment to reach economy of scale. Examples of novel and improved strategies for cost-efficient thin-film deposition and absorber formation are presented in this paper. Within the framework of a new thin-film PV research alliance under the name Solliance, a CIGS demonstrator line has recently become available for accelerating R&D of cost-effective processes and equipment, and for demonstrating their capabilities in improving CIGS in terms of product performance and lifetime.

A new platform for CIGS equipment development

In 2010 and 2011 around 5% of the value creation of the total worldwide PV equipment market was realized by Dutch companies – not only by Netherlands-based OEMs, but also, for a substantial part in the form of custom-built systems and subassemblies, by Dutch industrial contractors along the equipment supply chain. In order to fully exploit the potential for thin-film PV production, a research alliance was founded in 2011 under the name Solliance, located in Eindhoven, and with financial support from the Dutch province of Noord Brabant. Although Solliance was founded as a collaboration between Dutch research partners ECN, TNO, the Holst Centre and Eindhoven University of Technology, the concept from the start was to create a regional cluster in Europe. So far, imec (Belgium) and Forschungszentrum Jülich (Germany) have joined the alliance, and further partnerships are under negotiation. An open research centre has been created in Eindhoven, where new equipment investments of Solliance are integrated with facilities that have been brought together by research partners and participating industrial stakeholders to form three thin-film research lines.

> “To fully exploit the potential for thin-film PV production, a research alliance was founded in 2011 under the name Solliance.”

In December 2012 a reference demonstrator line for copper indium gallium selenide (CIGS) research was opened, and demonstrator lines for organic photovoltaic (OPV) technology and thin-film Si are currently under construction. Bridging the gap between fundamental research and industrial application is thus promoted by bringing together infrastructure and co-workers from research institutes, industry and universities. Further synergy is encouraged by centring these activities on the High Tech Campus (the former Philips Research campus) in Eindhoven, where over 100 companies and more than 8000 researchers are located, and where additional facilities for high-end equipment, thin-film processing and characterization are shared. The site is one of the three cornerstones of the Eindhoven-Leuven-Aachen triangle (ELAT region), and the Solliance partners are thus located on all three corners of this triangle. The mission of Solliance is to provide industrial equipment and process solutions for thin-film PV, to develop new cell concepts and to create smart integration concepts with optimized lifetimes.

Challenges in CIGS production

Thin-film solar modules based on CIGS are extremely promising. It is the only type of large-area produced thin-film PV that rivals the presently dominant wafer-based (multi)crystalline silicon modules in terms of efficiency. CIGS is therefore economically feasible for residential applications where limited roof area is available. In addition, as CIGS can be directly produced on a wide variety of substrate materials, including building construction materials such as glass and steel, it has the potential to significantly reduce area-related balance of system (BOS) costs. Further, it shares the possibilities of other thin-film technologies (CdTe, OPV, a-Si) of achieving competitive production costs and potential for very high volume production, for example roll-to-roll (R2R) production on flexible substrates. And, finally, it is aesthetically attractive, as it can be produced with a wide range of forms and patterns, in combination with a homogeneous black appearance or an added colour. No other thin-film PV technology has been demonstrated in such a variety of forms and carrier materials as CIGS.

Although the full scope of this promise has yet to be proved by successful and economically sustainable production on a sufficiently large scale, CIGS modules produced by a number of manufacturers have already been on the market for a number of years. Most CIGS modules are currently produced on flat glass or brought to market with glass encapsulation. In 2010 a total CIGS volume of well over 200MW$_p$ was produced by a number of companies with production capacities of the order of tens of megawatts. In 2012 Solar Frontier in Japan ramped up their CIGS production on a scale of many hundreds of megawatts, aiming at 1GW, and recently reported a profit-making financial quarter in the midst of PV overproduction turbulence. This shows that CIGS on rigid glass is in the running for utility- and rooftop-scale PV. At the same time, several companies have chosen to utilize the feasibility of CIGS on alternative and flexible substrates in order to address the market for integrated consumer devices and automotive applications. Flexible products without glass encapsulation have also been certified and introduced to the market.

Challenges and goals

Although the same general layer build-up is used by most CIGS producers, a wide variety of compositions (Ga,S and Se content, but also additives such as Na), composition gradients, morphologies and interlayers are employed. CIGS is a material with a very complicated phase diagram, and as a consequence the resulting properties are very dependent on the processing route that is followed to achieve a certain composition. Many recipes exist for the growth of these layers and which employ a wide variety of deposition methods. In the last decade between 40 and 80 industrial initiatives on CIGS production have been known, and almost every one of them employs a proprietary process, often requiring very specific, nonstandard equipment. Moreover, the work field of CIGS is currently hampered by a technology diversification, which hinders the achievement of a sufficient economy of scale.

This situation leads to the following challenges and roadmap goals:

- To reduce cost by choosing low-cost and rugged (controlled uniformity) high-yield processing routes, and by developing more-generic equipment solutions for these routes to obtain a better economy of scale.
- To improve quality by reducing the gap between laboratory efficiency records (20.3–20.4%) and those obtained in industrial practice (12–14%), while pushing the records further (23%) and improving lifetime.
- To improve fundamental understanding of material formation and properties, and most notably the role of interfaces (grain and layer boundaries), which are less dependent on specific recipes and type of process.
- To identify important process and material parameters and to improve their control (e.g. explore the behaviour and control of impurities to achieve cost reduction by reducing purity-level requirements of source materials).

> "The goal of the Solliance programme is low-cost mass production using improved material and process control."

The goal of the Solliance programme is therefore low-cost mass production using improved material and process control, finally aiming at R2R production on flexible substrates. Innovations in R2R printing and curing, web handling and registration are accessible through collaborations with the OPV programme of Solliance. For the absorber layer, the focus of the Solliance CIGS programme is atmospheric, sequential CIGS formation – in other words the deposition of a CIG precursor layer, which is selenized and crystallized in a subsequent annealing step. A lot of emphasis is being placed on

- material and process development for the transparent conductor (TCO) and additional layer modifications for improved light management;
- replacement of the CdS layer by Cd-free and tuneable alternatives;
- barrier layers at the interface between device and substrate to enable more freedom of choice for (low-cost) substrates;
- flexible encapsulation for a longer lifetime.

As all these process steps are interdependent, it is necessary to develop individual process steps within the context of a complete demonstrator cell or module. Therefore, based on commonly known individual process steps, a research-scale line for the realization of reference CIGS demonstrators has been brought into operation. This reference line will be used for research and demonstration of innovations in individual alternative process steps.

To support these goals for material, process and equipment development, a substantial amount of work in the areas of cost of ownership modelling and accelerated lifetime testing is being undertaken.

Reference line using co-evaporation

As a reference for device, process and equipment innovations, a line of equipment has been built for the fabrication of complete CIGS demonstrator modules of dimensions up to 30 × 30cm^2. Glass substrates as well as framed sheets of foil can be handled. The standard process sequence is based on soda-lime glass substrates. After magnetron sputtering of molybdenum, a CIGS absorber layer is deposited by co-evaporation using a custom-designed system from 44Solar. A CdS buffer layer is added by chemical bath deposition with a Tenuis system from Singulus Stangl. Sputtering of an intrinsic ZnO film and an Al-doped ZnO transparent conductor complete the layer stack. Test samples are divided into individual test cells by mechanical scribing, while monolithically integrated module formation by ps-laser scribing is also available.

In collaboration with the University of Nantes (Prof. J. Kessler) a test cell efficiency

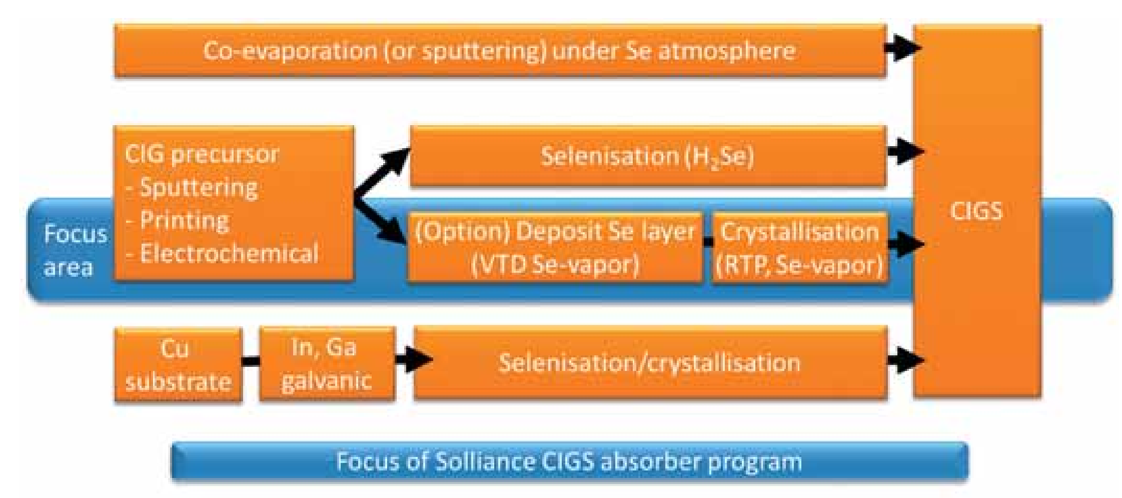

Figure 1. Schematic representation of different approaches for CIGS absorber formation. The focus of the Solliance CIGS programme is indicated in blue, i.e. elemental Se-based sequential CIGS formation by rapid thermal processing (RTP).

of 14.9% (aperture area) was achieved in the first six months after start-up of the line. For reference and research purposes, reproducible and homogeneous samples of sizes 5 × 10mm^2 up to 10 × 10cm^2 can be made available. Typical project activities are the evaluation of alternative substrates (special compositions, barriers, surface topologies), the demonstration of thinner co-evaporated absorber layers for testing new light-management concepts (nanotexturing and nanophotonics), and the performance evaluation of novel transparent conductors and back-end interconnection schemes. As a specific example, CdS replacement by fast atomic layer deposition (ALD) of Cd-free layers will be covered below, but first the CIGS absorber formation will be discussed.

CIGS absorber formation

Several approaches for forming the CIGS absorber are used by different groups of manufacturers and researchers, as shown schematically in Fig. 1. The first approach is to deposit all constituents directly in one process, either by simultaneous co-evaporation from typically four sources, or by (for example) sputtering CIG composite targets under a Se atmosphere.

A second approach is commonly referred to as 'sequential processing.' In this two-step process, a CIG precursor layer is deposited first, for which a number of dry or wet processes can be used; then, in the next step, Se (and/or S) is added and alloy formation and recrystallization are performed by thermal annealing. For this second approach, much development has taken place with regard to H_2Se-gas-based selenization. This typically takes place in batch processes, which deliver good uniformity and quality, but at the cost of long processing times requiring many oven systems in parallel. Moreover, H_2Se is less desirable owing to costly safety issues. A lot of research has therefore been recently devoted to reducing the process time and to switching to elemental Se-based processing. In order to prevent formation of undesired material phases, which can be irreversible and lead to phase separation, rapid thermal processing (RTP) is required.

Finally, a third approach has also been demonstrated, in which the substrate chosen is such that it provides one of the constituents of the absorber layer. Using copper substrates, subsequently coated with indium or indium/gallium alloys, fairly good quality absorbers are known to have been produced by sulphurization of this coated metal stack (by the former thin-film specialist Odersun).

On the basis of favourable cost of ownership analyses, the sequential-processing route has been chosen as the focus of absorber development in the Solliance programme.

> "The sequential-processing route has been chosen as the focus of absorber development in the Solliance programme."

Research line using sequential absorber formation

For the first step of sequential processing – the CIG precursor formation – several routes have been explored. In-house CIG precursor deposition by DC magnetron sputtering from Cu/Ga and In targets is available. Specific research activities in the in-line electrochemical deposition of CIG on specifically activated molybdenum-coated glass substrates, utilizing an in-line panel-plating line from MECO, are ongoing. Solution-processed or printed precursor layers have also been evaluated. In the rest of this paper, only the second step of the sequential process will be discussed, namely the Se-based atmospheric RTP processing of a CIG precursor layer.

High-throughput low-cost selenization

The results presented here were obtained using an R&D selenization tool from Smit Ovens (Fig. 2). The tool was developed using selenization mass-production technology while keeping the requirements of R&D in mind. The result is a versatile system with many capabilities and good repeatability, which enable an efficient development of a selenization process with direct scalability to a mass-production solution.

This novel CIGS-formation concept combines a number of process and equipment improvements that offer significant reductions in CAPEX and OPEX relative to state-of-the-art technology. In contrast to many crystallization tools that are available worldwide, this is a non-vacuum tool in which the process is performed at atmospheric pressure while the reactive gas mixture is safely contained. Inert nitrogen is used as the carrier gas for elemental selenium transport. The purchase price of elemental selenium per unit mass is approximately a quarter of the price of the sole industrial alternative, hydrogen di-selenide (H_2Se). In addition to this inherent price difference, H_2Se has significantly higher safety costs, related to transport and handling of this hazardous gas. Successful examples of elemental Se-based processing, resulting in very competitive module efficiencies, have already been reported by other researchers [1].

Fig. 3 shows the cost of ownership calculations, which illustrate the impact of the higher H_2Se price per unit mass of selenium. Calculations are based on a 66MW production line with a cycle time of 60 seconds for a panel format of 1.60 × 0.68m^2. Comparison is made for three different in-line tools, all based on the Smit Ovens concept. First, an H_2Se process is assumed with no pre-deposited selenium in the precursor, followed by five minutes' soaking at 580°C. Second, an elemental selenium deposition process is performed by a vapour transport deposition (VTD) process on the precursor, followed by a crystallization process that incorporates an intermediate soaking step and a subsequent soaking step at 580°C for five minutes. Finally, there is an elemental selenium process with five minutes' soaking at 580°C without VTD or an intermediate soaking step.

It should be mentioned that currently competitive efficiencies are obtained by applying H_2Se in a batch oven. In this process the batch oven itself is heated up and cooled down in one very time-

Figure 2. The R&D selenization tool built by Smit Ovens to facilitate process development at Solliance. One-to-one translation of the set-up to a full-scale production line is possible.

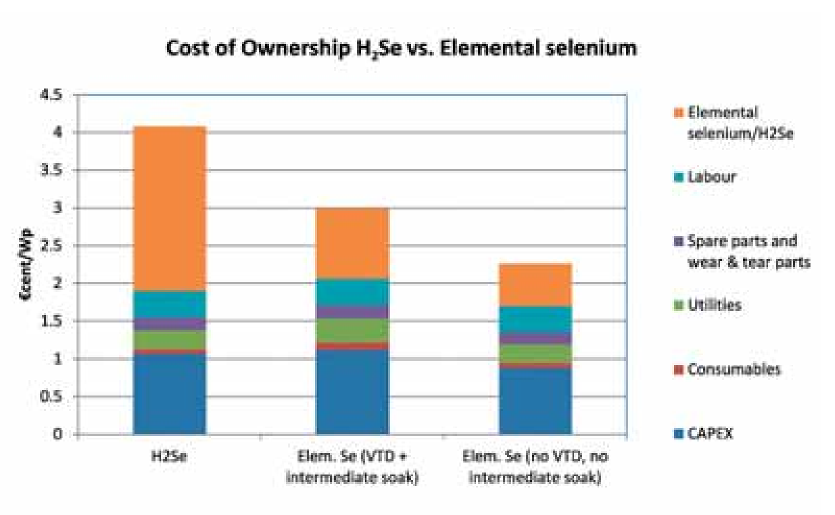

Figure 3. Cost of ownership calculations, illustrating that the choice of source material has a significant impact on the cost of CIGS absorber manufacturing.

consuming run in which a number of panels are crystallized. On the basis of certain calculations (not illustrated here) it could be concluded that batch processing is not a cost-competitive route for mass production because of the high CAPEX and energy costs.

A typical process flow of the R&D selenization tool is as follows. First, an optional selenium layer can be deposited on top of the CIG precursor in a cold VTD section. Second, CIGS crystallization takes place in an RTP oven section which allows a high flexibility in its thermal profile, created by the use of three independent RTP chambers. In particular, the flexibility in realizing high and homogeneous heating rates of the CIGS substrate is essential; it is known from research work of many companies and institutes around the world that this heating rate influences crystal growth dynamics and is an important parameter. Additional supplies of selenium at the various stages of the thermal profile are provided by three independent selenium sources. Selenium flux can thus be controlled independently of the product temperature, which is a unique feature of the technology concept. Further flexibility is offered by both fast- and slow-cooling possibilities, the absence of restrictions in the transport sequence between the various chambers, and the provision of special carriers for small-sized substrates or foils.

This flexibility gives effective and repeatable control of the process in order to efficiently develop the optimum

Tool features	Specification	Benefits
Multiple dimensions and types of substrate	Glass and foil	Flexibility for R&D
Freely programmable process		Flexibility in process development
Maximum substrate temperature	650°C	Processing capability, resulting in highest efficiencies
Fast and repeatable substrate heat-up rate	15°C/s	
Fast and repeatable substrate cool-down rate	3°C/s	
Control of partial vapour pressure	0–100%	
Uniform substrate temperatures	±2°C	Effective and repeatable processing, enabling efficient R&D
Uniform Se distribution/absorbance	±2%	
Data logging for substrate and tool		Enhanced analyses of R&D results
Industry-standard seals (vacuum)	< 10ppm O_2	Low leakage rates, low O_2 content
Substrate (un)loading via load lock		
Hot wall design		No reactor pollution, less cleaning, low cost
Electrical heaters (Se and S resistant)		Long lifetime, high uptime, low cost

Table 1. Features and specifications of the selenization equipment.

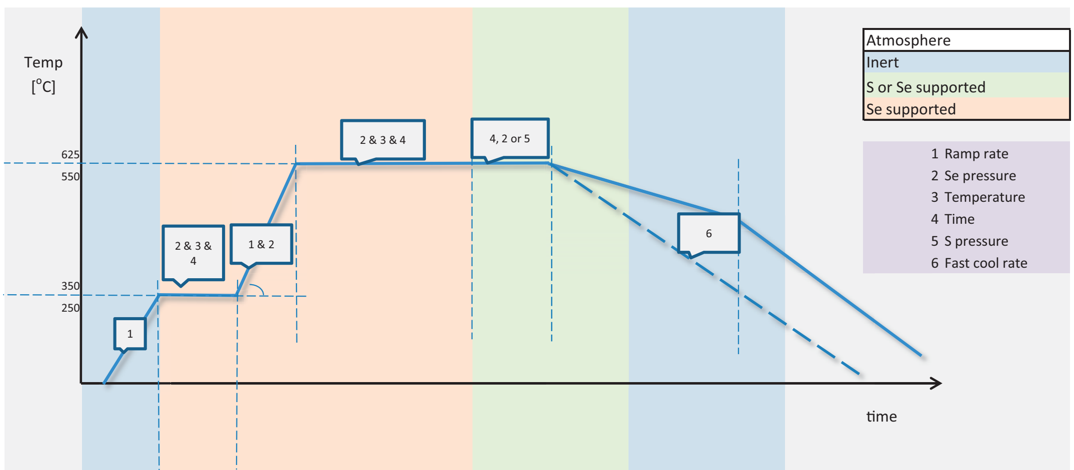

Figure 4. The available process variables of a two-step temperature profile with the R&D tool used.

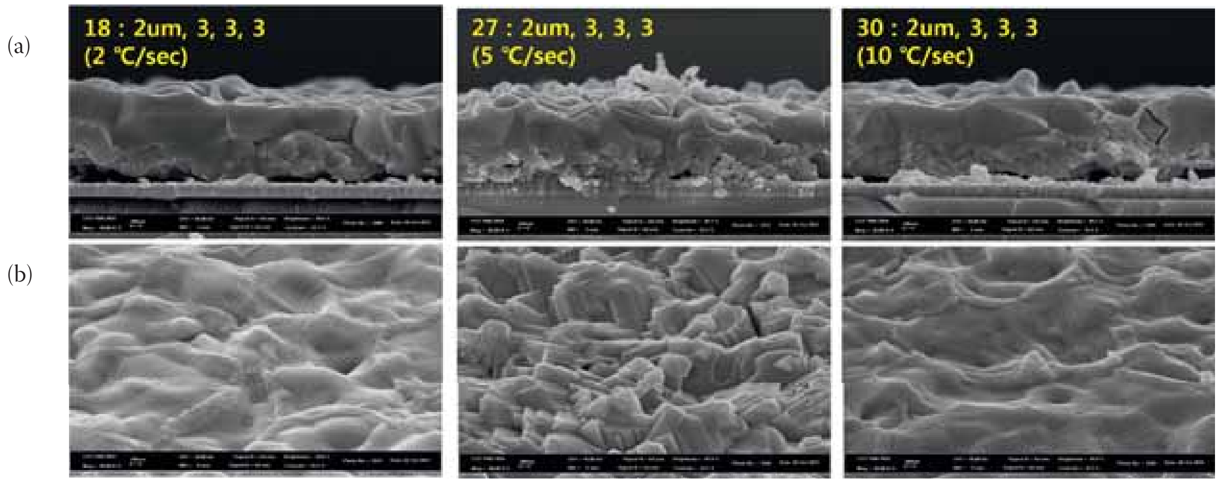

Figure 5. SEM images of absorber layers that have been made utilizing various heating rates with the 30 × 30cm² selenization tool: (a) cross section; (b) top view. (CIGS absorber thickness = 2μm.)

process with the correct crystal composition, size and interfaces. More detailed specifications of the system are presented in Table 1.

A typical example of the temperature profile of a two-step selenization process performed with the research tool is given in Fig. 4; the freedom for modifying process temperature and pressure parameters is indicated. In this specific example an additional intermediate soak in a selenium atmosphere is used (first horizontal section on the graph).

A specific capability is the application of very fast heating rates while maintaining good temperature uniformity over the width of the substrate. For example, in a 50-second heating cycle in an 800°C chamber a substrate is heated with a ramp rate of 11°C/sec to 600°C. During this fast heating stage a temperature spread of less than 12°C over the full 600 × 300 × 3.2mm³ substrate is realized. After this step the substrate is soaked in a 600°C chamber, and the temperature spread decreases to less than 4°C.

Scanning electron microscopy (SEM) images of CIGS layer samples produced from sputtered precursor layers, under various temperature ramp rates, are shown in Fig. 5. No intermediate soak was used. The impact of the heating rate on the morphology and density of the layers is clearly visible. The layer characteristics can be further investigated using other available analysis methods, such as XRD, XRF, EDX, SIMS, photoluminescence and profilometry.

Sulphurization steps can also be incorporated in the full-scale production machine. In this way, a very generic equipment solution is made possible for a wide variety of selenization and sulphurization processes, optimized for different types of precursor layer. By adapting the length of individual sections of the machine to the required time intervals for each step, the throughput of the total process can be optimized further. A dedicated in situ XRD set-up has been designed to study crystal structure along the thermal trajectory, thereby further optimizing layer quality at reduced process times.

Spatial ALD for fast deposition

In the standard reference process, a CdS buffer layer is deposited after the formation of the CIGS absorber layer. It has been shown by numerous authors, and commercial producers too, that it is possible to replace this buffer layer by cadmium-free alternatives: examples are Zn(O)S and In_2S_3, which in principle also offer the possibility of improved cell efficiency because their optical transmission is higher than that of a CdS window layer, thereby enabling more light to reach the absorber layer. The required thicknesses of these layers are of the order of tens of nanometres, and the layers are preferably deposited by 'soft' processes which do not generate interface damage.

Wet chemical processing and sputtering are already being applied, but logistic and (waste) cost aspects related to the wet chemical method, and the inherent risk of interface damage using sputtering methods, give rise to continued interest in a third method that has been proved to yield very desirable results on a laboratory scale. This method is gas phase chemical deposition from volatile precursors by ALD. ALD is already a well-established technique in the microelectronics industry because of its high-quality characteristics, such as high conformality and film quality, and excellent thickness control down to Ångström level.

An emerging field of application of ALD is flexible electronics, including flexible displays, flexible organic light-emitting diodes (OLED) and flexible solar cells. ALD can be used as a production technique in the creation of, for example, transparent oxide (semi)conductors (e.g. ZnO), moisture barriers (e.g. Al_2O_3) and buffer layers for CIGS (e.g. Zn(O)S).

In all these applications, cost effectiveness and throughput are very important. However, conventional, time-sequenced ALD is inherently very slow, and merely upscaling the conventional method to accommodate large substrate sizes is costly. In order to achieve high throughput and cost reduction, there have been important developments in ALD,

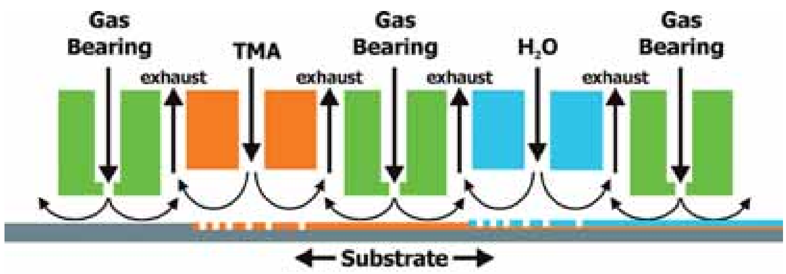

Figure 6. Principle of spatial ALD with separated gas flows for alumina deposition on flat rigid substrates.

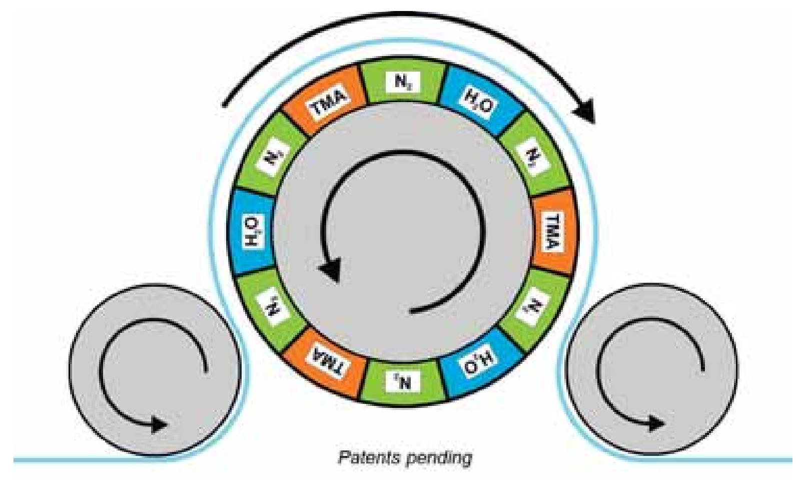

Figure 7. Principle of spatial ALD with separated gas flows for R2R application on flexible substrates.

one of which is 'spatial ALD'. Whereas for conventional ALD the precursors are dosed sequentially in time with purge steps in between, in spatial ALD the precursors are dosed simultaneously and continuously, but at different physical locations. The main advantage of spatially separating the half-reactions is that the purge steps between the precursor dosages, as required in conventional ALD, become obsolete. The result is dramatically increased deposition rates, limited by chemistry rather than pumping speed: reductions in processing time by an order of magnitude or higher have been demonstrated [2 and references therein,3,4].

In spatial ALD it is essential to have the precursors separated at all times, since cross reactions would lead to chemical vapour deposition (CVD) conditions. TNO has developed a spatial ALD concept based on gas bearing technology, in which the reactor is divided into separate zones, exposing the precursors one by one to a substrate that moves underneath the reactor. The reaction zones are surrounded by an inert gas flow that prevents the precursors from mixing. In this concept, the gas shields also act as gas bearings: this means that the reactor part is suspended with respect to the substrate, with a very small gap between, which can be as small as a few micrometres. The gas bearing function offers virtually frictionless movement between the reactor part and the substrate, and the small gap facilitates the gas separation function. Because of the separated precursors there is no parasitic deposition on the reactor parts. Deposition rates exceeding 1nm/s have been achieved for alumina from trimethyl aluminium (TMA) and water. Based on these principles, a mass-production tool for aluminium oxide passivation of crystalline silicon wafers has recently been brought to the PV market by start-up company Solaytec.

After the development of equipment solutions for spatial ALD on silicon wafers, an R2R concept was also developed and successfully demonstrated. Using spatial ALD on flexible substrates imposes additional boundary conditions on the process and equipment. First, because of the limited temperature stability of many polymer-based substrates, deposition temperatures are required to be low (e.g. <120°C). Second, the deposition equipment has to be capable of handling and processing flexible substrates, either sheet to sheet or roll to roll, while maintaining the required gas separation.

An R2R spatial ALD tool that can continuously deposit alumina and other materials on flexible substrates, such as polyethylene terephthalate (PET) foil, has been realized. The spatial ALD concept using gas bearings, as described earlier, now involves a cylindrical shape instead of a flat one. The cylinder, or drum, contains a multitude of TMA and water half-reaction zones as illustrated in Fig. 7. These zones are separated and surrounded by nitrogen gas bearings. The foil to be coated is transported over the drum, where the gas bearing function ensures that the foil is not touching the drum. When moving the foil over the drum, ALD deposition takes place; the deposited layer thickness is determined by the number of half-reaction zones that the foil passes over. High deposition rates can be achieved by rotating the drum in the opposite direction to the foil motion. Total layer thickness is therefore determined by substrate speed as well as the frequency of drum rotation.

Figure 8. R2R tool for spatial ALD on 30cm-wide foils.

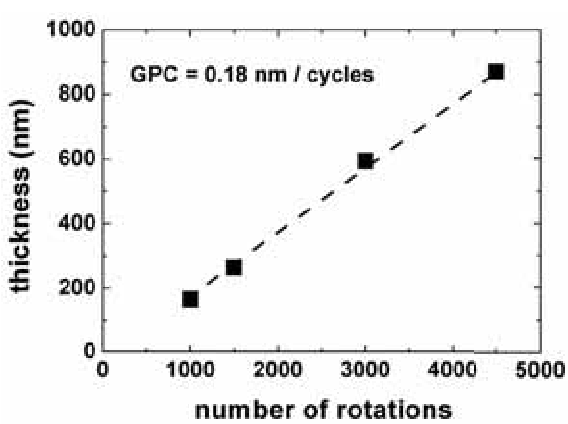

Figure 9. Deposited ZnO layer thickness as a function of the number of ALD cycles.

The main benefits arising from the R2R concept are that there is no mechanical contact between the deposition side of the foil and the reactor, and that there is a minimum of moving parts. This contactless operation, together with the low number of moving parts, minimizes particle generation, which can lead to a risk of, for example, pinholes in barrier layers. Furthermore, many types of substrate material can be used, as long as they have sufficient flexibility to be transported over a cylindrical drum.

"The main benefits arising from the R2R concept are that there is no mechanical contact between the deposition side of the foil and the reactor, and that there is a minimum of moving parts."

Besides the contactless operation of the substrate-over-drum motion, the gas supplies to the rotating drum are also accomplished without any mechanical contact. Again, gas bearing technology in combination with gas separation is used to supply the bearing gases and precursors to the drum from both sides. Reaction products and excess precursors are also exhausted through these contactless gas feed-throughs. The configuration is such that the TMA precursor is supplied and exhausted on one side of the drum, while the water vapour is supplied and exhausted on the other side. In this way, the precursors stay separated until finally exhausted in the scrubber system outside of the reactor.

The R2R spatial ALD tool that is currently in operation has been used to deposit alumina layers of various thicknesses between 5 and 100nm on PET foil and other substrate materials (Fig. 8).

An equipment solution for spatial ALD on large-area rigid substrates (glass) has been designed, and a demonstrator tool will be available at the end of 2013. It will

Figure 10. Hybrid degradation set-up, allowing exposure to illumination, elevated temperature and humidity.

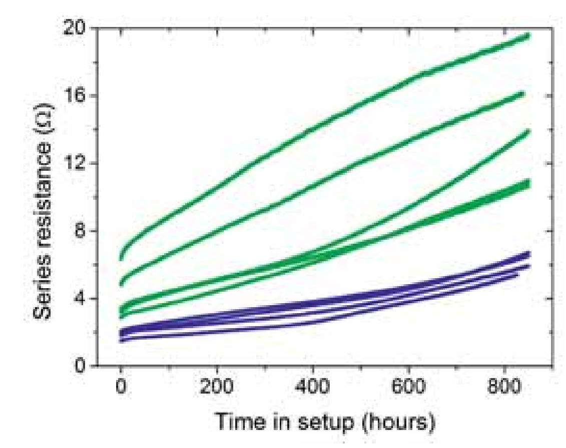

Figure 11. Series resistance as a function of time in the set-up of single CIGS (blue) and interconnected CIGS (green) samples. Operating conditions for the set-up are: 85°C temperature, 85% relative humidity and AM 1.5 illumination.

be evaluated for large-area application of buffer layers as well as for applying other functional layers in the CIGS system. Spatial ALD of ZnO has already been demonstrated on smaller samples using a set-up in which the substrate is rotating under two spatially separated gas inlets, thereby depositing one atomic layer per rotation cycle. The perfectly linear behaviour in Fig. 9 (taken from Illiberi et al. [5]) demonstrates true ALD. ZnO deposition rates of up to 1nm/s and above were demonstrated at temperatures of up to 250°C. At a precursor partial pressure of 4.5mbar, layers were obtained with higher than 90% optical transmission, resistivity around 4mΩcm, charge carrier density of $10^{19}/cm^3$, and charge mobility of $10cm^2/Vs$. Higher carrier densities ($7\times10^{19}/cm^3$) and charge mobilities ($30cm^2/Vs$) were also recorded. Doping with Al and In has been successfully demonstrated with this spatial ALD set-up, and a dedicated set-up for using H_2S will shortly be available for demonstration of fast ALD of Zn(O)S.

It is only briefly mentioned here that the high-rate, low-temperature CVD of high-quality transparent conductive oxides (TCOs) is also being developed in parallel. Atmospheric plasma-enhanced CVD, as well as low-pressure plasma-enhanced CVD, are currently under development for the deposition of doped ZnO in CIGS applications. This work, which has been reported elsewhere, completes the desired approach of a full line of atmospheric processes for the production of the CIGS cell layer stack (apart from the currently used molybdenum back electrode).

Quality evaluation: understanding degradation of CIGS

The electricity cost of PV is determined not only by production and installation costs, but also by module lifetime. Knowledge of the degradation processes in CIGS cells and modules is therefore very important for identifying the lifetime-limiting factors which can be translated into process and device improvements. Processes, equipment and control are therefore developed at Solliance within the context of not only product quality but also product lifetime. Specific knowledge regarding this last aspect is obtained by both standard and advanced accelerated lifetime testing.

One example of advanced lifetime testing is the hybrid degradation set-up shown in Fig. 10. CIGS samples are exposed to AM 1.5 illumination, as well as to elevated temperature and humidity, thereby accelerating the degradation behaviour with three relevant environmental factors and allowing the in situ measurement of the *I-V* characteristics. This set-up is equipped with a data-processing system that allows on-line interpretation of the data and real-time monitoring of the degradation behaviour [6].

Fig. 11 shows an example of the development of a specific cell parameter – the series resistance – of both CIGS cells and mini-modules in the set-up as a function of time. All samples exhibit an increase in this resistance, probably caused by a decreasing conductivity of the zinc oxide. Furthermore, the mini-modules (green) show a much faster increase than the single cells (blue), which can be explained by degradation of the monolithic interconnection region. Similar information is obtained for the other cell parameters. By performing such real-time accelerated lifetime measurements on samples produced under controlled process variations, trends can be visualized and lifetime-limiting factors identified. The results are validated by comparison with field tests carried out by third parties, and model-based approaches (based on a validated background in accelerated lifetime modelling of consumer electronics) are used to gain a more basic understanding.

Summary

Solliance, a recently founded research alliance in the Eindhoven-Leuven-Aachen region, is a programme in which TNO, ECN, imec, the Holst Centre, Forschungszentrum Jülich and Eindhoven University of Technology collaborate on device, process and equipment development for the production of thin-film PV. In collaboration with industry, shared demonstrator lines and facilities for CIGS, OPV and thin-film Si are made available. Against this background, R&D in CIGS focuses on more-generic process and equipment development for low-cost, well-controlled, high-rate and high-yield production. To achieve this, Solliance has chosen to place particular emphasis on atmospheric processes and sequential CIGS absorber formation for H_2Se- and Cd-free production and R2R-compatible processing.

> "Solliance has chosen to place particular emphasis on atmospheric processes and sequential CIGS absorber formation for H_2Se- and Cd-free production and R2R-compatible processing."

To accelerate the development of economically competitive solutions, Solliance offers equipment manufacturers a platform where facilities can be shared not only for confidential technology assessments and demonstrations, but also for collaborative R&D. A CIGS demonstrator research line on 10 × 10cm^2 and 30 × 30cm^2 scales, based on co-evaporation, is made available. This can be used as a reference process for demonstrating and accelerating innovative concepts for more efficient production, for demonstration and testing of improved device architectures, and for fundamental research. This approach is illustrated by examples, including: atmospheric, H_2Se-free, in-line absorber formation by RTP; spatial ALD for the formation of Cd-free buffer layers; and in situ monitoring of accelerated lifetime testing.

Although not discussed in this paper, it should be mentioned that an important part of the Solliance CIGS programme is devoted to utilizing the participants' background experience in CIGS for the development of copper-zinc-tin-sulphide/selenide (CZTS)-based devices. New material and device concepts for CZTS are being explored in close collaboration with existing CIGS equipment manufacturers.

Acknowledgements

The authors would like to acknowledge the work and inspiration of all the team members who have contributed to the implementation of the Solliance programme; the support of the partnering institutes and companies is also gratefully acknowledged. The crucial backing of the Province of Noord Brabant – both in terms of financial support for investments in facilities and projects, and in terms of strategic support – is greatly appreciated. The funding in particular of Interreg Vlaanderen Nederland, the European Union and the local governments in the Solar Flare project is acknowledged for making this work possible.

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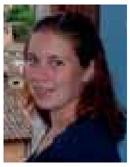
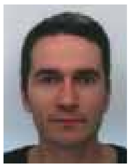
Dr. Ando Kuypers has led the Solliance CIGS programme since 2011. He received his Ph.D. in plasma physics from FOM Institute AMOLF in Amsterdam. From 1989 to 1992 Ando worked on thin-film process development at ASM International, and since 1993 he has managed projects and research groups in thin-film technology at TNO, with a focus on process development for PV applications.

Raymond Knaapen studied dynamic systems and control. In 1999, he received his PDEng in mechatronic design from the Stan Ackermans Institute in Eindhoven, after which he worked on high-precision machine design at Philips Research and Philips Applied Technologies. Since 2007 Raymond has been a senior systems engineer at TNO, specializing in equipment for spatial ALD and semiconductors.



Mirjam Theelen works as a research scientist at TNO, with a focus on CIGS deposition. She is also a part-time Ph.D. student at Delft University of Technology, where she is studying the degradation behaviour of CIGS solar cells. Mirjam received her M.Sc. in chemistry from Radboud University Nijmegen in the Netherlands.

Marc Meuris is the programme manager and team leader of the Alternative Thin-Film PV programme at IMOMEC, the imec division of the University of Hasselt in Belgium. Since the launch of the programme in 2010, Marc's work has involved studying new and innovative materials for thin-film PV applications, with a main focus currently on the CZTS material system.



Maarten van der Vleuten is a CIGS process manager at Smit Ovens. In collaboration with customers over the past four years, his focus has been on process and equipment development for CIGS absorber formation. Maarten previously worked on optical storage applications (DVD, blu-ray) at Philips Electronics, and has a background in applied physics.

Wiro Zijlmans is the director of Smit Ovens. After acquiring the company in 2001, Wiro has successfully transferred its line of business from the display and glass industry to a focus on the development and supply of advanced thermal equipment for thin-film PV manufacturing. Close cooperation and personal involvement with R&D has led to intensive collaboration with PV research institutes in the Netherlands.

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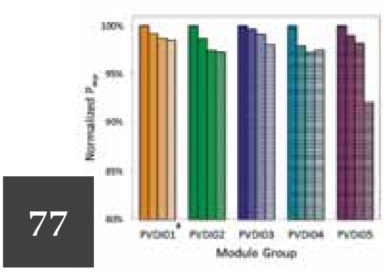
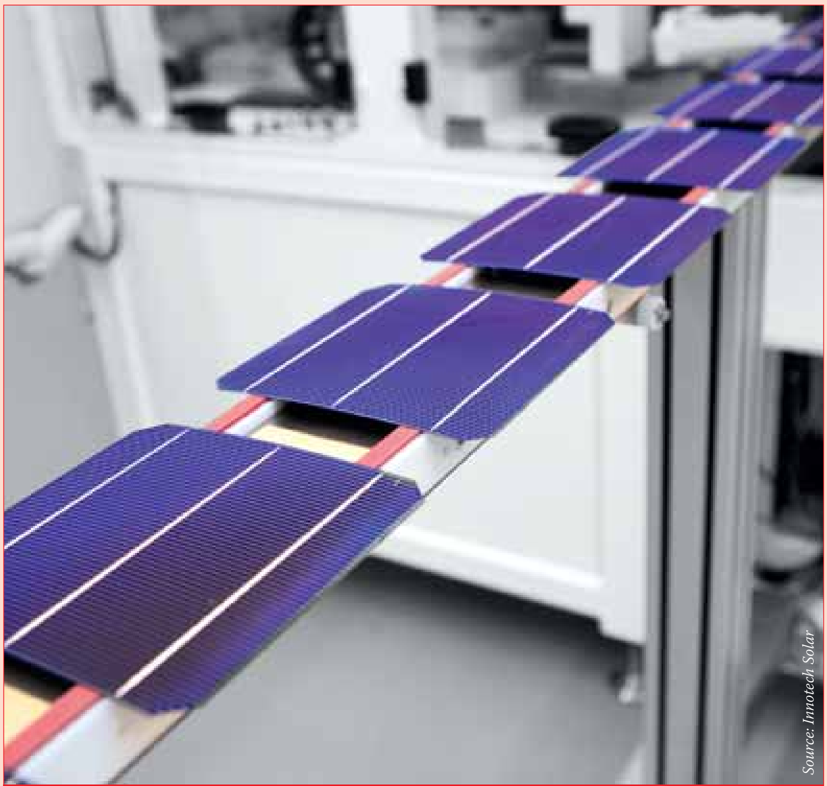


Crunch in module availability as EU hardens stance against China

The European Commission's anti-dumping investigation into PV modules shipped into EU countries from China is having a major impact on module availability and forcing distributors, project developers and installers to alter purchasing decisions. The start of import registration for Chinese modules has prompted a scramble among many distributors to cancel orders as they fear direct ordering will make them liable for any retroactive duties. Thin margins and a highly competitive market place in Europe have already resulted in distributors going bankrupt or significantly scaling back operations to reduce short-term financial constraints. The added uncertainty over whether duties could be very high has sealed decisions to withhold further orders with Chinese module manufacturers. The problem has been exacerbated by the unwillingness of Chinese manufacturers now to ship modules into Europe except directly to customers.


Source: Innotech Solar

The start of import registration for Chinese modules has prompted many distributors to cancel orders.

Order Focus

ReneSola teams with Solairedirect for module production

Furthering its efforts to outsource extra PV module production outside of China, ReneSola has signed a toll manufacturing agreement with Solairedirect SA, the South African-based subsidiary of French-owned integrated project developer, Solairedirect. ReneSolar said that under the module tolling agreement, Solairedirect SA would assemble 120MW of ReneSola-branded modules for a period of three years at Solairedirect Technologies module assembly plant in South Africa. Solairedirect Technologies will also purchase 20MW of the tolled modules for use in projects in the country as well as a further 34MW of the modules for use outside South Africa.

JA Solar delivers 35MW of modules for five Israeli solar projects

Chinese PV equipment manufacturer JA Solar has started to ship 35MW of its modules to Siemens for installation at five PV projects in Israel owned by Arava Power Company. Three of the five projects are located in the Arava Desert whilst the remaining two will be built in the Negev Desert. Under the terms of the module supply agreement, JA Solar will provide Siemens with a total of 122,936 high-efficiency polycrystalline PV modules, each with an average output of 290Wp. Delivery began in January and is expected to complete by May.

Yingli Green to ship an extra 1GW in 2013; module prices rising

A net loss in 2012 of nearly US$500 million was overshadowed by Yingli Green's shipment guidance for this year increasing by a massive 1GW. Yingli Green said that 44% of revenue came from China in the fourth quarter of 2012, yet expects a further 40% increase in module shipments into the domestic market in 2013. The company expects significant market share growth in Japan, while growth will also be seen in certain European markets, the USA and emerging markets. Based on global PV installations expected to be in the range of 30-32GW in 2013, Yingli Green is targeting around a 10% global market share.

JinkoSolar to supply 115MW to two South African projects

JinkoSolar has been selected to supply two PV power plant projects in South Africa with a total of around 115MW of modules. The projects form part of the South African Renewable Energy Independent Power Producers Procurement programme, phase 2. According to Jinko Solar's project description and data compiled by PV-Tech, the projects would seem to be those of German-based project developer, Scatec Solar and financed by investment fund, Norfund of Norway.

Source: GregTheBusker

JA Solar will provide modules for Siemens' installation in the Negev Desert.

Hanwha SolarOne sees massive shipment swing away from Germany to Japan

Chasing higher margin business in Japan, India and Thailand in the fourth quarter of 2012 resulted in Hanwha SolarOne's sales in Germany plummeting to only 8% of total sales, down from 39% in the third quarter. The company has become bullish on business prospects in 2013, guiding over 300MW of module shipments in the first quarter and guided full-year shipments to be between 1.3GW and 1.5GW, effectively at full capacity of over 400MW of production in the second-half of the year.

Business News Focus

Suntech's European arm stops paying creditors

Suntech Power Holdings' European subsidiary, Suntech Power International has gone to a court in its locality in Switzerland to stop bankruptcy proceedings. The subsidiary has been granted a provisional moratorium for two months on creditor claims for payment by the court in Schaffhausen, Switzerland. Furthermore, According to reports, Suntech Power Holdings' Dr. Shi, the ousted executive chairman and current CEO, David King have both been detained by Chinese police. Reports have also suggested that the police were investigating the company's financial accounts for possible irregularities.

JinkoSolar lands US$58 million from CDB for domestic PV development

Adding to its US$1 billion, five-year financing deal with JinkoSolar, China Development Bank has signed a US$58 million loan agreement with the module manufacturer to fund PV power plant projects in China. More recently, JinkoSolar secured US$128 million bond in China, said to be used for capital expenditure and working capital purposes.

Chinese banking commission adds PV sector to credit risk list

The China Banking Regulatory Commission has warned Chinese banks that the country's PV industry represents a credit risk, according to reports. The warning comes after Suntech Power Holdings' subsidiary, Suntech Wuxi, was forced into bankruptcy restructuring by eight Chinese bank lenders and prompted several of the company's suppliers to report bad debts and possible losses.

Solar lease companies face criticism over calculating energy savings

Solar companies marketing third party lease agreements have started to face increasing criticism over the way they calculate energy savings to customers in California. Earlier this year, a class action was brought against Sunrun, a California-based residential installer that operates in 10 states. The suit filed at a Los Angeles court on behalf of Shawn Reed, a Sunrun customer, demands a jury trial over its claims that Sunrun's marketing was deceptive and overstated the savings in future electricity costs.

Quarterly Results

Conergy optimistic about 2013

Unshackled from its polysilicon purchasing contract with MEMC and tight financial controls, Conergy expects a positive cash flow in 2013. However, the PV module manufacturer and project developer reported negative earnings before interest, taxes, depreciation and amortisation (EBITDA) of US$90 million, though down from negative EBITDA in 2011 of US$105 million. The company reported a 37% decline in sales to US$620 million in 2012, despite sales volume remaining relatively stable at 370MW, 6% down from 2011. The sales decline was due to price declines of 40%.

Source: Conergy

Conergy expects a positive cash flow in 2013.

SolarWorld delays financial reporting as it talks with creditors

Financial troubles at SolarWorld continue as the struggling PV module manufacturer delays reporting its full-year financial results as it talks with creditors over restructuring its debts. In a brief statement, SolarWorld said that its management was working on a restructuring deal with the helpd of Görg law firm and Houlihan Lokey investment bank.

aleo solar sees revenue fall as demand in key markets dwindles

German manufacturer aleo solar has recorded a 39% drop in revenue in its 2012 annual report published today. Final figures for the year confirm preliminary estimates of a fall in revenue from US$591.5 million last year to US$358.5 million. EBIT and taxes for 2012 closed at US$99 million, up from US$39 million in 2011. But the EBIT margin fell to -27.7% from -6.6% last year and earnings per share fell to negative US$8.3 from negative US$3.16.

Testing & Certification News Focus

SunPower modules take top three positions in international yield test

US-based module manufacturer SunPower has been ranked in the three top places in the PHOTON International 2012 module yield test. The company's SPR-327NE-WHT-D module came in first place with an annual yield of 1,144.1kWh per kW. The performance ratio estimates 95.2% according to a theoretical approach of 1,202 kWh per kW output. Chinese manufacturer Seraphim Solar System ranked fourth place with its SRP-220-6PB module, with a performance ratio of 93.6%.

UL certifies JA Solar modules for 1000 Vdc applications in North America

JA Solar's modules have received UL 1703 certification for use on 1000 Vdc systems in the United States and Canada from Underwriters Laboratories. The modules were tested in Intertek laboratories and also received ETL certification, according to JA Solar. According to the Solar Energy Industries Association the 1000 Vdc systems market in the US has an annual growth rate of 25%.

Alta Devices dual junction solar cell verified at 30.8% conversion efficiency

The US National Renewable Energy Laboratory has verified a new 'dual junction' thin film solar cell technology from Alta Devices with a conversion efficiency of 30.8%. Alta Devices said that its new dual junction technology used a second junction with Indium Gallium Phosphide as the absorber layer on top of the base single junction cell.

Trade Disputes Update

Mandatory registration for Chinese solar imports to Europe

The European Commission has initiated the registration of all solar products imported from China with immediate effect. Importers of solar modules, cells and solar wafers must from now on specify at customs whether the products were imported from China or were produced mainly in China. Importers may have to pay duties on these products if retroactive measures are imposed by the EC.

European solar industry divided over China tariffs

The European solar industry is split over whether the European Commission should impose trade duties on Chinese module manufacturers. According to a new survey of 532 European installers, 65% are in favour duties while 18% are against them. But a strongly worded letter sent to European trade commissioner Karel De Gucht, carrying 1,024 signatories from across the EU solar industry, said any duties

Source: SunPower

SunPower has been ranked in the three top places in the PHOTON International 2012 module yield test.

against Chinese manufacturers would have potentially severe consequences.

China calls for diplomacy in EU trade case

China is looking to diffuse tensions with Europe over the trade case launched against its manufacturers claimed to be dumping modules on the European market. A source from the Chinese Ministry of Commerce said to be close to the matter told media platform China.org.cn that the imposition of any duties resulting from the European Commission's ongoing trade investigation would be mutually harmful. In September last year, spokesman for the Chinese government Chong Quan, had expressed a desire for China and the EU to "resolve trade frictions through consultation".

However, in November China proceeded with its threatened retaliatory measures against the EU when it filed a complaint with the WTO claiming European Union member states "illegally" subsidised their manufacturers.

The commission will announce in early June whether to apply provisional anti-dumping duties on Chinese products and by early August on whether to impose preliminary countervailing levies. The duties would apply for five years. If tariffs are imposed, they can be collected 90 days retroactively, therefore from March 2013.

US investigates claims of Chinese module import duty 'evasion'

Importers of Chinese cells into the US may be evading anti-dumping (AD) and countervailing duties (CVD), according to the Coalition for American Solar Manufacturing. A US Department of Commerce analysis of US Customs and Border Protection (CBP) import data which indicates that "evasion of the AD and CVD orders on Chinese solar cells may be occurring". Commerce states that the data "suggests" that some importers may either be improperly declaring merchandise as not subject to the AD/CVD orders, or may be understating the value of the imported merchandise declared as subject to the relevant orders.

ReneSola to avoid EU tariffs by outsourcing solar module production

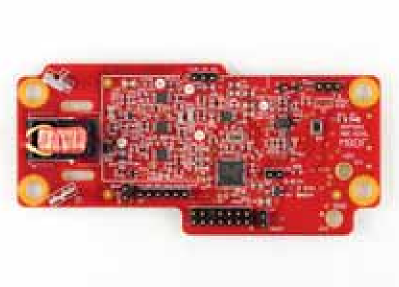
The threat of anti-dumping duties within the EU has prompted Chinese tier 1 module producer ReneSola to prepare to outsource over 400MW of module production to unidentified third parties not based in China. The company is the first Chinese module manufacturer to reveal its strategy to avoid duties, should the EU Commission decide in favour of punitive measures against dumping.

Source: ReneSola

ReneSola is preparing to outsource over 400MW of module production to unidentified third parties.

Product Reviews

Texas Instruments



Texas Instruments offers first reconfigurable DC arc detect reference solution

Product Outline: Texas Instruments has introduced the industry's first fully programmable DC arc detect reference solution. The RD-195 makes it faster and easier for designers to address a growing need to safeguard high-power DC systems against the catastrophic damage that can result from arc faults.

Problem: Electrical arc faults, predominantly due to faulty junction box components and/or design, have been known to cause PV module system fires.

Solution: Designers can programme the RD-195 to optimize the balance between arc-detection accuracy and false detection prevention to meet their system needs. The RD-195 is accompanied by a software application tool that enables alteration of threshold detection parameters. The RD-195 detects different types of arc, including series, parallel and ground arcs. It is designed to operate in noisy environments with RF interference. Additionally, all signal chain components in the solution operate across the full industrial temperature range of -40 degrees C to +85 degrees C.

Applications: PV modules arc detection and prevention.

Platform: The RD-195 reference solution features a software application tool that allows designers to fine-tune the system's arc detection threshold levels to increase its accuracy in detecting valid arcs and avoiding false detects. Also included are reference design CAD files. Technical support is available on the Precision Data Converters Forum in the TI E2ETM Community, where engineers can ask questions and get answers from TI experts.

Availability: March 2013 onwards.

KREMPEL

KREMPEL offers rear-side contacting backsheet material

Product Outline: Designed for solar modules with cells for rear-side contacting, the AKACON BCF PV backsheet is being offered by the KREMPEL Group and is ready for volume production. The backsheet comes with a copper layer and is structured according to customers' designs for back-contact cells.

Problem: The contacts are only located on the cell rear side. This means that space on the front is freed up so that cell output can be increased. Corresponding cell designs are available, as well as economically efficient process concepts and production lines. However, the new technology is still on the sensitive threshold between a promising concept and a marketable product.

Solution: The new AKACON BCF (back contacting foil) family of products has everything that is essential for rear-side contacting: highly conductive contact surfaces on the cell side and excellent electrical insulation on the outward facing side. At the same time, the new product is said to reliably perform all the other functions of a classical PV backsheet laminate, such as lasting protection against harmful environmental influences.

Applications: PV backsheet material specifically designed for copper-based back-contact solar cell module lamination.

Platform: AKACON BCF offers outstanding flatness and high dimensional stability; the thermal shrinkage is less than 0.1%.

Availability: March 2013 onwards.

KÖMMERLING

KÖMMERLING's 'HelioSeal' PVS 120 provides superior water and moisture vapour tightness frame sealing

Product Outline: KÖMMERLING has launched its new butyl-based framing sealant 'HelioSeal' PVS 120. By contrast to existing framing sealants on the market, HelioSeal PVS 120 is claimed to provide immediate green strength and superior water and moisture vapour tightness, and can be used by hand or in fully automated high-speed production lines.

Problem: Crystalline PV module makers, as well as those in the thin-film industry, know that water tightness alone is not enough for the protection of PV modules. It is also necessary to ensure the moisture vapour tightness of the whole system, especially in the framing area, as a parameter for durability. The PV industry is looking for sealing systems that can be easily used in the production process (e.g. one component, no mixing, fast curing, less waste).

Solution: HelioSeal PVS 120 is a butyl rubber-based hot melt framing sealant which is delivered ready to use. Easy handling means simple processing by using pail or drum melting equipment and minimal waste. Along with a high level of green strength, superior water and moisture vapour tightness (< 0.2g/m^2·day) is another main feature. Primerless adhesion to glass, aluminium, and galvanized and stainless steel are other valuable features.

Application: Long-life sealant for ultra-secure framing of thin-film and crystalline PV modules

Platform: HelioSeal PVS 120 can be supplied for automated application equipment from 20-litre pails to 200-litre drums for easy integration in production lines. HelioSeal PVS products are used for sealing both inner and outer components of modules with ease and the confidence of long-term durability with high resistance to ageing and stresses.

Availability: Currently available.

Fraunhofer PV Durability Initiative for solar modules

David H. Meakin, **Cordula Schmid** & **Geoffrey S. Kinsey**, Fraunhofer Center for Sustainable Energy Systems CSE, Boston, Massachusetts, USA
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ABSTRACT
The potential for PV modules to fail before the end of their intended service life increases the perceived risk, and therefore the cost, of funding PV installations. While current IEC and UL certification testing standards for PV modules have helped to reduce the risk of early field (infant mortality) failures, they are a necessary, but not sufficient, part of determining PV module service life. The goal of the PV Durability Initiative is to establish a baseline PV durability assessment programme. PV modules are rated according to their likelihood of performing reliably over their expected service life. Modules are subjected to accelerated stress testing intended to reach the wear-out regime for a given set of environmental conditions. In parallel with the accelerated tests, modules are subjected to long-term outdoor exposure; the correlation between the accelerated tests and actual operation in the field is an ultimate goal of the programme. As understanding of PV module durability grows, the test protocols will be revised as necessary. The regular publication of durability ratings for leading PV modules will enable PV system developers and financiers to make informed deployment decisions.

Introduction

Current IEC and UL certification testing is done on a pass/fail basis; assessment of the relative reliability risk and the guidance provided to manufacturers for improvement are therefore limited [1–4]. The tests also lack standard protocols for comparing the relative durability risk between different module designs. Without these benchmarks, financial models must instead depend on a patchwork of methods to create predictions for relative durability. This makes it difficult to quantify which solar modules are best suited to a particular installation. The uncertainty creates confusion that increases perceived risk, delays financing and ultimately raises the cost of building PV power plants.

First announced in 2011, the PV Durability Initiative is a joint venture between the Fraunhofer Center for Sustainable Energy Systems CSE and the Fraunhofer Institute for Solar Energy Systems ISE. The aim is to create an open-source durability assessment protocol that will eventually form the basis for an international industry standard.

> “The aim is to create an open-source durability assessment protocol that will eventually form the basis for an international industry standard.”

The accelerated test component is an extension of familiar reliability stress tests [5–8]. Since the acceleration factors of most stress tests are not yet known, the protocol combines accelerated testing with long-term outdoor exposure testing (Fig. 1). Until the acceleration factors for various stress tests are identified, the relative comparison of modules remains the best means of assessing (relative) module service life. To enable a comparison of different module technologies to be made, performance is converted to a rating on a scale of zero to five. The modules are rated for both performance and safety. Modules in group 1 (potential-induced degradation) are rated based on their performance at the end of the test, following light exposure. Modules in the remaining groups are rated based on their ‘normalized cumulative performance’, which is the mean of their performance at each test interval, weighted by the final performance value and normalized by the initial value. Weighting by the final performance value is intended to give a higher rating to modules that show the least degradation from the tests with combined stress effects. In the years ahead, outdoor measurements of the modules under test will be used to allocate the proper acceleration factors for the accelerated test sequences.

The programme requires that, where possible, commercial modules be purchased on the open market, to avoid selection bias. If the module design is not available on the open market, the module ID is annotated to indicate how the modules were acquired.

The manufacturers of modules tested in the programme have the option of withholding their identity from reports. However, the data generated remains (an anonymous) part of the dataset, for continuous comparison with the rest of the field. As the Durability Initiative continues, a background of previous results will be available to compare with the recent additions. Testing in accordance with this protocol has so far been completed on five commercial module types, with a second test group currently in progress. The first five module designs tested five of the top eight, by volume, single-crystal silicon module manufacturers in 2012. The module design identified below as ‘PVDI01[a]’ is the SunPower E20 module, manufactured by SunPower, Inc. (The superscript 'a' highlights a nonstandard characteristic: the modules were selected by Fraunhofer CSE from a list of available modules at a wholesaler).

Test sequences and results

The test protocol is broken down into five test groups (Fig. 1). A minimum of sixteen modules is currently required to complete the tests. Modules are initially characterized, then assigned to a particular test sequence. The modules assigned to the control set are stored in a temperature-controlled environment and are used to confirm the consistency of the power measurements. As each module progresses through its assigned test sequence, it is repeatedly characterized: in group 4, for example, each module is characterized after every set of two hundred thermal cycles. At each interim test point, electrical performance is determined and electroluminescence (EL) and infrared (IR) images are collected. In some instances, wet leakage current and insulation resistance are also measured.

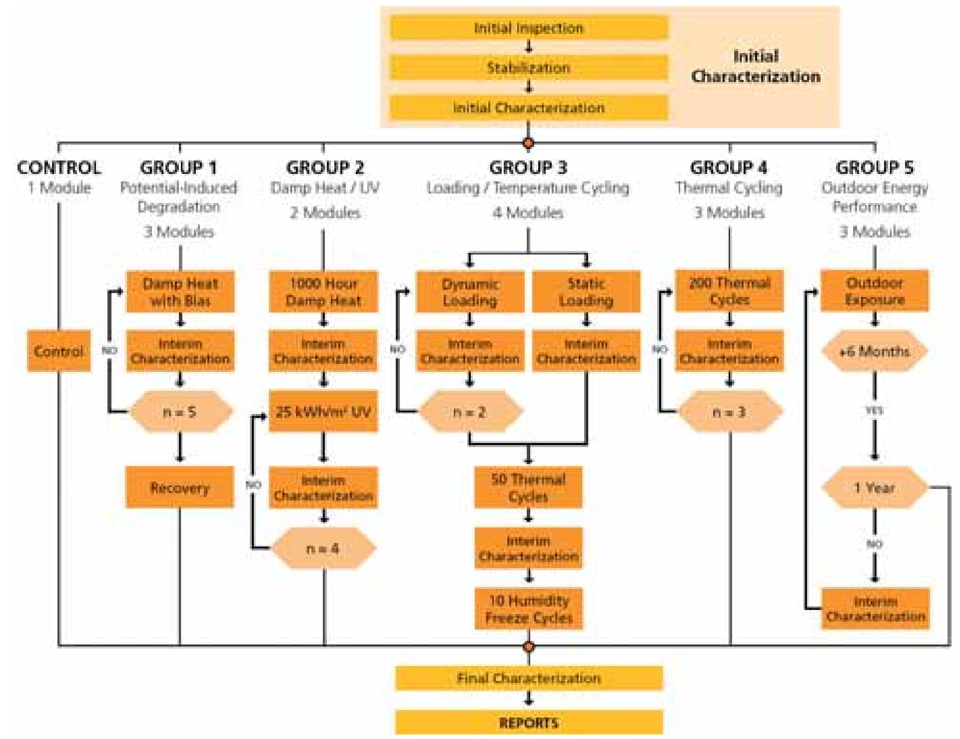

Figure 1. The PVDI test sequences.

Initial characterization and stabilization

Commercial modules purchased on the open market arrive at the test facility in their standard shipping container, having undergone typical shipping stresses. The modules are unpacked and visually inspected for any manufacturing defects or for damage suffered during shipping.

Following a visual inspection, the modules are light soaked to allow for any light-induced degradation to occur. Light soaking requires a minimum of 60kWh/m^2, and may take upwards of 600kWh/m^2 to complete. The time required to complete this pre-conditioning is technology dependent; thin-film technologies generally take longer to stabilize than crystalline or polycrystalline silicon technologies. During light soaking, the modules are maintained at their maximum power point, and current–voltage (IV) curves are collected periodically. Light soaking is completed once the modules have reached a stable performance level. Stability is determined by taking measurements from three consecutive periods to check if they satisfy the condition $(P_{max} - P_{min})/P_{mean} < 2\%$.

After stability has been achieved, the initial characterization is performed: measurement of light current–voltage (LIV) at standard test conditions (STC); EL imaging; IR imaging; and measurement of wet leakage current and insulation resistance.

The initial performance data is used throughout the test sequence to normalize successive performance measurements. It is also used in the comparative analysis of the nameplate performance ratings.

Group 1: potential-induced degradation

The group 1 test sequence is designed to assess a module's ability to perform under the stress of high electrical potential. The class of degradation mechanisms caused by a high potential between internal and external components is collectively referred to as potential-induced degradation (PID) [9]. Since PV modules may be installed where the electrical potential between the module and the earth ground can be positive or negative, they are tested at both positive and negative electrical biases. The magnitude of the electrical bias during testing is set to the module's rated maximum system voltage.

The test begins by mounting the module in a vertical orientation (to reduce condensation accumulation) in a heat and humidity chamber. The electrical leads of the module are shorted together and connected to the biasing power supply. The opposite polarity of the power supply is connected through a sensing resistor to the frame of the module or to other conductive mounting points. Since the most common PID mechanisms occur under negative bias, the current procedure requires that two modules be negatively biased and one positively biased. Each module is exposed for a total of 400 hours under bias at 85°C and 65% relative humidity. Interim measurements of a module's performance are taken at 50, 100, 200, 300 and 400 hours, and after recovery. Recovery is done by exposing the module outdoors or to artificial light while keeping the module at its maximum power point for no more than 25kWh/m^2.

In order to represent operating conditions, a light bias (illumination) should also be applied during voltage biasing. Since the configuration of most heat and humidity chambers precludes this, modules are currently exposed to light soaking only after heat and humidity exposure, to assess for recoverability of performance.

Depending on the module design and the failure mechanism involved, some module designs will recover their power performance when the high electrical bias is removed or reversed. Other modules have exhibited resistance to, and recovery from, PID when operated near their maximum power point under light exposure [1] or by raising the cell temperature to the normal operating cell temperature. For such modules, PID is not expected to have an impact in operation.

The results of the PID testing are summarized in Fig. 2. Module design PVDI01[a] exhibited degradation under positive bias but recovered after exposure to light when operated at the module's maximum power point. One of the two PVDI02 modules exhibited degradation under negative bias and did not recover. Both PVDI03 modules degraded under negative bias and did not recover.

Module designs PVDI02 and PVDI03 appear to have the greatest risk of PID degradation. PVDI04 and PVDI05 have a low probability of exhibiting PID failures in the field. Under positive bias, PVDI01[a] showed power degradation, followed by recovery after light soaking. Since bias without illumination is unlikely for

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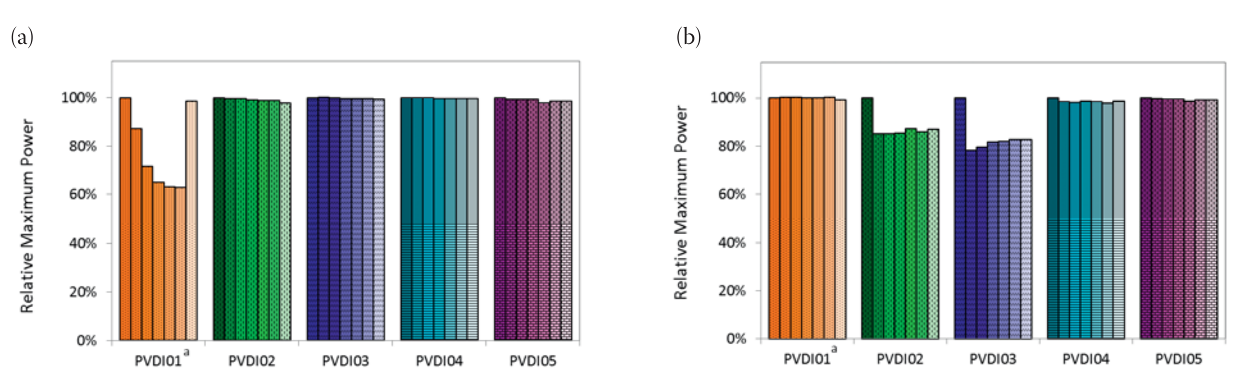

Figure 2. PID tests under (a) positive bias and (b) negative bias. To determine the PID rating, the final performance value after light soaking is used.

modules in operation, this illustrates the need for 'combined effects' testing that better mimics field operating conditions. PVDI01[a] has a low probability of exhibiting PID degradation under field operating conditions.

Group 2: damp heat and UV light

The group 2 test sequence is designed to assess a module's susceptibility to high-moisture conditions, elevated temperatures and high levels of UV radiation. The damp heat and UV assessments were combined into a single test sequence to provide a means of evaluating the effects of UV on modules in damp environments. UV degradation is usually accelerated at higher temperatures. UV exposure can then lead to weakened adhesion of encapsulants, for example, which in a damp environment can lead to corrosion.

The test begins by mounting the module in a vertical orientation in a heat and humidity chamber. Each module receives a small bias current to monitor the continuity through the module during the test. Following heat and humidity exposure, the modules are placed in a UV chamber, where they are subjected to high-intensity UV light for a total dose of 100kWh/m^2. The exposure is carried out in four steps, with characterization and re-saturation of the modules between iterations. The modules are re-saturated by exposing them to damp heat for forty-eight hours, to counter the drying effects of the UV exposure.

The current damp heat UV test sequence did not demonstrate significant degradation among any of the modules tested (Fig. 3). The wear-out regime for these conditions had therefore not yet been reached. This test may be revised in the future in order for the wear-out regime for UV exposure to be reached.

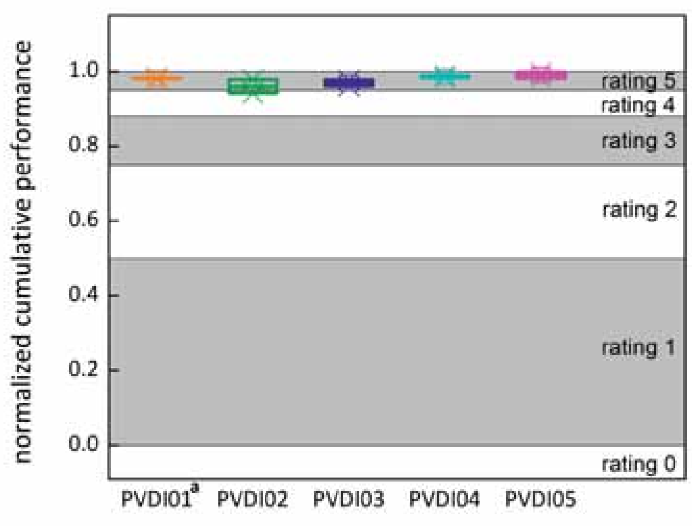

Figure 3. Cumulative performance following damp heat and UV exposure. The box indicates the interquartile range. The whiskers are determined by the 5th and 95th percentiles. The median is shown as a horizontal line within the box, the mean is indicated by a square, and the 1st and 99th percentiles are displayed as x symbols.

Group 3: static and dynamic loading, thermal cycling and humidity freeze

The group 3 test sequence is designed to assess the effect of both static and dynamic loading on a module's performance and package integrity.

The dynamic load portion of the test is designed to assess the effects of intermittent loads, such as wind loads. This test is carried out at a low temperature, at which the effects are expected to be most severe. The modulus of many encapsulants will increase dramatically as the module temperature approaches the encapsulant's glass transition temperature. This stiffening of the encapsulant results in greater stress transmission to the cell and interconnects, which may lead to, for example, cell cracking and interconnect failure.

The dynamic loading, to a maximum force of 2.6kPa, is applied normal to the surface, in both positive and negative directions with respect to the plane of the module at rest. This is performed twice, with an interim characterization to record any change in performance and to inspect for the appearance of cell cracks and damaged interconnects.

A module's ability to withstand static mechanical loads for prolonged periods is significant primarily for regions where snow loads are present. The test is performed at a temperature of –40°C in order to increase the stress in and between materials [10,11]. For the static test, the module is loaded in a downward direction (opposite the normal of the sunward module surface) under a force of 5.6kPa for three one-hour periods, with a rest period between these loading periods.

> "A module's ability to withstand static mechanical loads for prolonged periods is significant primarily for regions where snow loads are present."

Following load testing, the modules are subjected to thermal cycling and humidity freeze stresses; this is done to amplify crack propagation initiated during the load tests (Figs. 4 and 5).


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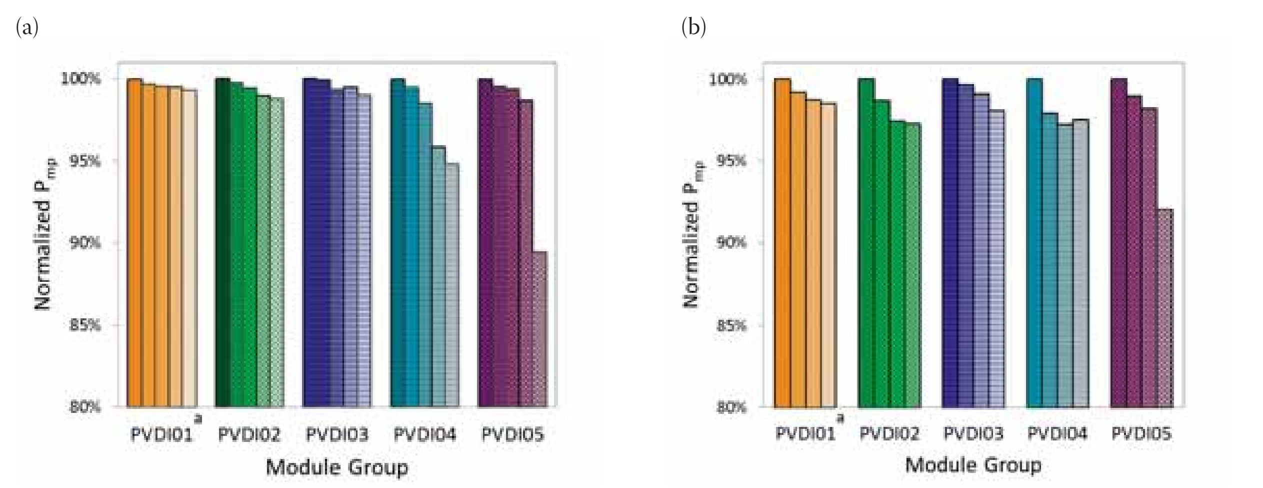

Figure 4. Mean degradation of two modules at the various test intervals of (a) dynamic and (b) static mechanical loading. The specific intervals are: initial, after loading, after 50 temperature cycles and after 10 humidity–freeze cycles.

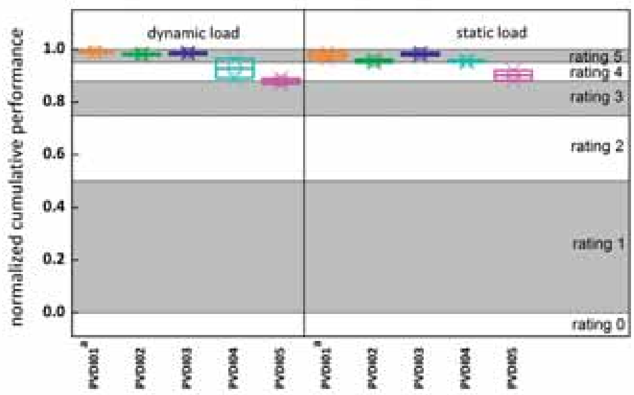

Figure 5. Cumulative performance under dynamic and static loading.

Group 4: thermal cycling

The group 4 test sequence assesses a module's ability to withstand the effects of shade-induced, diurnal and seasonal temperature changes. Under normal operating conditions, a module will be subjected to daily temperature excursions as well as more rapid temperature changes due to transient cloud cover. When temperature transients occur, stresses can be induced inside the modules as a result of the different thermal expansion characteristics of the various materials [12].

The modules are biased with a current equivalent to their short-circuit current I_{sc} to simulate the heating effects due to current flow under normal operating conditions. The chamber is cycled between –40°C and +85°C at a constant rate, with a dwell of 10 minutes at each temperature extreme. Each module undergoes a total of 600 cycles; characterizations are performed after every 200 cycles.

The results of the thermal cycling are shown in Fig. 6. It is interesting to note that modules from PVDI03 and PVDI04 exhibited more degradation than they did during dynamic and static mechanical loading.

Group 5: outdoor energy performance

The group 5 test sequence is designed to assess a module's performance under real-world (non-accelerated) operating conditions. Three modules of each

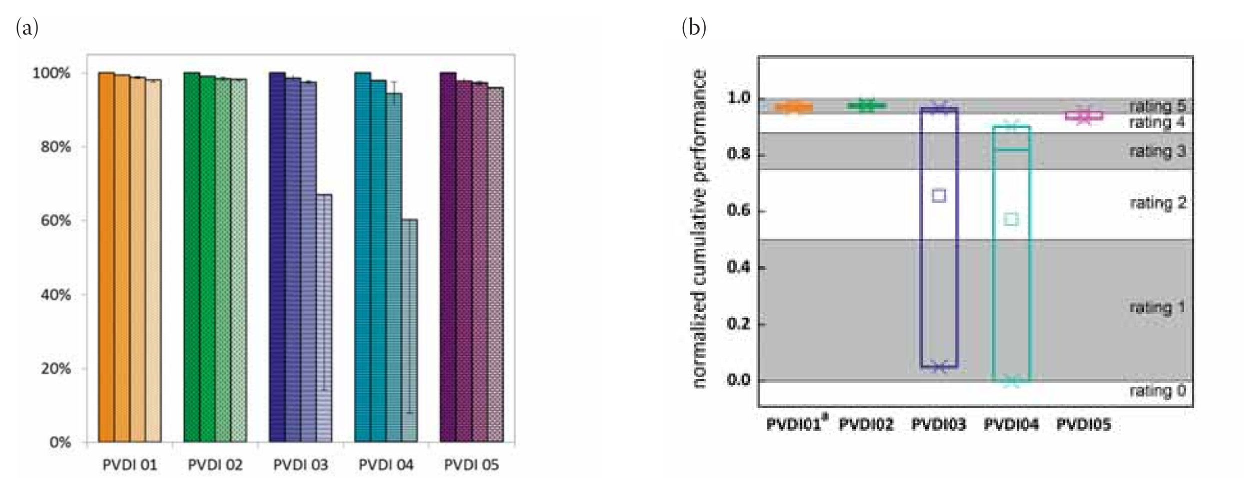

Figure 6. Performance degradation in thermal cycling: (a) results at each interval of 200 cycles; (b) normalized cumulative performance.

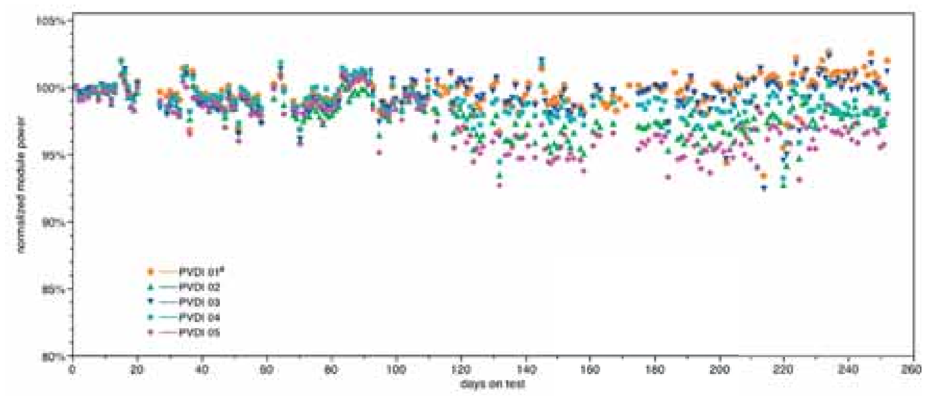

Figure 7. Outdoor performance to date.

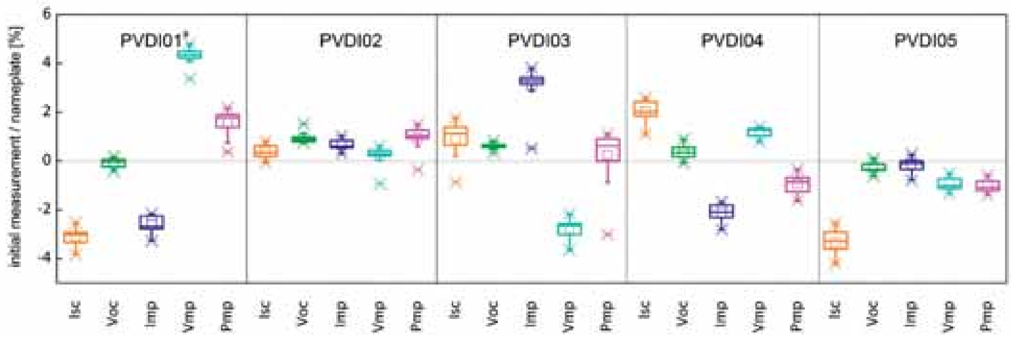

Figure 8. Baseline performance parameters with respect to nameplate rating.

type are installed on an outdoor test station and continuously monitored for long-term degradation effects. One module is instrumented with a power supply that maintains the module at its maximum power point and sweeps IV curves at preset intervals; this data is used to calculate the performance ratio of the module. The other two modules are maintained at a fixed load near the maximum power point.

All three modules are removed from the test rack at six-month intervals, visually inspected and tested at STC, then returned to the outdoors. Modules will be monitored on an ongoing basis for several years. The outdoor data will be compared with the accelerated test data, as well as with outdoor data from analogous module designs at other outdoor sites around the world. The ultimate goals are to understand long-term wear-out, identify new failure modes and determine the acceleration factors that are necessary to correlate the accelerated test results to outdoor operating lifetime (Fig. 7).

Nameplate rating comparison

Fig. 8 illustrates initial module (STC) performance relative to the nameplate rating. Manufacturers may intentionally rate their modules below their expected initial performance in order to provide a performance buffer and reduce the risk of warranty claims. The results shown in Fig. 9 indicate that each of the module designs are within the manufacturers' specified power tolerance limits.

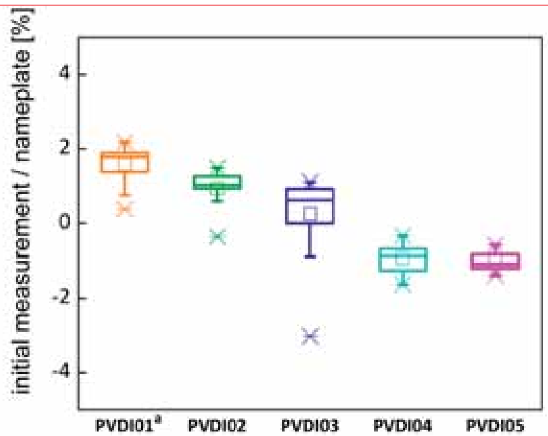

Figure 9. Ratio of initial measured P_{max} to nameplate rated P_{max}.

Module ratings: performance and safety

Modules are rated for both performance and safety. The module design's performance (Tables 1 and 2) is based on the measured electrical maximum power at STC. The safety rating is based on module package integrity (Table 3). Wet leakage resistance and dry insulation resistance measurements are used for the safety rating (Tables 4 and 5).

Rating	Performance (P)
5	P > 0.95
4	0.88 < P < 0.95
3	0.75 < P < 0.88
2	0.5 < P < 0.75
1	P < 0.5
0	0

Table 1. Module performance rating ranges.

ID	Environmental conditions				
	PID	Damp heat/UV	Dynamic load	Static load	Thermal cycling
PVDI01[a]	5	5	5	5	5
PVDI02	4	5	5	5	5
PVDI03	4	5	5	5	2
PVDI04	5	5	4	5	2
PVDI05	5	5	3	4	4

Table 2. Performance ratings.

Module rating	Rating criteria
5	$R \geq 400M\Omega$ and $\Delta R \leq 1.0\%$
4	$80M\Omega \leq R < 400M\Omega$ or $R \geq 400M\Omega$ and $\Delta R > 1.0\%$
3	$40M\Omega \leq R < 80M\Omega$
2	$400k\Omega \leq R < 40M\Omega$
1	$200k\Omega \leq R < 400k\Omega$
0	$R < 200k\Omega$

Table 3. Module safety (package integrity) rating.

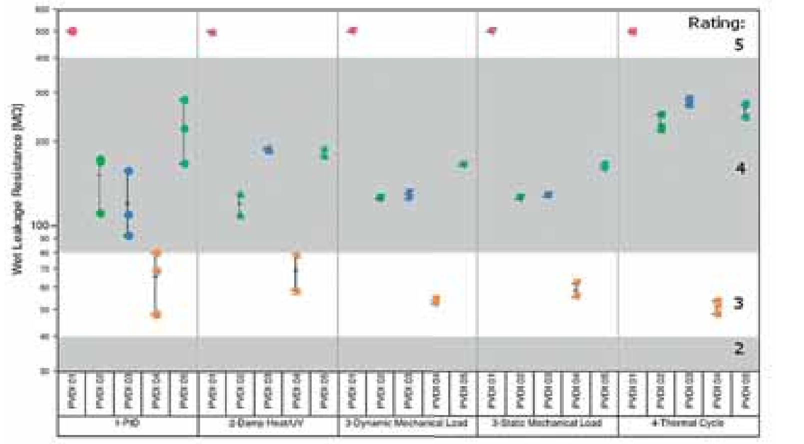

Figure 10. Wet leakage resistance results for all modules by project and test group.

"Modules are rated for both performance and safety."

Module performance ratings

The rating categories are:

- **PID:** This category indicates a module's ability to survive in an environment where there are large potentials (600–1000V DC) between the active circuit of the module and ground.
- **Damp heat/UV:** This category indicates a module's ability to perform as specified in environments where humidity is expected to be a significant environmental condition.
- **Static and dynamic loads:** The static load category indicates a module's ability to perform in an environment where it will be regularly subjected to static mechanical loads, such as heavy leaves, snow or ice. The dynamic load category indicates a module's ability to perform as specified in environments where it will be subjected to changing mechanical loads, such as wind.
- **Thermal cycling:** This category indicates a module's ability to perform as specified in environments where there are temperature extremes and an expectation that the temperature will vary widely diurnally and annually.

Module safety rating: package integrity

The integrity of the package determines the safety of the module with respect to shock and fire hazards. Package integrity is determined by a combination of the wet leakage and dry insulation resistances measured at the conclusion of a test sequence. This resistance is dependent on the voltage applied, the area of the module and the resistance of the module's insulating materials. Measurements are normalized for area and then binned according to the IEC leakage resistance limits [13] and an equivalent resistance for ground fault circuit interrupters per UL 943 [14]. The equivalent resistance at 5.0mA is 200kΩ for a system voltage of $1kV_{DC}$. This method ensures that no module receives a rating above zero if it has a leakage current greater than 5.0mA. Table 3 summarizes the package integrity rating criteria. Resistance values are given for the normalized leakage resistance density R, and ΔR is the change in the resistance relative to the initial measurement.

Appendix: Characterization techniques

Visual inspection

Visual inspection has two purposes: first, to detect defects caused by the manufacturing process and shipping; and second, to detect physical changes in the module after it has

ID	Wet leakage resistance [MΩ]			Dry insulation resistance [MΩ]		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
PVDI01[a]	>500	>500	>500	>500	>500	>500
PVDI02	110	250	158	314	>500	>500
PVDI03	92	286	174	>500	>500	>500
PVDI04	48	80	59	205	>500	>500
PVDI05	159	283	207	428	>500	>500

Table 4. Wet leakage resistance and dry insulation resistance measurements for the project modules, across all test groups.

ID	Environmental conditions				
	PID	Damp heat/UV	Dynamic load	Static load	Thermal cycling
PVDI01[a]	5	5	5	5	5
PVDI02	4	4	4	4	4
PVDI03	4	4	4	4	4
PVDI04	3	3	3	3	3
PVDI05	4	4	4	4	4

Table 5. Ratings of module safety based on wet leakage resistance measurements. All modules received a rating of 5 for dry insulation resistance.

(a) (b) (c)

Figure 11. Defects observed on incoming modules: (a) backsheet scratch; (b) foreign particle; (c) metal particle.

been exposed to stress. In the case of visual defects (e.g. debris incorporated during manufacturing, as seen in Figs. 11(b) and (c)), while some may not affect the performance of a module, others may either have a direct impact on performance or signal larger lapses in manufacturing quality assurance. The scratch in the backsheet shown in Fig. 11(a) and the delamination shown in Fig. 12 are likely indicators of reductions in safety and/or performance. There is a possibility that the scratch shown in Fig. 11(a) will cause the module to exhibit lower wet leakage resistance. This scratch may lead to eventual breakdown in the backsheet, since it has exposed the underlying insulating layer. This layer is now more susceptible to UV degradation and may become embrittled and fail. The delamination in Fig. 12 will cause the underlying cell to underperform owing to loss of transmitted light. It is also possible that temperature/humidity cycles over time will cause the defect to grow.

> "Dark IV measurements are used to investigate subtle changes in the series resistance and shunt resistance of the module."

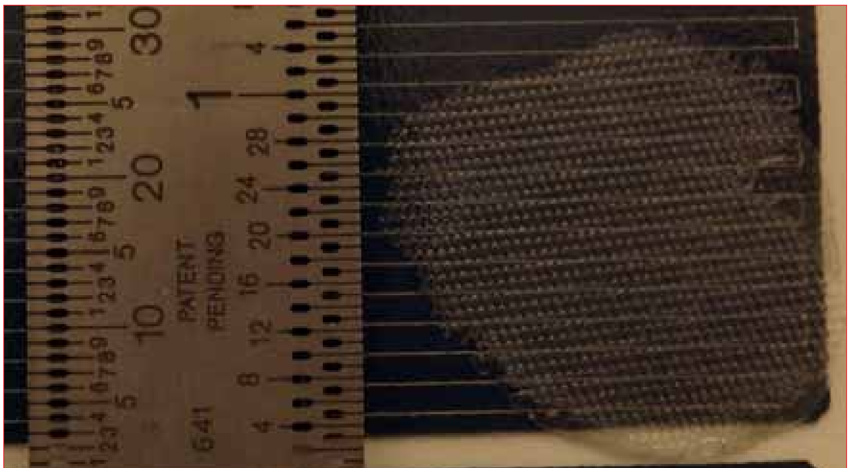

Figure 12. Delamination observed after damp heat exposure.

The observations made during visual inspection are used to determine why one module may be responding to stress differently from others of the same type. Defects are also tracked for progression or growth as a function of continuous stress over time.

Light and dark IV performance

LIV measurements are made under both STC and operating conditions. For operating-condition measurements, the global irradiance, module temperature and wind speed are recorded at the time of the measurement.

Dark IV measurements are used to understand the changes that are taking place inside the module as a function of the stresses applied to the modules. The measurements are used to investigate subtle changes in the series resistance and shunt resistance of the module; these resistances are extracted from the characterization curve (Fig. 13).

Series resistance is the slope of the curve as it approaches the open-circuit voltage (V_{oc}). An increase in series resistance can be an indication that the resistivity of conductive pathways within the module is increasing. This can be caused by loss of contact, corrosion, oxidation, or delamination of the cell metallization.

Shunt resistance is the slope of the curve as it approaches the short-circuit current (I_{sc}). A decrease in shunt resistance can indicate that there are leakage pathways

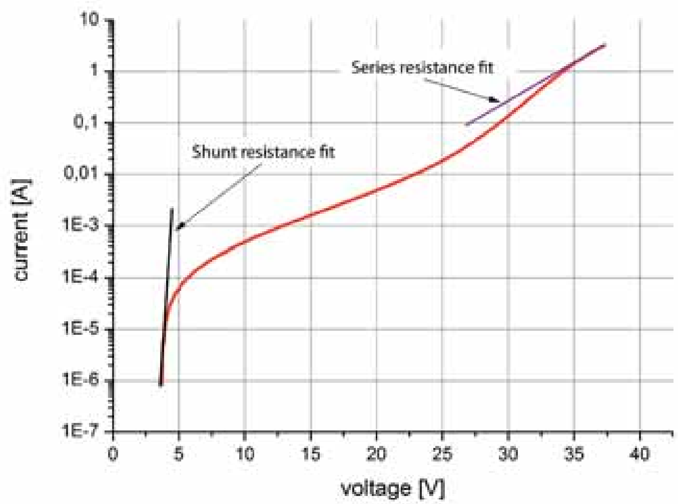

Figure 13. Typical dark IV trace.

PV Modules

developing between the module layers or within the cells themselves (caused by cracks or a breakdown in the cell junction).

Changes in various key parameters following stress can indicate the type of effect the stress has had on the module. For instance, a decrease in I_{sc} can indicate that the module is not receiving as much light as it was before the stress. This can be caused by delamination (leading to light scattering), or by discoloration of the encapsulation (leading to an increase in absorption before the light reaches the cell).

Wet leakage resistance

The wet leakage resistance test interrogates the insulation of the module under wet operating conditions, such as moisture from condensed humidity, rain, fog or melted snow. If moisture enters the module, it can cause corrosion and/or a ground fault, leading to both performance degradation and safety hazards. The test detects defects in packaging integrity that would allow electrical power to pass from the internal, active circuit of the modules to the outside surfaces.

The wet leakage resistance test is performed by shorting the module leads together and placing it in a bath of water, with surfactant added to increase the water's conductivity. The measurement is made by applying to the leads a voltage equivalent to the module's rated system voltage, and measuring the current flowing out of the module and into the water bath.

The resistance is calculated to account for the difference in size of different modules: if leakage is distributed across the module area, the leakage current will scale with module area. IEC module qualification standards IEC 61215 and IEC 61246 require that a module have greater than 40MΩ•m^2 resistance to pass qualification. Normalized for a 1m^2 module area, the threshold is therefore 40MΩ; this is equivalent to currents of 15μA and 25μA at system voltages of 600V DC and 1000V DC, respectively.

Dry insulation resistance

The dry insulation resistance test measures the quality of the insulating materials that isolate the electrically active components of the module from the exterior surfaces. It is similar to wet leakage resistance testing, except that the module is tested dry and the voltage applied (6000V) is higher than most rated system voltages.

Electroluminescence imaging

EL imaging is a non-destructive test which is used for spatially resolved characterization of silicon solar cells. This imaging method can be used to detect and characterize defects in solar cells (including cracks), ribbon defects and electrical degradation of cells (Fig. 14).

Infrared imaging

IR imaging is used to characterize defects that are recognizable by their heat signature when injected with an electrical current. These defects are typically hot spots, non-uniform current distributions within a cell, or open-circuit conditions. IR imaging was performed on each module after the application of a forward bias current equivalent to I_{sc}. The baseline images were used to differentiate between pre-existing thermally related phenomena and those that manifested during stress testing (Fig. 15).

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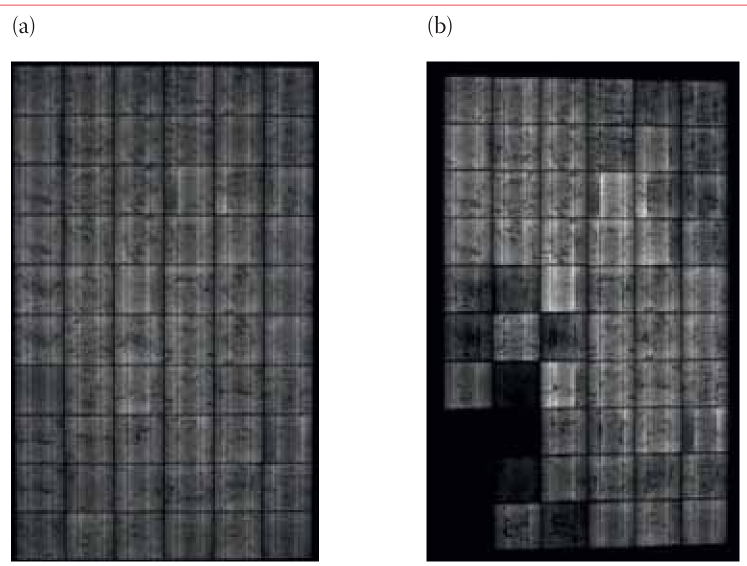

Figure 14. EL image of a module (a) before and (b) after PID stress testing.

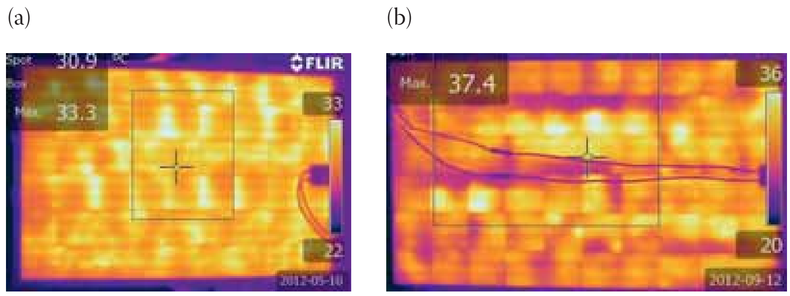

Figure 15. IR image from (a) initial characterization and (b) after 600 hours of thermal cycling.

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Power Generation

First Solar takes global EPC top spot

US giant First Solar became the world's largest engineering, procurement and construction contractor (EPC) last year, according to a report from IHS Research. The study also revealed a shift in the global EPC rankings, with US and Asian companies supplanting their previously dominant European counterparts at the top of the table. Fellow US EPC SunEdison came second on the 2012 list, up from fourth place in 2011. Four Chinese companies also made the top ten. Indian company Larsen & Tourbo also performed strongly, rising from 15th place in the 2011 rankings to 11th last year with around 200MW of projects developed.

IHS Research dubbed First Solar 2012's largest EPC.

Business News Focus

Solarcentury launches international expansion with senior appointments

British PV company Solarcentury has announced a series of international appointments as part of its plan to expand into new markets. Amongst others, Solarcentury named Bertrand Belben as the company's new director of international business development. He will lead Solarcentury's programme for international expansion, with particular responsibility in the emerging markets including Africa and Latin America.

Solarcentury has announced a series of international appointments as part of its plan to expand into new markets.

juwi eyes international expansion

German renewable energy firm juwi Group is eyeing up international business opportunities and is expecting around 50% of its business to be generated outside of Germany by 2015. In a recent report by IHS Research on the top engineering, procurement and construction contractors in 2012, juwi was ranked fifth, one place up from 2011.

Borrego Solar plans Puerto Rican expansion

Borrego Solar Systems, a developer and installer of grid-connected PV systems, is planning to install 23.5MW of PV capacity in the next couple of years in the Puerto Rican solar market. The company will develop its first utility-scale projects on the island with a 2.3MW, 1.2MW and 20MW project in the pipeline. The two smaller projects will be constructed in the first year while the construction of the 20MW project is slated to begin in 2014.

Draker boosts overseas expansion with first Japan project

Monitoring and solar system company Draker has completed the installation of its first panel-to-grid monitoring solution in Japan. The 705kW Ami Solar Park has been implemented with Draker's monitoring solution which combines AC and Clarity DC systems.

EAM Solar eyes Italian PV market following successful IPO

Utility firm EAM Solar is eyeing up the Italian PV market following the successful completion of its initial public offering (IPO) at the beginning of April on the Oslo Stock Exchange. The company has announced it will initially focus on acquiring large-scale projects in Italy, while France and the UK will represent secondary markets.

Foxconn plans solar portfolio in Asia, Europe and America

Taiwan-based electronics manufacturer Foxconn has announced a portfolio of solar projects in China, America, Europe and China. According to the Chinese Ministry of Commerce, Foxconn is to commence construction of a solar R&D centre, five PV component factories and 20 PV power plants in Guangxi Province, in southern China.

Finance News Focus

Mosaic gets go-ahead for US$100 million Californian solar investments

California-based solar crowd funder Mosaic has received approval from regulators to offer US$100 million worth of solar investments to California residents. To date, Mosaic has raised over US$1.1 million from more than 1,000 investors to finance twelve rooftop solar power plants in California, Arizona and New Jersey.

JinkoSolar lands US$58 million from CDB for domestic PV development

Adding to its US$1 billion, five-year financing deal with JinkoSolar, China Development Bank (CDB) has signed a US$58 million loan agreement with the module manufacturer to fund PV power plant projects in China. The previously placed US$1 billion financing deal with CDB was said at the time to support JinkoSolar in expanding busines overseas including PV project development and EPC activities as well as support potential merger and acquisition strategies. The collapse into bankruptcy of Suntech Wuxi, the main operating arm of Suntech Power Holdings has sent shockwaves through Chinese banking and led to tighter credit risk assessments across the PV supply chain in China.

S.A.G. Solarstrom receives €40 million from Deutsche Bank

Germany's S.A.G. Solarstrom has received a solar financing commitment for €40 million (US$52 million) from Deutsche Bank. Solarstrom said the financing would be put to use for various solar projects to be implemented in 2013 and 2014 in Germany.

IDB provides US$41 million loan for three Chilean PV plants

The Inter-American Development Bank (IDB) has approved a loan package worth US$41.4 million to fund the development of three PV plants in the Atacama Desert in northern Chile. The loan — which consists of US$20.7 million from IDB's ordinary capital and US$20.7 million from the Canadian Climate Fund — will be used to build, operate and maintain the Pozo Almonte and Calama PV project. The estimated total cost of the project is US$82.7 million.

Bill Gates gives boost to renewables storage

Bill Gates has given financial backing to the development of a new energy storage system aimed at cutting the intermittency of renewable energy technologies such as solar. The billionaire Microsoft founder has been named as one of a number of backers who are collectively investing US$35 million in Aquion energy, a Pittsburgh-based clean-tech firm that is developing a new water-based battery system.

Source: World Economic Forum

Bill Gates is backing the development of new energy storage systems.

The financing round led by Bright Capital has secured Gates and Gentry Venture Partners as new investors and return investments from Kleiner Perkins Caufield & Byers, Foundation Capital and Advanced Technology Ventures.

NADB finances 5MW solar project at San Diego University

NRG Solar has secured a US$19.2 million loan from North American Development Bank (NADB) to fund the development of a 5MW PV system at a university in San Diego. As part of the development plans, the San Diego State University (SDSU) Imperial Valley Campus located in Brawley, California, will become home to the 5MW system which will cover approximately 16 hectares of the campus. The system will be equipped with polycrystalline modules supplied by Trina Solar mounted on ViaSol single-axis trackers.

Source: Andrew Gordon

San Diego State University will become home to a 5MW solar system.

CFN provides US$2 million to finance 1MW PV plant in Eucador

Corporación Financiera Nacional de la República del Ecuador (CFN), a financial company owned by the government of Ecuador, has released its first "trade credit" for a renewable energy project. The state-owned company has provided US$2 million to local PV developer Empresa Energía Planta Fotovoltáica to fund a 1MW PV plant which is currently under construction in the municipality of Mulaló, Ecuador.

NewWorld Capital finances Soltage solar portfolio

NewWorld Environmental Infrastructure is to invest in an 11.6MW portfolio of solar projects of projects in Connecticut and Massachusetts developed by Soltage. The portfolio consists of six PV projects, the construction of which will begin later this month. The company has formed a partnership on the investment with CleanTech Alliance Fund, a subsidiary of North Sky Capital of Minneapolis, in Minnesota. Under this co-partnership both companies will provide financial support to the project.

Contracts News Focus

SunEdison, Thermax and Azure Power join forces for 5.5 MW Indian rooftop PV project

India's state-owned Solar Energy Corp has selected California's SunEdison, India-based Thermax and Azure Power India to construct 5.5MW of rooftop PV systems in Bangalore, Chennai, Delhi and Gurgaon in India. According to reports the project constitutes part of a 10MW rooftop PV project. The companies were selected as part of a competitive tender for this bigger initiative. The systems will be installed on rented rooftops, with the generated electricity feeding directly into the grid.

World Bank brings solar energy to residents' homes in Kiribati

The World Bank has signed an agreement with the government of Kiribati to deliver solar energy to the residents of the Pacific island nation. The Australian government and the Global Environment Facility will jointly finance this project. In total the project will receive US$4.3 million from both sides. Development body AusAID Australia will offer US$3.3 million for the project connected to the Pacific Region Infrastructure Facility (PRIF) while the remaining US$1 million will come from the Global Environment Fund.

Source: Brad Hinton

World Bank has signed an agreement to deliver solar energy to Kiribati.

M+W Group wins EPC contract for Israel's largest PV plant

Germany-based M+W Group has secured an EPC contract for the construction of what is said to be the largest PV power plant in Israel. Owned by Enlight Renewable Energy, a subsidiary of privately owned Israeli company Eurocom Group, the 55MWp solar facility will be located near Moshav Ohad, around 100 kilometres south of Tel Aviv, and built in cooperation with M+W's subsidaries M+W Israel and M+W Solar. The project will cover a total surface area of 1 million square metres, which will become home to more than 180,000 crystalline PV modules and 60 central inverters.

Balochistan government and CK Solar Korea ink MoU for 300MW solar project

The government of Balochistan and CK Solar Korea have signed a memorandum of understanding to develop a 300MW PV project near Quetta, Pakistan. It has been estimated that the project would require an investment of around US$900 million and will be developed by CK Solar Korea on a total of 607 hectares of leased land in the towns of Khuchlak and Pishin.

Germany and European Commission help Greece expand renewable energy sector

Germany, the European Commission and Greece have signed a joint declaration of intent to reform and expand the Greek renewable energy sector. All parties concerned aim to help Greece to profit both from the recent fall in technology costs, especially in the PV sector, and from Germany and the EU's experience in the renewable energy sector, thus making the country fitter to address the challenges of renewable energy expansion.

Major new pact signed between GCL-Poly and Yingli Green

GCL-Poly will use Yingli Green's PV modules for its project pipeline that stands at around 1GW in a major new pact between the two companies. The three-year strategic agreement between China's largest polysilicon and solar wafer producer and both China's and world's largest PV module manufacturer encompasses polysilicon and wafer supply, through to R&D initiatives on material quality and cost reductions.

Winaico supplies modules for Australian solar demonstration site

Taiwanese module manufacturer Winaico has delivered its polycrystalline PV modules for installation at the Desert Knowledge Australia Solar Centre (DKASC), a solar demonstration facility in Alice Springs. The demonstration site is funded by the Australian government and tests various commercial solar technologies in the arid conditions of Alice Springs. Results from the site provide the industry with long-term system level data proving the reliability of solar generators. A standard and automated metering system has also been established in order to gather performance data which helps to confirm the reliability of solar technologies and its power quality.

Walgreens alliance with SolarCity aims to expand renewable energy in Colorado

The US' largest pharmacy chain Walgreens has signed a partnership with clean energy provider SolarCity to bring renewable energy provision to its stores in Colorado. SolarCity will install new solar systems on 22 Walgreens stores across 14 different cities in the state. The new solar systems are estimated to reduce more than 47.5 million of carbon dioxide (CO2) emissions the next 20 years, which is equal to 25,711 tree planting as the Environmental Protection Agency predicts.

Other News

Australian rooftop PV installations clear one million landmark

Nearly 2.5GW of PV capacity had been installed on just over one million domestic and business rooftops in Australia as of the end of March 2013, according to the country's Clean Energy Regulator. Australia's Clean Energy Council ascribes the five-year boom (the country had just 20,000 PV systems in 2008) to government incentives and falling system costs.

Power-One sells more than 1 million PV inverters

Power-One has said it has surpassed the 1 million milestone for PV inverters sold worldwide and boosted its installed base to over 10GW.

The company said that it operates in North America, India, Australia, Latin America, Japan, China, the Middle East and Africa, echoing the globalization of the PV industry in recent years.

Masdar inaugurates world's largest operational CSP plant

The 100MW Shams 1 project — which has been dubbed the world's largest operational CSP plant — has been officially inaugurated at a ceremony held on 17 March. The ceremony was attended by Sheikh Khalifa bin Zayed Al Nahyan, President of the United Arab Emirates (UAE) and ruler of Abu Dhabi in addition to a number of other leaders in the UAE. Located near Madinat Zayed in the western region of Abu Dhabi, the 100MW grid-connected project covers more than 2.5 square kilometres of land — equivalent to 285 football fields — and has the capacity to generate enough electricity to power 20,000 homes.

Government of Uruguay inaugurates country's first solar power plant

The government of Uruguay will celebrate the country's first solar power plant at an inauguration ceremony due to be held later today. Owned by Uruguay's energy regulator Dirección Nacional de Energia (DNE), the 481kWp installation has been constructed alongside the Salto Grande hydroelectric dam near the border with Argentina. The US$4 million PV system is equipped with 2,240 modules and two 250kW inverters. DNE will be responsible for providing operation and maintenance services for a period of 10 years.

Solar industry should team up with electric vehicle companies

Solar and electric vehicle companies should join forces to boost their chances of market penetration, recommends *Solar and Electric Vehicle Cross-Marketing Strategies*, a report from Navigant research which found that plug-in electric vehicle (PEV) owners prefer clean renewable power such as solar.

Source: Winaico

Winaico has delivered modules for installation at the Desert Knowledge Australia Solar Centre.

Product Reviews

Enecsys

Enecsys' second-generation micro-inverter claims 33% increase in power output

Product Outline: Enecsys has introduced its second-generation micro-inverter platform, including a new communications gateway and online monitoring service. The technology is said to power-scale up to 300W AC enabling the use of many high-powered 60-cell modules, providing maximum energy harvest in the smallest footprint.

Problem: System owners, integrators, installers and financiers backing third-party-owned systems need to place a premium on the ability to maximize energy harvest to provide sufficient return on investment.

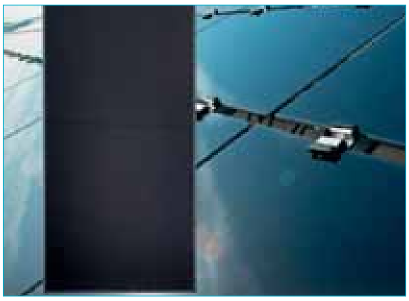
Solution: The Enecsys second-generation micro-inverter is claimed to dramatically boost energy harvest through a combination of improved efficiency and increased maximum output power ability; it yields up to a claimed 33% improvement in maximum power output over the prior Enecsys offering. This is offered in two packages: one specifically to respond to integration opportunities across a wide range of panel manufacturers who offer integrated AC modules, and a traditional rack-mount version enabling custom installer configurations. It is also redesigned in a new patented form factor with an integrated mounting method, making it better suited for integration by OEM partners into AC module product families.

Applications: Can power-scale up to 300W AC, enabling the use of many high-powered 60-cell modules and integration into many AC module product families.

Platform: The Enecsys second-generation micro-inverter is currently offered in single versions in increments from 240W up to 300W maximum AC output, with a micro-inverter industry-leading peak efficiency of 96.5%. A simplified cabling solution enables improved installer productivity with faster and lower-cost installations.

Availability: April 2013 onwards.

First Solar



First Solar's Series 3 CdTe thin-film PV module platform offers harsh environment capability

Product Outline: First Solar has launched a new evolution of its Series 3 CdTe thin-film PV module platform. The 'Series 3 Black' is said to incorporate First Solar's latest advances in conversion efficiency as well as additional features to enhance its performance in utility-scale power plants.

Problem: According to First Solar, around 90% of PV power plants are located in hot temperature climates where module temperatures are above 25 degrees C. Limiting the effects of temperature provides operators and owners with optimum plant yield. Providing further enhancements for harsh desert environments increases reliability.

Solution: The all-black module's change in appearance results from the use of an advanced, all-black edge seal technology combined with an innovative encapsulation material that further enhances its field durability. The Series 3 Black's performance in a wide range of operating environments is further validated by its new IEC 60068-2-68 "sand and dust test" certification, which measures durability in harsh desert environments. The Series 3 Black is expected to have module conversion efficiencies of 12.9% to 13% plus.

Applications: Industrial and utility-scale PV power plants.

Platform: The certification complements existing salt mist and ammonia certifications to provide a comprehensive range of independent testing in the harshest operating conditions. The Series 3 Black module maintains all the existing IEC certifications and UL listings for the Series 3 family, which enable the 1000-volt system designs that typify the utility-scale power plants.

Availability: First Solar began to implement the Series 3 Black enhancements in production modules earlier this year.

Hanwha Q CELLS

Hanwha Q CELLS' Q.PRO-G3 series module comes in a lighter and slimmer design

Product Outline: Hanwha Q CELLS has introduced its versatile polycrystalline-based Q.PRO-G3 series module. Using its Q.ANTUM high-efficiency solar cell technology (19.5% conversion efficiencies) and potential-induced degradation-free (PID) technology, the module also employs a lighter and slimmer design, using higher tensile aluminium frame.

Problem: A lighter and slimmer module design allows more modules per box and provides easier installation, offering reductions in logistics and storage costs as well as less packaging waste.

Solution: The new polycrystalline module features high-performance cells based on Q.ANTUM technology, which generates higher module power. Q.ANTUM has a dielectric cell back side, reflecting light waves that have passed through the cell, thus enabling the use of otherwise lost light energy. The module's new high-quality anti-reflection glass further boosts power yields to facilitate polycrystalline solar modules with power classes of up to 265Wp. Q.PRO-G3's lighter and slimmer design allows easier handling, and reduces warehousing and logistics costs by up to a claimed 29%.

Applications: Hanwha Q CELLS is offering the Q.PRO-G3 module for residential, industrial and utility-scale power plants.

Platform: The new thin (35mm) frame design features a high-tech aluminium alloy that allows for wind loads of up to 5,400Pa while reducing module weight to 19kg. A new junction box and connectors increase module reliability and energy output through improved heat management and stability.

Availability: The international roll-out of the Q.PRO-G3 module will take place from March 2013 onwards.

Product Reviews

LG Solar

LG Solar launches upgraded 'Mono XT NeoN' high-performance module

Product Outline: LG Solar's latest high-performance module, Mono XT NeoN, is based on n-type cells and is claimed to provide 20% more output than the previous reference module, Mono X. The mounting process is claimed to be easier for installers because of the module's reduced weight and improved assembly mechanisms.

Problem: Increasing module efficiency and simplifying mounting process for technicians offers the ability to reduce overall system costs and prices.

Solution: LG Solar achieves a peak performance of 280 to 300 watts per 60-cell module as a result of various in-house improvements. The focus is on the bifacial cell, which also captures the light reflected from the backsheet onto the cell back side, resulting in an increase not only in the light yield, but also in the energy and financial return for the solar power user.

Applications: Residential and industrial PV systems.

Platform: The monocrystalline high-performance module consists of 6 x 10 cells and has an overall size of 164 x 100 x 3.5cm, weighing 16.8kg. But it's not only the lighter weight that makes assembly smoother for installers; the new cable management system makes it simpler to connect all of the modules, LG claims. With a pressure load of 5,400Pa and a black, anodized aluminium frame, the Mono XTM NeoN is extremely resistant to stormy weather. LG Solar provides a 10-year product guarantee and a 25-year linear performance guarantee for its solar modules.

Availability: April 2013 onwards.

Sputnik Engineering

Sputnik's SolarMax 360 TS-SV central inverter provides PV power plant flexibility and yield optimization

Product Outline: The new SolarMax 360 TS-SV central inverter from Sputnik Engineering AG and the TS-SV Compact Station, with a rated output power of 720kW, are designed as a cost-effective solution for large PV power plants. The 360TS-SV has a European efficiency of 97.4%.

Problem: Central inverters with higher rated output power mean that PV plants and operators can employ fewer inverter stations, resulting in reduced overall costs.

Solution: The SolarMax 360 TS-SV central inverter comes with an increased minimum input voltage and greater output voltage, enabling a rated output power which is 30kW higher than that of the 330TS-SV inverter. Two 360TS-SVs can be installed easily on site using the new TS-SV Compact Station. In this specification a 720TS-SV Compact Station provides a rated output power of 720kW. However, the station is also available as 660TS-SV Compact Station with two 330TS-SV inverters and a rated output power of 660kW. The 360TS-SV consists of three power units (each with 120kW) and can be operated either with one MPP tracker or with three independent MPP trackers. The former is suitable for PV power plants with a homogeneous module array and limited shadowing. If the plant consists of different types of surfaces, or if a part of the solar generator is shaded, three trackers in multi MPPT operation optimize the yield.

Applications: Utility solar plants.

Platform: The TS-SV Compact Station has a compact housing and is provided to the plant manufacturer as a turnkey solution. With a total weight of less than three tons, the TS-SV Compact Station is easy to install and transport. Two of these stations can be connected to the medium voltage mains via a plug & play facility using a compact transformer station.

Availability: Spring 2013 onwards.

Yamaichi Electronics

Yamaichi Electronics' field assembly F.A.T. connector reduces PV installations costs

Product Outline: Yamaichi Electronics has launched new versions of the field assembly F.A.T. connector in the Y-Sol4 series for PV installations.

Problem: As the prices of PV modules continue to decline they make up a smaller percentage of the overall cost of a PV power plant. The focus of cost-reduction efforts has moved to the various balance of system costs of projects.

Solution: Yamaichi Electronics has developed another connector version for 4 to 6mm² cable cross-sections. They extend the successful Y-Sol4 F.A.T. product line. The Y-Sol4 F.A.T. has a spring clamping mechanism for simple clamping of stripped cable in the field. This permits quick, effective assembly without crimping. The new versions of the Y-Sol4 F.A.T. are specifically suited for thin wire outer diameters of 4.5 to 6.1mm. Thin wires are popular in photovoltaic installations today because they are more cost-effective owing to material savings. The existing versions continue to cover the range of larger cable diameters from 6.1 to 7.6mm.

Applications: PV power plants.

Platform: Versions are now also available in the product line for cable cross-sections from 1.5 to 3.5mm². They are used for thin-film installation, for example. All the new versions are based on the familiar concept of tool-free field assembly. This permits the quick, reliable and cost-effective installation in the field without additional special tools. All the familiar technical data still apply, including the IP68 protection class, the 1000V TÜV rating and a current rating of up to 47A, guaranteeing a high-quality, reliable product.

Availability: March 2013 onwards.

Using satellite insolation data to calculate PV power output variability

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ABSTRACT
As the PV capacity of utility systems increases, utility planners and operators are becoming more and more concerned about the potential impacts of power supply variability caused by transient clouds. Utilities and control system operators need to adapt their planning, scheduling and operating strategies to accommodate this variability while at the same time maintaining existing standards of reliability. Effective management of these systems, however, requires a clear understanding of PV output variability and the methods to quantify it. The present objective is to develop analytical methods and tools to quantify PV fleet output variability. This paper presents a method using location-specific inputs for estimating correlation coefficients, and discusses the key findings that resulted from applying the method to three separate geographical regions in the USA. The approach has potential financial benefits for systems that are concerned about PV power output variability, ranging from individual distribution feeders to state-wide balancing regions.

Why measure PV output variability?

Whether forecasting loads and scheduling capacity several hours ahead or planning for reserve resources years into the future, utilities need to be able to quantify the expected output variability of their distributed solar resources – whether they consist of thousands or hundreds of thousands of PV systems spread across large geographical territories. The inability to adequately quantify PV output variability can have real operational and financial impacts. For example, a utility may underestimate reserve requirements, which would result in a failure to meet reliability standards and an unstable power system. On the other hand, overestimating reserve requirements may result in an unnecessary expenditure of capital and higher operating costs.

Variability over time intervals ranging from a few seconds to a few minutes is of primary interest, since control area reserves are dispatched over such time intervals. For example, regulation reserves might be dispatched at an ISO through a broadcast signal every five seconds. Knowledge about PV fleet variability in five-second intervals could be used to determine the resources necessary for providing frequency regulation service in response to power fluctuations.

"The inability to adequately quantify PV output variability can have real operational and financial impacts."

The ability to analyze PV output variability has led to findings that relative output variability across a fleet of PV resources decreases as geographic dispersion increases. This implies that, in the same way that smoothing occurs when electric loads from multiple customers are combined, smoothing also occurs when the output from multiple PV systems is combined, so long as the systems are located sufficiently far apart.

How is PV fleet variability defined?

Variability of a PV fleet is defined as a measure of the magnitude of changes in its aggregate power output corresponding to the defined time interval and taken over a representative study period. Note that it is the *change* in output rather than the output itself that is desired. Also note that, for each time interval, the change in output may vary in both magnitude and sign (positive and negative). The statistical metric that is employed to quantify variability is the standard deviation of the change in fleet power output.

It is helpful to graphically illustrate what is meant by output variability. The example shown in Fig. 1 shows data gathered on November 7, 2010 from a network of 25 weather-monitoring stations in a 400m ×

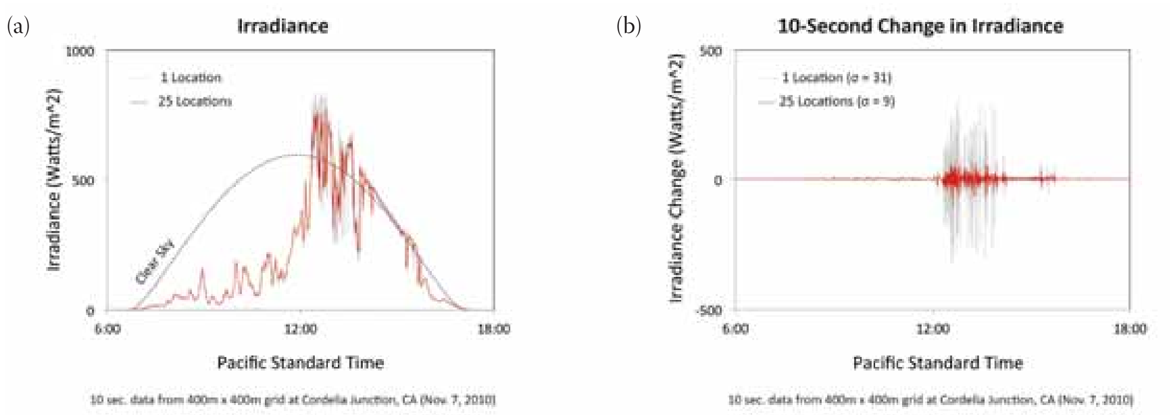

Figure 1. Data from a 400m × 400m grid at Cordelia Junction in California (November 7, 2010): (a) irradiance; (b) 10-second change in irradiance. A network of 25 locations reduces the 10-second variability by more than 70%.

400m grid located at Cordelia Junction in California [1]. Fig. 1(a) shows measured 10-second irradiance data (PV power output is almost directly proportional to irradiance); Fig. 1(b) presents the change in irradiance using a 10-second time interval. The grey lines correspond to irradiance and variability for a single location, and the red lines correspond to average irradiance distributed across 25 locations. The results suggest that spreading capacity across 25 locations rather than concentrating it at a single location reduces variability by more than 70% in this particular instance.

PV variability measurement approaches

Numerous approaches exist for calculating the output variability of a fleet of PV systems. One of these might be referred to as a 'fleet computation' approach and is taken as follows:

1. Identify the PV systems that constitute the fleet to be studied.
2. Select the time interval and time period of interest (e.g. 1-minute changes evaluated over a 1-year period).
3. Obtain time-synchronized solar irradiance data for each location where a PV system is to be sited.
4. Simulate the output for each PV system using standard modelling tools.
5. Sum the outputs from the individual systems to obtain the combined fleet output.
6. Calculate the change in fleet output for each time interval.
7. Calculate the resulting statistical output variability from the stream of values.

A more viable approach is to streamline the calculations through the use of a general-purpose PV output variability methodology. The method needs to quantify short-term fleet power output variability using the observations that:

- sky clearness and sun position drive the changes in the short-term output for individual PV systems;
- physical parameters (i.e. dimensions, plant spacing, number of plants, etc.) determine overall fleet variability.

Hoff and Perez [2] have already developed a simplified model as a first step towards a general method to quantify the output variability resulting from an ensemble of equally-spaced, identical PV systems. Output variability was defined as the standard deviation of the change in output over some time interval (such as 1 minute) using data taken from some time period (such as 1 year). The simplified model covered the special case where the change in output between locations is uncorrelated (i.e. the impacts of clouds at one site are too distant to have predictable effects at another for the particular timescale considered), the fleet capacity is equally distributed, and the variance at each location is the same. Under these conditions, it was shown that fleet output variability equals the output variability at any one location divided by the square root of the number of locations. Other investigators, for example Mills and Wiser [3], have derived a similar result that relates variability to the square root of the number of systems when the locations are uncorrelated.

Development of analytical tools to quantify PV output variability

Utility planners clearly require a tool that can reliably quantify the maximum output variability of PV fleets using a manageable amount of data and analysis. The methods referred to above would potentially meet this requirement if the changes in output between locations were uncorrelated (i.e. correlation coefficient is zero). In actual fleets, however, PV systems will generally

Region	Southwest	Southern Great Plains	Hawaii
Location #1	Latitude: 32° to 42° Longitude: –125° to –109° Grid size: 2.0°	Latitude: 35° to 38° Longitude: –99° to –96° Grid size: 1.0°	Latitude: 19° to 20° Longitude: –156° to –155° Grid size: 0.5°
Location #2	0.1°, 0.3°, …, 1.9° from location #1	0.1°, 0.3°, …, 2.9° from location #1	0.1°, 0.2°, …, 1.0° from location #1
Time intervals	1, 2, 3 and 4 hours	1, 2, 3 and 4 hours	1, 2, 3 and 4 hours
Clear sky irradiance	10 irradiance bins in intervals of 0.1kW/m^2	10 irradiance bins in increments of 0.1kW/m^2	10 irradiance bins in increments of 0.1kW/m^2

Table 1. Summary of input data.

have some degree of correlation, so any planning tool will have to incorporate correlation effects into the calculation of actual fleet variability.

"Any planning tool will have to incorporate correlation effects into the calculation of actual fleet variability."

In this study a step has been taken towards a general method by analyzing the correlation coefficient of the change in clearness index between two locations as a function of distance, time interval and other parameters. The analysis used hourly global horizontal insolation data from SolarAnywhere to calculate the correlation coefficients for 70,000 station pair combinations across three separate geographical regions in the USA (Southwest, Southern Great Plains and Hawaii). The measured correlation coefficients taken from these combinations were then compared to a model that could prove useful when integrated into utility planning and operations tools.

For this method, PV fleet variability was defined as the standard deviation of its power output changes using a selected sampling time interval (such as 1 minute or 1 hour) and analysis period (such as one year), as expressed relative to the fleet capacity. To simplify the work, the variability was formulated in terms of the change in insolation rather than the change in PV power.

As stated earlier, sky clearness and sun position drive the changes in short-term output for individual PV systems. Mills and Wiser [3] and Perez et al. [4] subsequently isolated the random component of output change and examined changes attributable only to changes in global clear sky (or clearness) index. The global clearness index equals the measured global horizontal insolation divided by the clear sky insolation.

This paper continues in the direction of Mills and Wiser and Perez et al. and focuses on changes in the global clearness index. The analysis is performed as follows:

1. Select a geographical region for analysis.
2. Select a location for the first part of the pair.
3. Select a location for the second part of the pair.
4. Select a time interval for the analysis.
5. Select a clear sky irradiance level bin.
6. Obtain detailed insolation data.
7. Calculate the change in the clearness index.
8. Calculate the correlation coefficient.
9. Repeat the calculation for all sets of location pairs, time intervals and clear sky irradiance bins.

Case study results

This study was carried out to investigate the existence of patterns that help to better quantify correlation coefficients. A method was tested that produces the desired output parameter of the correlation coefficient of the change in the clearness index between two separate locations. The inputs to this method include the distance between the two locations, the time interval and the location-specific

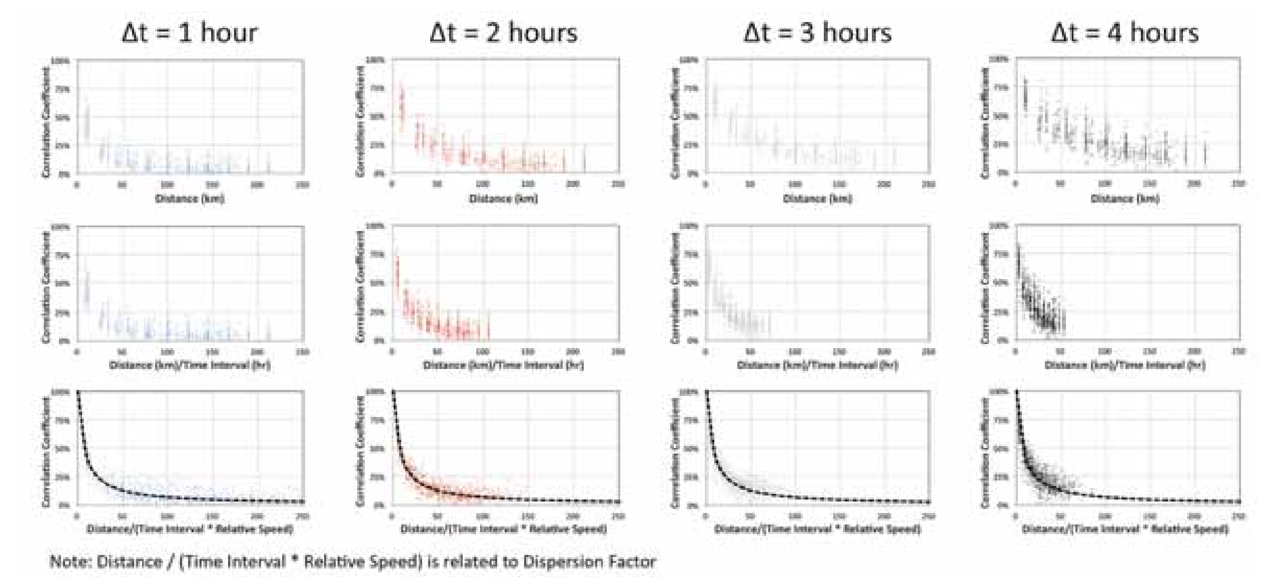

Figure 2. Correlation coefficients presented by time interval for the Southwest.

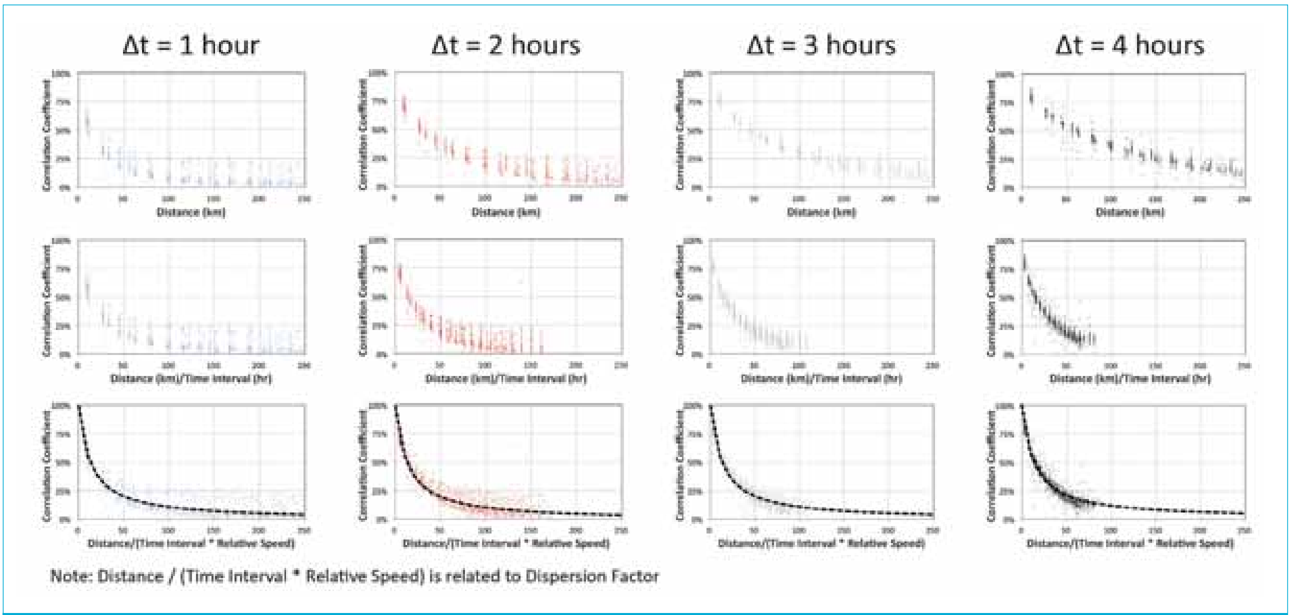

Figure 3. Correlation coefficients presented by time interval for the Great Plains.

parameters based on empirical weather data, particularly cloud speed.

Three separate geographical regions in the USA were selected for analysis: Southwest, Southern Great Plains and Hawaii (see Table 1). The first location was selected using a grid size of 2.0°, 1.0° and 0.5° for the Southwest, Southern Great Plains and Hawaii respectively. The second location was selected between 0.1° and 2.9° (about 10–300km) from the first location (other map coordinates were available but the selected points provided sufficient data for the analysis).

Hourly insolation data covering the period January 1, 1998 to September 30, 2010 for each of the two locations was obtained from SolarAnywhere [5]. The analysis was then performed as described above for time intervals of 1, 2, 3 and 4 hours and for 10 separate clear sky irradiance bins. This analysis resulted in more than 70,000 correlation coefficients.

Fig. 2 presents a randomly selected set of correlation coefficients for the Southwest. The graphs in the columns summarize the results for each time interval of 1, 2, 3 and 4 hours. The graphs in the rows present the measured correlation coefficients versus several alternative candidate sets of variables. Specifically, the top row presents the

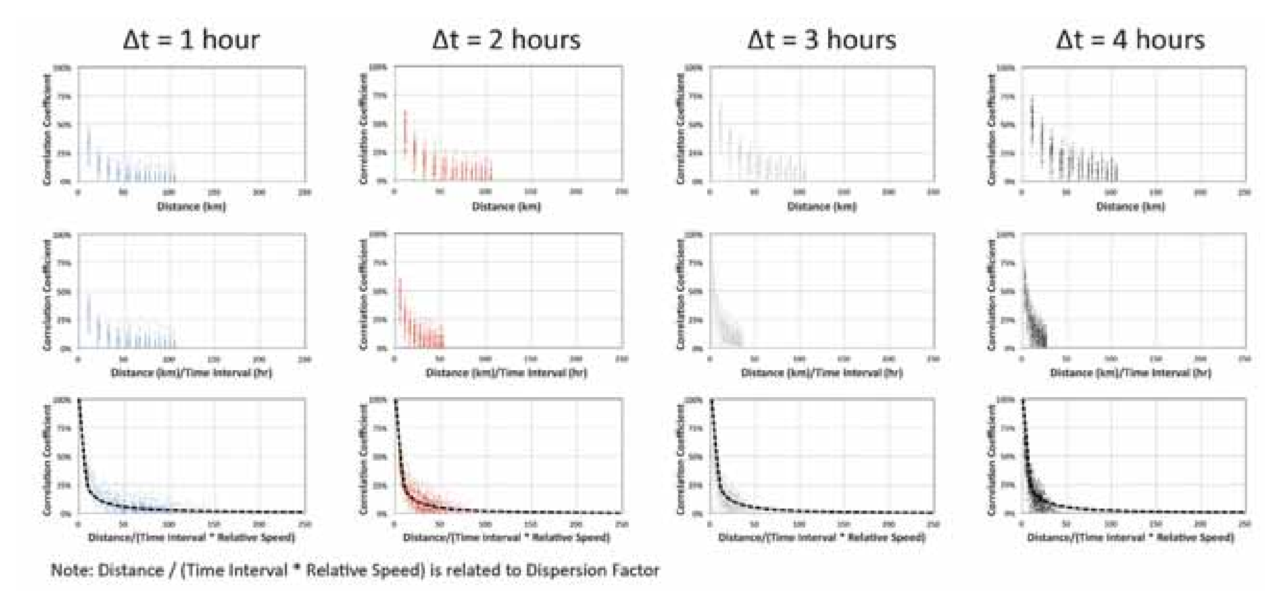

Figure 4. Correlation coefficients presented by time interval for Hawaii.

correlation coefficients versus the distance between the two locations, while the middle row presents the correlation coefficients versus the distance divided by time interval. The graphs shown in the bottom row are the correlation coefficients versus the distance divided by the product of time interval and relative speed (this term is related to the dispersion factor DF, introduced by Hoff and Perez [2]). The dashed line in the bottom graphs represents the results of a generalized method, proposed in this paper for use in future tools, that will be validated in the present analysis. Calculations using parameters obtained from SolarAnywhere were used to obtain these results.

Figs. 3 and 4 present the results relating to the Great Plains and Hawaii for comparison purposes. The patterns presented in the graphs are similar across all time intervals for the three geographical locations.

"Critical factors that affect output variability are the clearness of the sky, sun position and PV fleet orientation."

Key findings: correlation versus distance

Critical factors that affect output variability are the clearness of the sky, sun position and PV fleet orientation (i.e. dimensions, plant spacing, number of plants, etc.). To improve accuracy, a parameter called the dispersion factor (DF) was introduced. This factor incorporates the layout of a fleet of PV systems, the timescales of interest and the motion of cloud interferences over the PV fleet.

The results of the study demonstrated that relative output variability resulting from the deployment of multiple plants decreased quasi-exponentially as a function of the generating resource's DF. The results demonstrated that relative output variability

- decreases as the distance between sites increases;
- decreases more slowly as the time interval increases;
- decreases more slowly as the cloud transit speed increases.

These findings are consistent with other studies. Mills and Wiser [3] analyzed measured 1-minute insolation data over an extended period of time for 23 time-synchronized sites in the Southern Great Plains network of the Atmospheric Radiation Measurement (ARM) Program. Their results demonstrated that the correlation of the change in the global clearness index decreases as the distance between sites increases, and decreases more slowly as the time interval increases.

In another example, Perez et. al. [6] analyzed the correlation between the variability observed at two neighbouring sites as a function of their distance and of the considered variability timescale. These authors used 20-second to 1-minute data to construct virtual networks at 24 US locations from the ARM Program [7] and the SURFRAD Network, together with cloud speed derived from SolarAnywhere, to calculate the station pair correlations for distances ranging from 10m to 100km and for variability timescales ranging from 20 seconds to 15 minutes. Their results also showed that the correlation of the change in global clearness index decreases as the distance between sites increases, and decreases more slowly as the time interval increases.

The consistent conclusions of all studies are that as the distance between sites increases, the correlation decreases, and as the time interval increases, the correlation decreases more slowly. This latest study presents the additional finding that the correlation decreases more slowly as the speed of the clouds increases.

Conclusions

The analysis yields several key findings. First, consistent with previous studies, the correlation coefficients decrease with increasing distance. Second, also consistent with previous studies, this decrease occurs more slowly with longer time intervals. An alternative way of viewing this result is that correlation coefficients decrease at a similar rate when plotted versus distance divided by time interval. Third, the scatter in the results is further decreased when a relative speed is introduced for the first location in the pair of locations. Finally, the generalized method (shown by the dashed black lines in the bottom row of graphs in Figs. 2–4) fits the empirical data quite well when calibrated using the location-specific derived input parameters.

"The scatter in the results is further decreased when a relative speed is introduced for the first location in the pair of locations."

These results are important because they enable the methods to be applied to fleet simulation to accurately determine PV fleet output without having to measure high-speed power or irradiance data at every location.

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About the Authors

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Market Watch

IHS bullish on PV demand, forecasting over 35GW in 2013

Market research firm IHS has released a new forecast for the photovoltaics industry that is more bullish about global installations in 2013 than many others.

Confirming its previous projection, IHS said that global PV installations in 2012 reached 31.4GW, a 14% increase over the previous year. In contrast, NPD Solarbuzz had recently confirmed it put global installations at 29GW for 2012. However, IHS noted that grid-connected PV capacity was actually lower than the total installation figure which it said had reached 30GW in 2012. IHS said this was due to lengthy delays in connecting major PV projects in countries such as China and India.

The better than expected estimates for 2012 carry forward for 2013, according to IHS, forecasting another year of double-digit growth with installations topping 35GW, another year of record installations.

Source: Denver International Airport/NREL

IHS said that global PV installations in 2012 reached 31.4GW

Market Trends News Focus

Asia Pacific and Central Asia solar to exceed 3GW by 2017

PV capacity in the Emerging Asia Pacific and Central Asia (EAPCA) region is forecast to exceed 3GW by 2017, according to a new report from market analyst company NPD Solarbuzz.

With only 723MW of PV demand in 2012, the report, Emerging PV Markets: Asia Pacific and Central Asia Report, states this represents a strong compound annual growth rate of 28%.

Solar PV demand across the EAPCA region remains highly fragmented and is characterised by a diverse range of policies and end-market drivers, which is consistent with PV industry adoption in other emerging markets.

The report acknowledges that the Southeast Asia region is now widely recognized as a leading hub for upstream manufacturing.

Global solar capacity nearing 100GW milestone

Despite the uncertainties plaguing the European and Chinese markets in particular, a new report has revealed that 28.4GW of solar PV capacity was installed in 2012, bringing total global capacity to 89.5GW in the 23 countries in the International Energy Agency's study. The report, *Snapshot of Global PV* by the International Energy Agency, looked at 23 countries. It said that another estimated 7GW of capacity is in the pipeline which would increase the total to 96.5GW from 2011's 28.9GW. And the agency said that with installations worldwide difficult to quantify with precision, the 100GW milestone has already been passed in the first quarter of this year. The IEA report notes that PV has become a major source of electricity extremely rapidly in several countries all over the world. The speed of its development stems from its unique ability to cover most market segments, from the very small individual systems for rural electrification to utility-size power plants (today above 100MW). From the built environment to large ground-mounted installations, PV finds its way, depending on various criteria that make it suitable for most environments.

Market Trends News Focus

NPD Solarbuzz expects bumpy road for China's PV project business in 2013

PV power plant installations in China are expected to fluctuate significantly on a quarterly basis throughout the next 12 months, according to the latest NPD Solarbuzz quarterly report. Installations in China are expected to reach over 7GW in 2013, yet seasonality and policy incentive deadlines have already seen demand weaken in the first quarter that has had a negative knock-on effect on global PV demand in the quarter.

Source: Canadian Solar

PV demand in China fell to around 900MW in the first quarter, said NPD Solarbuzz.

BNEF forecasts weaker than expected US solar market; Japanese market soars

A new Bloomberg New Energy Finance (BNEF) report has significantly raised its PV installation forecast for Japan in 2013, yet points to the US market being weaker than expected. Previously, BNEF said that it expected PV installations in Japan to reach between 3.2GW to 4GW in 2013. However, that forecast has been radically upgraded to between 6.1GW and 9.4GW. The significant revision to the forecast was said to be due to

Source: Dennis Schroeder / NREL

The BNEF forecasts the US market being weaker than expected.

the large number of utility-scale PV projects that have recently been announced and the rapid increase in module shipments in the fourth quarter of 2012.

Business News Focus

VC solar investments slump amid boom for lease companies

Venture capital investments in solar have slumped to a record low just as funding booms for third party lease companies, according to Mercom Capital's Solar Funding and M&A Report which found that only US$126 million was invested in solar in the first quarter of this year, compared with US$220 million last quarter and US$324m in the first quarter of 2011. This is the second lowest quarter for VC funding since 2008.

Mosaic gets go-ahead for US$100 million Californian solar investments

California-based solar crowd funder Mosaic has received approval from regulators to offer US$100 million worth of solar investments to California residents. Following approval, Mosaic has launched the first of a series of solar projects available for investment. To date, Mosaic has raised over US$1.1 million from more than 1,000 investors to finance twelve rooftop solar power plants in California, Arizona and New Jersey.

Standard Bank Group, ICBC sign South African renewable energy project financing deal

Standard Bank Group and the Industrial and Commercial Bank of China (ICBC) have inked a US$2.2 billion deal to fund renewable energy projects in South Africa. Under the terms of the deal, the banks will jointly provide debt financing for projects awarded preferred bidder status under the country's Renewable Energy Independent Power Producer Procurement programme. Standard Bank will also act as the lead arranger for the projects. For ICBC, Standard Bank's single largest shareholder, the deal will help to increase awareness of the solar investment opportunities in South Africa among Chinese companies.

NADB finances 5MW solar project at San Diego University

NRG Solar has secured a US$19.2 million loan from North American Development Bank (NADB) to fund the development of a 5MW PV system at a university in San Diego. As part of the development plans, the San Diego State University (SDSU) Imperial Valley Campus located in Brawley, California, will become home to the 5MW system which will cover approximately 16 hectares of the campus. The solar park is expected to generate enough electricity to meet the demand of around 1,935 households.

Balochistan government and CK Solar Korea ink MoU for 300MW solar project

The government of Balochistan and CK Solar Korea have signed a memorandum of understanding to develop a 300MW PV project near Quetta, Pakistan. At a press conference Fuad Hashim Rabbani, Pakistan's provincial energy secretary, revealed that the project would require an investment of around US$900 million and will be developed by CK Solar Korea on a total of 607 hectares of leased land in the towns of Khuchlak and Pishin.

Japan green-lights 400MW island PV project

Plans for a 400MW PV project on an island situated off the coast of the city of Sasebo in Nagasaki Prefecture in southwest Japan, have been approved. The US$1.1 billion project will become one of the country's largest solar power plants and is rumoured that it will be constructed by a consortium which includes German PV developer Photovolt Development Partners. Following the approval, construction is now reportedly scheduled to begin in May.

IDB provides US$41 million loan for three Chilean PV plants

The Inter-American Development Bank (IDB) has approved a loan package worth US$41.4 million to fund the development of three PV plants in the Atacama Desert in northern Chile. The loan – which consists of US$20.7 million from IDB's ordinary capital and US$20.7 million from the Canadian Climate Fund – will be used to build, operate and maintain the Pozo Almonte and Calama PV project. The estimated total cost of the project is US$82.7 million. When it comes online in late 2013, it will represent Chile's largest solar PV project. Solarpack Chile will be responsible for providing EPC services. It will also provide operational, maintenance and asset management services.

New Jersey, Rhode Island and North Carolina US$13 million funding for PV projects

Professional business bank Bridge Bank Energy and Infrastructure Group (EIG) has announced the closure of a US$13 million financing deal for several solar installations in the US. True Green Capital Management, an American investment institution and EPC MP2 Capital, have received funding for projects in New Jersey, Rhode Island and North Carolina. EIG, a subsidiary of Bridge Capital Holdings, provided US$7.2 million in funding to True Green Capital Management for the construction of a solar installation project in Rhode Island that will supply energy to a major international utility that provides power to the consumer and commercial markets in the north east as well as a series of solar facility installations located in New Jersey.

Capacity News Focus

Germany installs 211MW PV capacity in February

Germany registered over 211MW of newly installed PV capacity in February, according to new figures from the German Federal Network Agency. Although this is a decrease from January when 275MW

Source: juwi

Germany registered over 211MW of newly installed PV capacity in February.

were added to the German grid, this is a slight increase from the previous February when 200MW were added.

India achieves 1.4GW cumulative capacity

India has achieved a total cumulative capacity of 1,447MW for grid-connected solar PV. According to statistics from the Indian Ministry of New and Renewable Energy (MNRE) India added 210MW in February, taking the total grid-connected solar deployed in this financial year to 505MW. The country is targeting a total of 800MW of new solar capacity by the end of the financial year ending this month. The Indian solar market has been estimated at US$2.05 billion by business consulting firm Frost & Sullivan, up from US$1.05 billion last year.

Australian rooftop PV installations clear one million landmark

Nearly 2.5GW of PV capacity had been installed on just over one million domestic and business rooftops in Australia as of the end of March 2013, according to the country's Clean Energy Regulator. Australia's Clean Energy Council ascribes the five-year boom (the country had just 20,000 PV systems in 2008) to government incentives and falling system costs. The Clean Energy Council said this translates to about 2.5 million Australians living in homes with solar panels.

Greece hits almost 2GW of installed capacity

Greek grid operator Hellenic Transmission has announced Greece installed 1.615GW of solar PV capacity in February, adding 211MW in February, down from 278MW added in January. This means Greece now has a total installed PV capacity of 1.732GW. About 329MW of the mainland's total installed capacity comes from PV systems that are 10kW in size or smaller. The three regions with the most installed capacity are Central Greece (263.4MW), Peloponnese (235.9MW) and Western Greece (192.7MW).

Netherlands to achieve 4GW by 2020

Exponential growth in the Dutch solar market will culminate in 4GW being installed by 2020 claims a study by the National Action Plan for PV, an industry group of installers, utility companies and think tanks. It states the growth will be a result of the fall in module prices and the liberalisation of the off-grid market in the Netherlands. The potential for long-term installation capacity is 100GW. At present, the Netherlands has a capacity of approximately 900MW.

UK adds 350MW in Q1 2013

In line with positive predictions for the UK solar industry, the country has completed at least 350MW of solar installations in the first quarter of 2013. According to Bloomberg New Energy Finance, this includes a record number of large ground-mounted PV projects, which were able to take advantage of higher incentive rates before cuts came into effect on April 1.

Policy Watch News Focus

Malaysia's 20MW PV quota snapped up in one hour

Malaysia's Sustainable Energy Development Authority (SEDA) has received a positive response to its PV tender for PV systems under 500kW for non-individuals.

According to the chairman of SEDA Malaysia, YB Tan Sri Dr Fong Chan Onn, the 20MW quota — which was launched on 2 April 2013 — was allocated within the first hour of opening the online application system. In total, 137 applications were submitted in the first 60 minutes.

Drastic cut proposed for Queensland FiT

Solar feed-in tariffs (FiT) in Queensland could face drastic cuts after a report from the Australian state's competition authority, the QCA, claimed they are increasing electricity prices. The QCA, commissioned last year by the Queensland government last year to set a "fair and reasonable" FiT level for the state, maintained that the solar bonus scheme had been set too high when it was first introduced in 2008. As a result it said the FiT would "sharply" increase electricity prices over the next three years and would end up costing US$3.6 billion by the time it comes to an end in 2028.

New York solar programme announces strong demand despite Sandy delays

New York State's solar programme announced strong demand despite the destruction of Hurricane Sandy last year. The New York State Energy Research and Development Authority awarded US$46 million for 52MW of commercial sector projects. The deadline had been extended for a month to 5 December in the wake of Hurricane Sandy. Governor Andrew Cuomo's office this week announced the first of three rounds of awards to 76 projects for installations larger than 50kW. The awards were made to 28 recipients in 33 counties across the state.

Fiscal breaks on offer for non-FiT Italian PV systems

In line with Italy's new national energy strategy, the Italian Revenue Agency will introduce tax breaks for off grid PV systems without access to the country's feed-in tariff. A statement from the Italian solar association Gruppo Imprese Fotovoltaiche Italiane (Gifi) said that PV systems installed with a maximum budget of €48,000 from 1 July 2013, will have access to a fiscal break of 50%. This includes systems under the net metering scheme.

EU urged to adopt Europe-wide renewables policy

The European Union should introduce universal renewable energy support mechanisms for all member states to reduce tension between conflicting policies.

This is the main conclusion from a report by the European Parliament's Committee on Industry, Research and Energy, which underlines how disparities between renewables markets within the EU have led to a situation within which different support mechanisms, potentials and different levels of technology maturity co-exist.

Wallonia, Belgium, adopts new green certificates scheme

A new green certificate (GC) mechanism aimed at opening up renewables to low income households has been adopted by the government of Wallonia, Belgium.

The Wallonia government hopes the newly approved "Qualiwatt" certificate, which supersedes the "Solwat" GC, will simplify and speed up administrative procedures as well as decrease the cost of renewables installations. Furthermore, the government is also adopting a "made in Europe" bonus for solar panels and a new standardised contract and insurance policy to ensure the protection of consumers from illegal installers.

Germany and European Commission help Greece expand renewable energy sector

Germany, the European Commission and Greece have signed a joint declaration of intent to reform and expand the Greek renewable energy sector. All parties concerned aim to help Greece to profit both from the recent fall in technology costs, especially in the PV sector, and from Germany and the EU's experience in the renewable energy sector, thus making the country fitter to address the challenges of renewable energy expansion.

R&D spending analysis of top PV module manufacturers in 2012

Mark Osborne, Senior News Editor, Photovoltaics International

ABSTRACT
R&D expenditure by major PV module manufacturers has not been immune to the PV industry's period of profitless prosperity. However, spending in 2012 was not affected to the extent that many would have expected, with a number of companies increasing their R&D activities and boosting staffing levels to meet R&D roadmap requirements. This paper discusses the current trends in R&D spending and staffing levels, highlighting both leaders and laggards.

R&D spending patterns

As Fig. 1 shows, there has been a direct correlation between the growth of the PV industry since 2007 and increased allocation of financial resources to R&D activities by leading PV module manufacturers. In 2012, however, that trend was reversed for the first time as the industry struggled to deal with the second consecutive year of chronic manufacturing overcapacity, declining ASPs, and financial losses for all but one CdTe thin-film manufacturer.

With capital expenditures primarily relegated to maintenance, R&D spending at 12 of the major module suppliers combined has decreased from the highs seen in 2011. R&D spending in 2012 declined to US$464 million, down from a peak of US$510.4 million in 2011.

Separately, the 11 c-Si producers within the featured group spent US$332 million on R&D activities in 2012, down from the US$369.9 million peak of 2011. However, the overall declines are relatively mild. The total decline was only US$46 million, or a 9% decline year on year. The c-Si producers cut spending by only US$35 million, or a 9.5% decrease year on year.

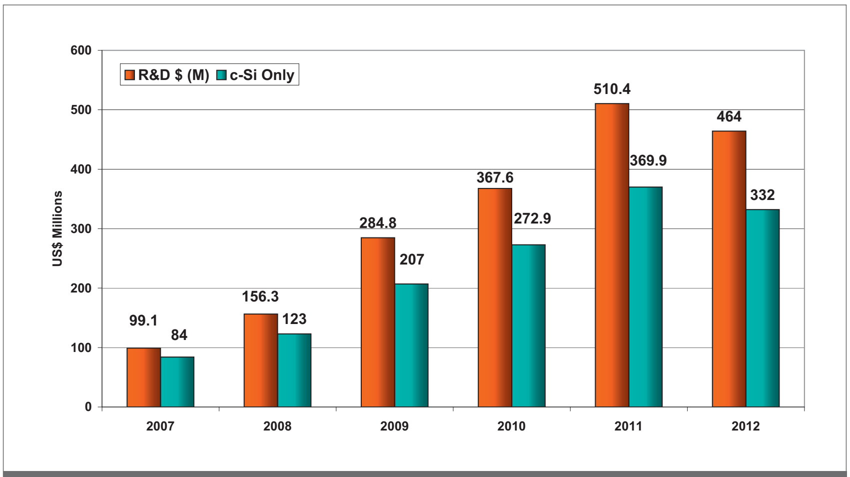

Figure 1. Top PV module manufacturers' combined R&D spending (US$ millions) 2007–2012.

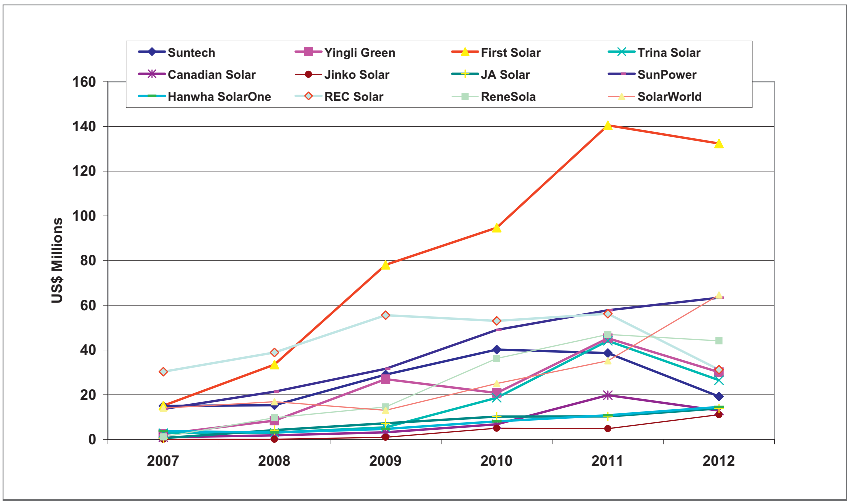

Figure 2. Top PV module manufacturers' individual annual R&D spending (US$ millions).

> "Companies are increasingly aware that R&D spending is a critical part of future earnings and differentiated product offerings."

The mild decline suggests that, despite the financial woes, companies are increasingly aware that R&D spending is a critical part of future earnings and differentiated product offerings. It should also be noted that, in the past, certain companies have said that they lowered spending because of the conclusion of specific R&D projects.

From Fig. 1 it is also evident that there was a significant jump in spending from 2008 to 2009; a similar spike in spending occurred in 2011 from 2010.

Fig. 2 highlights that seven companies reduced spending in 2012 from 2011 – these included First Solar, Yingli Green, Trina Solar, Canadian Solar, REC Solar and ReneSola. With respect to Suntech, we estimate (annual reports not released at time of print) that R&D spending declined from US$38.6 million in 2011 to US$19.2 million in 2012. The estimated decline is based on spending peaking in 2010 and the financial condition of the company over the 12-month period.

Since 2009 First Solar has topped the R&D spending ranks and has led its rivals by a wide margin. However, First Solar curtailed spending in 2012 by around US$8 million, compared with the previous year, which had seen spending peak at US$140.5 million.

Key to the declines were the relatively large cuts made by four of the seven companies that reduced spending – these included REC, Yingli Green, Trina Solar and Suntech.

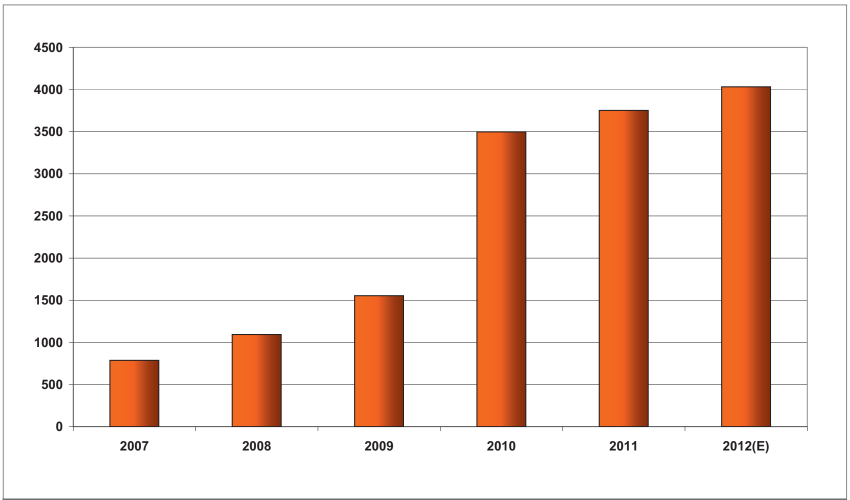

Figure 3. Top PV manufacturers' combined R&D employee numbers.

Importantly, five companies actually increased R&D spending in 2012, including SunPower, Hanwha SolarOne, SolarWorld and JinkoSolar. Noteworthy was SunPower, which increased spending from US$57.8 million in 2011 to US$63.4 million in 2012. SunPower has been a consistent high-ranking spender throughout the period covered, one of only four companies to be so.

At the other end of the scale, Hanwha SolarOne increased spending from US$10.8 million in 2011 to US$14.5 million last year. However, the company remained in the lowest group of spenders (below US$20 million per annum), which included Canadian Solar and the leading R&D spending laggard, JinkoSolar.

Guidance on R&D spending in 2013 remains limited; although companies typically guide shipment and revenue forecasts, few actually provide guidance with respect to R&D expenditure. Currently REC and SolarWorld have guided that 2013 spending would decline to US$22 million and US$52 million respectively.

R&D staffing patterns

There is a close correlation between R&D spending and staffing levels within R&D departments. Increased spending on R&D often includes costs with associated increased staffing levels.

However, Fig. 3 highlights that in 2010 there was an explosion in R&D staffing levels among the major producers covered in this report, compared with small, but noticeable, increases between 2007 and 2009. This, however, is not noticeably mirrored in overall spending levels for the same period, as shown in Fig. 1.

Dedicated R&D staffing levels increased from just over 1,500 in 2009 to just short of 3,500 in 2010, an increase of approximately 125% year on year.

Although spending leader First Solar significantly increased its R&D headcount in 2010, from 267 to 533, it was the c-Si manufacturers that started playing catch-up. Combined, they increased R&D headcount from 1,287 in 2009 to 2,965 in 2010, an increase of just over 130%.

"Staffing levels have continued to increase since 2010."

Staffing levels have continued to increase 2010, albeit at a significantly slower rate, reaching a total of 4,032 at the end of 2012. It should be noted that, although REC provides detailed employee data in its annual reports, the company does not break down employee levels dedicated to R&D.

The continued increase in R&D staffing levels throughout the last six years belies the fact that five companies (Trina Solar, JinkoSolar, Hanwha SolarOne, ReneSola and SolarWorld) reduced their R&D headcount in 2012 (see Fig. 4). Suntech is estimated to have reduced its R&D headcount in 2012 because of both headcount peaking in 2010 and the estimated reduction in R&D spending owing to its financial position over the last 12 months.

There were five companies (Yingli Green, First Solar, Canadian Solar, JA Solar and SunPower) that increased R&D-specific staffing levels in 2012. However, there could be an error in reported staffing levels at First Solar, for which it was necessary to extrapolate differently from previous years. Should the staffing levels have stayed the same or decreased, then overall headcount for the combined group of companies would have declined by only 120, or just over 3%.

Excluding First Solar, noteworthy is the fact that the massive increase in R&D headcount at Yingli Green in 2010 was not another anomaly. Yingli Green has continued to increase staffing levels, which reached a record high of 1,464 for the company and the sector in 2012.

At the opposite end of the scale, the laggard in R&D headcount is harder to reveal, notably as a result of inconsistent staffing levels of some companies over the period covered. Although JinkoSolar is one of the laggards, so too is JA Solar.

However, if we take a laggard to mean a company employing less than 100 in R&D activities in the last three years, then none (excluding REC) could be called a laggard in 2012. But JA Solar and SolarWorld would have been classified as laggards in previous years. The company with the lowest R&D headcount at the end of 2012 was actually Hanwha SolarOne with 104.

Six companies in 2012 (Hanwha SolarOne, JA Solar, SolarWorld, JinkoSolar, ReneSola and Canadian Solar) had headcounts of between 100 and 200, while there were significant leaps for Suntech (estimated), First Solar and Trina Solar.

R&D spending rankings and analysis

Leading in R&D spending rankings (Fig. 5) has historically had little correlation with the same companies ranked on a revenue, shipment or production level basis. Only First Solar has achieved a

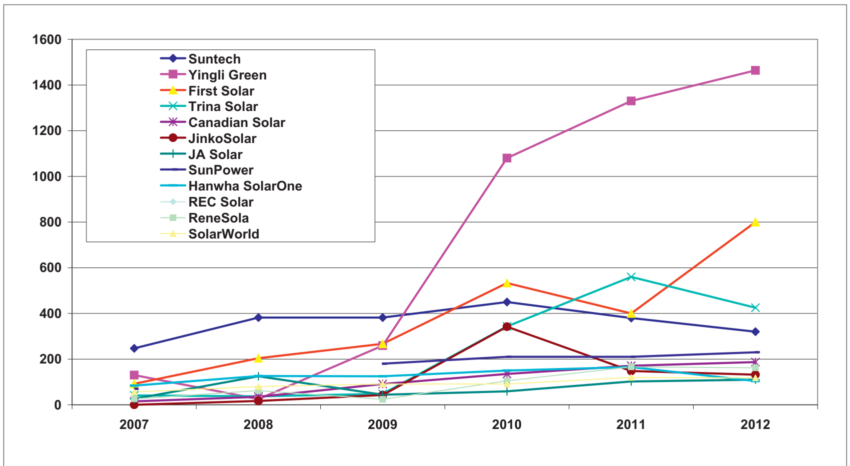

Figure 4. Top PV module manufacturers' R&D headcount by company.

Ranked	2007	2008	2009	2010	2011	2012	Market Ranked 2012
1	REC	REC	First Solar	First Solar	First Solar	First Solar	2
2	First Solar	First Solar	REC	REC	SunPower	SolarWorld	N/A
3	Suntech	SunPower	SunPower	SunPower	REC	SunPower	9
4	SolarWorld	SolarWorld	Suntech	Suntech	ReneSola	ReneSola	N/A
5	SunPower	Suntech	Yingli Green	ReneSola	Yingli Green	REC	N/A
6	Hanwha SolarOne	ReneSola	ReneSola	SolarWorld	Trina Solar	Yingli Green	1
7	Trina Solar	Yingli Green	SolarWorld	Yingli Green	Suntech	Trina Solar	4
8	Yingli Green	JA Solar	JA Solar	Trina Solar	SolarWorld	Suntech	3
9	ReneSola	Trina Solar	Trina Solar	JA Solar	Canadian Solar	Hanwha SolarOne	10
10	Canadian Solar	Hanwha SolarOne	Hanwha SolarOne	Hanwha SolarOne	Hanwha SolarOne	JA Solar	8
11	JA Solar	Canadian Solar	Canadian Solar	Canadian Solar	JA Solar	Canadian Solar	5
12	Jinko Solar	Jinko Solar	Jinko Solar	Jinko Solar	Jinko Solar	Jinko Solar	7

Figure 5. Top PV manufacturers' ranking by R&D spending 2007–2012.

market leadership position within a given year while holding the leadership position in R&D spending. At the other end of the scale, JinkoSolar has seen its market ranking rise rapidly over the last few years and is currently ranked seventh in the market.

Fig. 5 also highlights that, at the lower laggard level of R&D spending, Canadian Solar, JinkoSolar and Hanwha SolarOne have consistently underspent compared with rivals, yet are market ranked 5, 7 and 10 respectively.

However, with regard to JinkoSolar and Hanwha SolarOne, both companies increased spending in 2012, and notably JinkoSolar more than doubled spending. In respect of Hanwha SolarOne, the company is fast-tracking its assimilation of former Q-Cells cell and module technology in a 'copy smart' strategy, and spending could continue to rise modestly over the next few years.

Another trend highlight is the fact that three manufacturers (SolarWorld, ReneSola and REC) had not been in the top 10 market rankings yet have consistently been positioned high in the R&D rankings.

Although REC had led the R&D rankings ahead of First Solar, the company dropped to near the middle of the table last year. Primarily, REC had spent heavily on developing its FBR polysilicon technology and wafer technology. Wafer technology investments at ReneSola also dominated R&D activities and are expected to continue but also include the development of its Virtus wafer/cell and module offerings.

In the case of SolarWorld, recent high-spending activity has been focused on monocrystalline wafer technology as well as the development of performance PERC cell technology. SolarWorld expects to commercialize both activities in 2013, which could explain its guidance that R&D spending would decline in 2013.

There is a certain sense of relief in being able to correlate First Solar's and SunPower's consistently high spending strategies with their cell and module conversion efficiency records. SunPower recently launched its X-Series module, employing its latest Maxeon Gen 3 solar cell technology, which has conversion efficiencies of over 24%. The modules have efficiencies of 21.5% and above. First Solar has recently reported a range of record CdTe thin-film cell and module records both in the lab and at the manufacturing level. Already this year, R&D test cells produced at First Solar's Perrysburg, Ohio, factory and R&D centre have been verified by NREL to have reached a new record cell conversion efficiency of 18.7%.

The company has also been focused on bringing higher cell and module efficiencies from the lab to fab at a faster pace than ever before.

However, the news in February 2013 that First Solar would acquire US-based monocrystalline solar cell start-up TetraSun shook the industry. Having exited R&D into competitive CIGS thin-film technology and rejuvenated its commitment to CdTe technology, First Solar has plans to begin 'tentative' production of TetraSun's copper-based monocrystalline cells in the second half of 2014.

It would be reasonable to predict that First Solar's R&D spending levels will continue to be at high levels for several more years to come.

"R&D spending for the majority of the group has been closely tied to new product introductions but with an emphasis on the development of lower cost processing."

Conclusion

Overall, R&D spending for the majority of the group has been closely tied to new product introductions but with an emphasis on the development of lower cost processing. According to the latest edition of the ITRPV, significant changes are predicted, especially in the field of solar cell design and a related move to n-type mono wafers and a switch to copper metallization starting in 2015. Indeed, a whole suite of evolutionary changes from wafers, materials, cells and modules is expected that should require, and has already forced, some leading companies to continue to invest in R&D activities, with that trend expected to continue in the mid-term.

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Record breaking start to 2013 puts UK on solar world map

According to recent NPD Solarbuzz channel checks, supplier surveys, module shipment analysis and updated project pipeline data, the UK is forecast to be the fifth largest PV market globally during quarter one of this year.

In fact, based on new analysis and research featured in the forthcoming NPD Solarbuzz Quarterly report, the market share of the UK will approach 10% of global PV demand this quarter and the UK market will exceed the 0.5GW level for the first time ever in a single quarter.

This has also come amidst a climate that, during the past three months in the UK, has not really been indicative of a vibrant PV industry. In fact, even during the past few weeks, there has been a wealth of conflicting messages that has dominated local news, and has certainly been prioritised over any undue PV euphoria.

ROC and a hard place

To begin with, let's capture some of the domestic headlines to get a handle on local energy issues from the past few weeks; this may help explain why PV record breaking performance is not being championed by the tabloids.

First, the proposed new Hinkley Point nuclear power station is close to getting the final green light to generate "vast amounts of clean energy", with discussions between EDF and the UK government moving towards a compromised position over long-term contract strike price levels.

Furthermore, the recent coalition Budget also saw fracking get a somewhat unexpected blessing from chancellor George Osborne, who said: "Shale gas is part of the future. And we will make it happen." Indeed, it would appear that the UK has latched onto fracking in a similar way to the fascination it has had with tidal energy dating back over several decades.

On the mainstream feed-in tariff-based PV market, data from DECC has also confirmed continued softness in the residential segment, due in part to seasonality (resulting from particularly challenging weather conditions across the UK) and the effects of revised FiTs with a one-way degression mechanism that leaves little scope for any already-depressed PV segment.

And just to compound matters, the summer FiT review phase of calendar year 2013 got rather abruptly shortened from three to two months – a fact that will only see automatic degression-based adjustments accelerated forward by exactly one month.

Ground mount ushers in 'phase four' of UK PV

The UK PV industry has been through several phases now as part of its long-term goal to become a key part of the UK's overall energy mix.

Phase one can be considered as everything pre-FiT. Phase two was the FiT-frenzy period of 2011. Phase three was the fiT-hangover and adjustment phase leading up to the end of 2012. And phase four was ushered in at the start of 2013, driven by a rejuvenated UK ground-mount sector.

It remains somewhat ironic that Renewable Obligation Certificats (ROCs) were originally the intended platform for offshore wind and that DECC's initial altruistic PV ambitions were to empower low-income households through subsidising PV micro-generation through FITs in combination with other energy efficiency savings schemes. But that's the past.

Nobody expected PV pricing to be where it is today, and as such

we end up in a position where ROCs create a win-win situation for DECC and the UK PV industry, with both ground-mount and commercial rooftop having a stable incentive scheme to 2017. From a global PV perspective, it really doesn't get more long term than that. It is actually far more valuable in the short term than any renewable energy portfolio aspirations that are underpinned by dates as far out as 2025 or 2030.

Over the past few months, the number of proposals for large-scale, megawatt, ground-mount solar farms has approached 200 and planned installations include accessing ROC levels both pre and post April 2013. Even once we filter out the projects that are highly unlikely to get financed or to proceed, the pipeline remains considerable.

The net effect of all this is that PV demand in the UK can now lay claim to two landmark achievements:

- During the first three calendar months of Q1'13, cumulative PV demand in the UK exceeded the 2GW level.

- Over the same period, PV demand is expected to exceed the 0.5GW level.

In fact, by the end of 2013, the UK should have passed the 3GW cumulative level, and the widely adopted 20GW-by-2020 mantra may indeed become a distinct possibility.

By having a strong ground-mount PV segment driving future growth, the UK has just moved one step closer to global PV industry participation. Globally, the ground-mount segment is forecast to account for over 45% of cumulative global PV demand of 230GW between 2013 and 2017.

It now just boils down to some type of amendment of FiTs that will give the <250 kW rooftop segment a lifeline. Then, the UK could become one of the few countries globally that has a strong and balanced PV industry for small-scale and large-scale, and rooftop and ground-mount.

Getting these changes in place before the national elections in May 2015 could now become the key deliverable from the collective voice of the UK PV industry and DECC. And at this point, phase five of UK PV activities are certainly likely to challenge for headline energy coverage with any future nuclear or fracking announcements from the Treasury.

This column is a revised version of a blog that originally appeared on PV-Tech.org.

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